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ENGR 4940U
Capstone System Design I

Design of Smart Traffic Signals for Autonomous Transportation and Connected Communities in Smart Cities

R1: Project Identification, Research and Requirement Specifications

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Abstract Executive Summary

Our report includes a table of content that helps the reader, followed by that we have our introduction of the overall project. We have described our project scope and what we will do in order to achieve these objectives. We have added the background about the traffic signal, what it is, how the modeling of the traffic has done and how it works. Wrote many literature reviews on the smart traffic in smart cities, which gave us some ideas about how our overall project will be. Then we have explained the design process, and how each team member will contribute to the overall project. For the scenario, we provide couples of them, and we have given our justification. And for the use cases, we provided some cases and what will be our expectation from this when we move forward with the project. After that we have described the stakeholder and their interests, followed by that we have stakeholder requirements and consumer requirements, and from these requirements we created a Traceability Matrix. After having all the requirements, we defined Acceptance Tests. We have described a project plan for achieving the deliverables outlined in the handbook that was given to us. Last but the least, we have added a contribution matrix, of how much percentage each person has given in this report.

Acknowledgement

We want to appreciate and sincerely thank our advisor Dr. Hossam Gaber for making this work possible. His guidance accompanies us through every phase of this report-writing. We also want to express our gratitude to our coordinator Dr. Vijay Sood for providing us with some inputs regarding the reports and the overall project.

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Abbreviations

ADAS	Advanced Driver Assistance Systems
ATLC	Adaptive Traffic Light Control
ATSC	Adaptive Traffic Signal Control
C-ITS	Cooperative Intelligent Transportation Systems
CPS	Countdown Pedestrian Signal
EV	Emergency Vehicle
IoT	Internet of Things
ITS	Intelligent Transportation Systems
NHTSA	National Highway Traffic System Administration
QoS	Quality of Service
RSU	Roadside Unit
SSC	Smart Cities and Communities
STS	Smart Traffic Signal
STSC	Smart Traffic Signals Control
TMS	Traffic Management System
TSC	Traffic Signal Coordination
TSP	Transport Signals Priority
VANET	Vehicular Ad Hoc Networks
VRU	Vulnerable Road Users
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything
WSN	Wireless Sensor Network

1. Introduction

As we move forward in time, the cities grow bigger and get more populated. By population growth, we would have more cars in the streets which leads to more traffic. Managing traffic congestion and enhancing traffic flow are two of the main obstacles to accomodating and supporting urban expansion. To control this traffic we have many strategies. One of them is using traffic signals to control the flow of the traffic on intersections.

Traffic signals manage mobility, goods shipping improves safety, reduces travel times and increases the flow of traffic. The traffic signals not only impact the intersection but also it controls the traffic flow of other streets and high-ways. Because of its big impact on traffic, the traffic signals must get updated. If we don't improve the functionality of traffic signals, the traffic flow will be out of control. Since we have the problem of traffic to handle and the classic traffic signals are outdated, we have to come up with newer ways of controlling traffic flows.

We will begin our project by performing a thorough literature review to help us understand the current traffic technology and recent technological advancements that can be implemented in our design. We will talk about the traffic optimization method used by current traffic control systems, stressing the different barriers to technology, industry norms, and the potential market the new invention is aiming to target. Modern project management approaches will be used to carry out the deliverables, such as generating a Gantt Chart for the project plan that highlights the precise tasks that each team member must perform.

1.1 Project Scope

Smart traffic signals are a solution to replace the old and outdated traffic signals. Smart traffic combines conventional traffic signals with a variety of sensors and artificial intelligence in order to effectively route automobile and pedestrian traffic. Classis traffic signals have many disadvantages. For example, according to studies conducted in the United States by the National Highway Traffic System Administration (NHTSA), from 1997 to 2004, an average of 51% of fatal traffic collisions were caused by drivers who disregarded red signals at intersections with traffic lights. [1]. Also, rear-end collisions are another type of defect. Studies show that when a new classic traffic signal is installed, a sudden decrease in angle collision happens but more rear-end collisions start [2].

Smart traffic are technologies that municipalities may now quickly and affordably improve safety and traffic flow on their local streets into their traffic cabinets and intersections. Additionally, implementing these systems now, or modernizing the city's current Intelligent Transportation Systems (ITS) infrastructure, can result in significant cost savings, increased system reliability, and great for the drivers as well. Vehicle-to-everything communication (V2X) is used with Intelligent vehicle-to-infrastructure (V2I). It improves traffic situational awareness throughout the whole road network.

These signals have the ability to learn and update themselves by using the data they gather and process it which decreases human interactions. Also, the new system is much smarter, and by implementing decision-making methods, it would have more flexibility to change and adapt.

This system has three stages to be fully operational:

- First stage is using the basics of the program to improve and enhance the traffic signals we have now.
- Second stage is doing more changes by removing the old components and softwares and adding new modules and software programs to it.
- Lastly, this system will be integrated in autonomous vehicles to operate without any hardwares. This stage is only achievable when 90% of the cars are autonomous.

The scoop of this project is to create and design a smart traffic signal management system for replacing the original systems. This system will help to increase the traffic flow, decrease accidents caused on intersections, faster travel time, lower wait time, less consumption, etc. The system will be following a procedure that has three stages for now. Each stage has a different plan to implement the device and when we get to the final stage, the system will be fully operational. The STS includes many components and softwares. The sensors will be used, improved, or removed based on the use of them, but mainly the scoop of the project will be creating an artificial intelligence to control the traffic flow by analyzing the data it captures.

Also, this AI will be used on a block chain which will be installed on the cars. The expectations to create a demo of this system will be in December 2022 and another demo in April 2023.

2. Background and Literature Review

2.1 Background

2.1.1 What is traffic?

The word 'Traffic' can be referred to as the movement of vehicles, pedestrians and cyclists that use roads for transportation at a specific time. Traffic is considered to be low when there are few vehicles on the road at that specific time and can change depending on time, weather and road conditions. If you live in a town or metropolitan area, you may notice in general that there are certain times where there are way more cars on the road and it is referred to as rush hour traffic. Such high traffic can result in congestion. "Congestion is the presence of delays along a physical pathway due to the presence of other users"[3,39]. Traffic lights serve a crucial function in controlling traffic as it helps vehicles and pedestrians to navigate intersections in a safe manner.

Fig 2.1: Rush-Hour Traffic

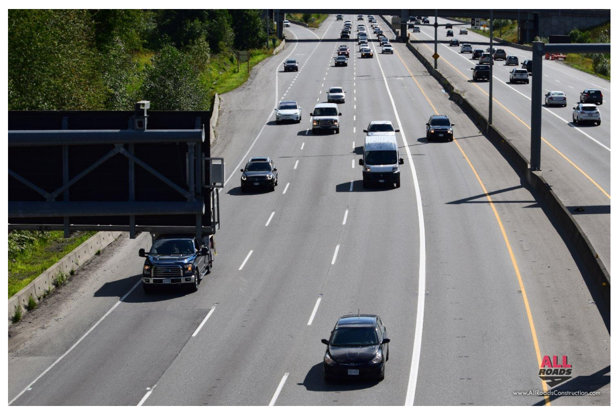

Fig 2.2: Low Traffic

2.1.2 What is a traffic signal?

A traffic signal, commonly referred to as a stoplight, manages the flow of vehicles through an intersection of two or more roads by visually instructing drivers when to go, slow down, and stop. Traffic signals occasionally also tell drivers when they can make a turn. These signals can be manually operated or run on a basic timer that alternates between allowing traffic to flow on one road for a set amount of time, then on the other for another set amount of time, before repeating the cycle. Signals are used by traffic engineers to reduce traffic congestion and enhance pedestrian and vehicle safety.

Signals used for traffic control are crucial. Traffic signals maintain safe and effective traffic flow. They demonstrate the right-of-way in opposing directions. Devices used for traffic control signals include markers, signs, and signals. They are employed to educate, direct, and regulate traffic. This comprises: Pedestrians, Drivers, Bicyclists. Before installing traffic lights, the need must be established. To ensure that the right and safe device is installed to suit the demands of the public.

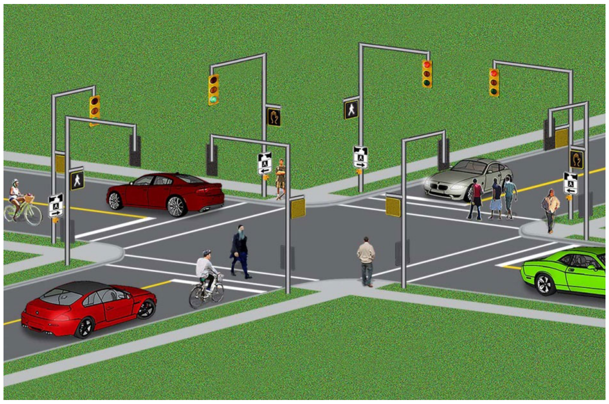

Fig 2.3: Basic Traffic Signal

2.1.3 Traffic Modeling

In North America when approaching an intersection, vehicles can go in three different directions which we call left, straight, and right movements(figure 1).
For the streets that have two or one line on each side, the movements get grouped together and usually we have Right-Straight movement and Left Movement or All Right-Straight-Left grouped together(figure 2).

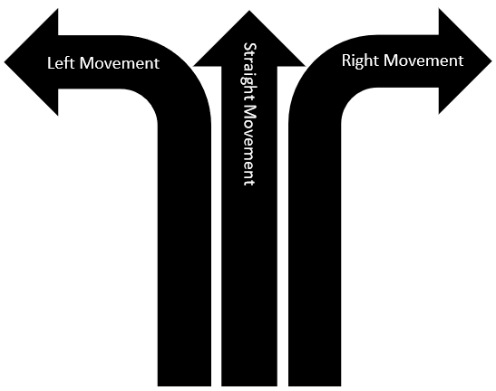

Fig 2.4: Three way movements

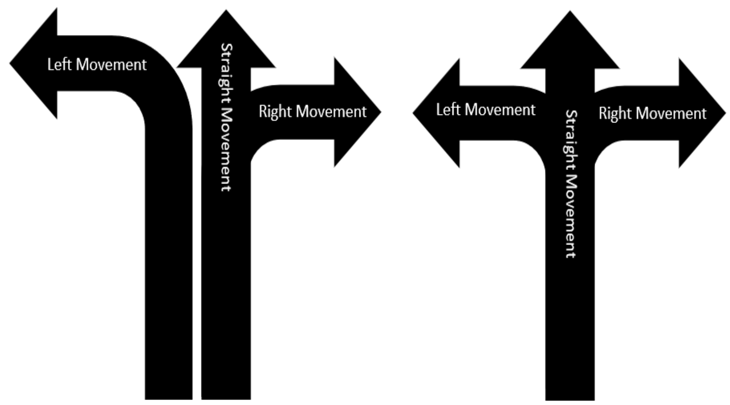

Fig 2.5: Combined movements

A normal 4-way intersection has 16 street lines, 8 vehicle motions and 4 pedestrian movements Figure 2.6. Based on what, a traffic signal should be implemented to control the flow of traffic.There are many different cases of motions and movements in the streets but this model is a preview of it.

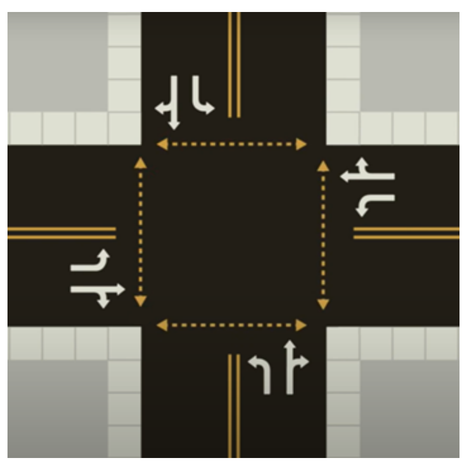

Fig 2.6: Normal Intersection Design

In continuation of the mentioned different traffic motions, there is a diagram(Figure 2.7) called ring-and-barrier which is used to draw different phases of signal and timing to operate accordingly. By using this diagram, we can create different plans of signal operation which are different from one another. In Figure 2.7 there are four different phases and two barriers specifically created for our intersection(Figure 2.8):

a) Phase 1: The major street left turns
b) Phase 2: The major street vehicle and pedestrian through movements.
c) Barrier 1: Used to clear the intersection.
d) Phase 3: The minor street left turns
e) Phase 4:the minor street vehicle and pedestrian through movements
f) Barrier 2: Used to clear the intersection before the cycle starts again.

This plan will work in a cycle and it will be repeated from a to f. This is just an example of how phasing arrangements of traffic signals work. There are a variety of plans which engineers create based on different intersection configurations and traffic volumes for each movement. Creating each plan needs a lot of analyzing and time[4].

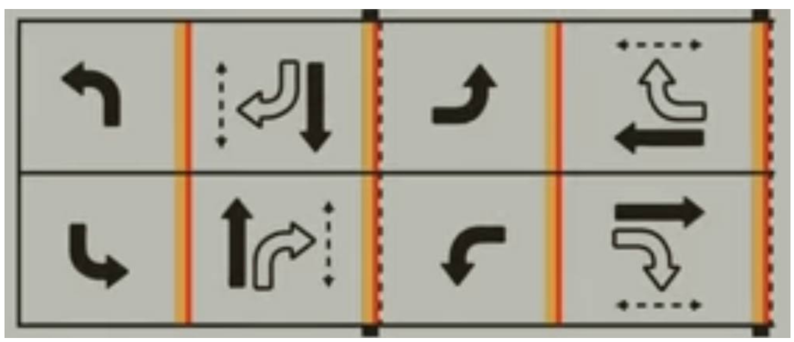

Fig 2.7: Ring-and-barrier diagram

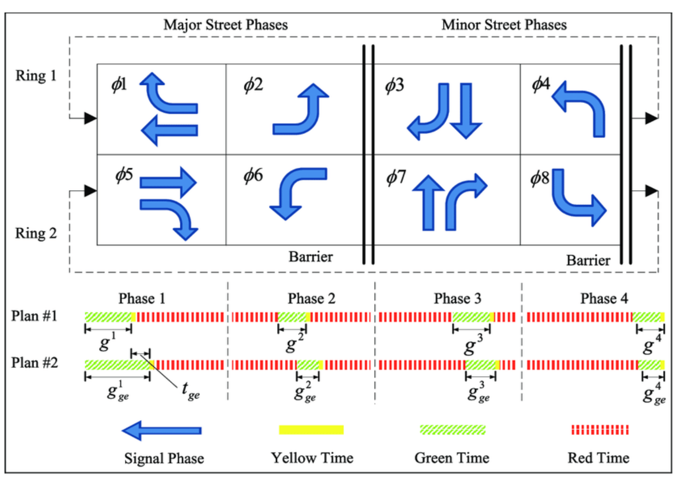

Fig 2.8: Ring-and-barrier diagram and Phases

2.2 Literature Review

Article 1 - Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities [3]

S H Alsamhi et al. outline drones, robots, machine learning, and the Internet of Things (IoT) are needed to implement these cutting-edge collaborative technologies in order to boost the intellect of smart cities by enhancing connection, power efficiency, and quality of service (QoS). It primarily focuses on determining how intelligent a city is, as well as on environmental concerns, life quality, community safety, and emergency response. The intelligence and knowledge of a city is measured in terms of its standard of life, healthcare, community safety, preparedness, and environmental issues "(such as energy efficiency, air quality, traffic monitoring, etc.)," Drones are now more readily available and less expensive because of developments in sensor, data analysis, and rechargeable battery technology. IoT's central tenet is that all things can interact and communicate with one another over the Internet, including cars, homes, buildings, and even inanimate objects like trees and rocks. This enables the creation of a smart world and vast global facilities for an information-driven society. Researchers looked into the effective deployment and mobility of drones to gather data from IoT devices on the ground with little transmission power and improved communication stability and connectivity [2]. Additionally, the cooperative wireless connection among IoT gadgets and drones is essential for offering a realistic alternative to a routing loop issue in conventional IoT systems and extending the life of the sensors through the most effective load distribution.

Article 2 - How connected vehicles and smart traffic infrastructure offer a roadmap to make cities safer [4]

M Yakub et al. described Cooperative Intelligent Transport Systems (C-ITS), often known as V2X (Vehicle-to-everything) technology, have the power to significantly improve North America's transportation infrastructure in terms of safety and efficiency. Experts discuss the potential and potential dangers in our most current webcast. According to statistics, 90% of automotive accidents are caused by human mistake. However, this issue may be overcome if cities adopted cutting-edge innovations such as Cooperative Intelligent Transport Systems (C-ITS). Intelligent, interconnected network called C-ITS permits wireless technology across cars, other drivers on the road, and infrastructure like cameras and traffic signals. It has the potential to greatly improve roadway transportation's expenses, safety, and productivity. "Machine-to-machine communication" is a phrase used in the industry to describe cooperative intelligent transport systems. In essence, they have such a platform that can interact at three different levels: infrastructure, driver, and vehicle. V2X, which denotes the ability of automobiles to connect with several cars and infrastructure, including cameras, Light Detection and Ranging (LiDAR), and road devices. V2X, which denotes the ability of automobiles to connect with several cars and infrastructure, including cameras, LiDAR, and road devices [4].

Throughout the end, as automation and connection increase, communication allows the purpose so that an automobile may communicate to some other automobile and they are able converse to determine which vehicle will do which action.

Article 3 - Intelligent traffic light design and control in smart cities: a survey on techniques and methodologies [5]

A. Agrawal and R. Paulus described significant issues, including traffic congestion, transit holdups, air pollution, fuel consumption, etc., that have arisen as a result of increased traffic in urban areas. Being a component of the Traffic Management System (TMS), traffic light signals at junctions play a crucial function in efficiently managing traffic.Traditional pre-timed regulated traffic lights are becoming a barrier when it comes to moving through heavy traffic, especially during rush hours.This study summarizes Adaptive Traffic Light Control (ATLC) systems created by utilizing current technologies like Wireless Sensor Network (WSN), Vehicle Ad Hoc Network (VANET), and image processing methods to collect real-time traffic statistics and analyzing the gathered data to adjust traffic lights with the help of intelligent controllers. They also provide a summary of the most widely used ATLC systems. They described the design of the system for managing traffic at smart intersections. The traffic control module and the traffic statistics collecting module are the two major components that make up the system architecture. They also introduce the traffic statistics collecting module, which provides a summary of the technologies utilized to measure the amount of traffic at intersections, including WSNs, VANETs, and image processing methods. The traffic control module is divided into three categories:

1. control at single, isolated junctions
2. control at numerous junctions
3. systems that make control choices by providing precedence to urgent transits. T

The use, design philosophy, and limits of a few current traffic control systems are described as a whole.

Article 4 - AI Perspectives in Smart Cities and Communities to Enable Road Vehicle Automation and Smart Traffic Control [6]

C Englund et al. state that using communication and information technology, smart cities and organizations integrate infrastructure, commodities, and functions to capture data and wealth management technologies. Another enabling technology that makes it possible for even the smallest item to connect to is the IoT. AI may be used to analyze data, uncover links, underlying causes, and trends, and offer recommendations for better behavior. In order to reduce energy consumption and increase traffic safety inside SCC, this article has emphasized how AI may be utilized to increase energy production and decrease greenhouse gas emissions. By developing sensor-based safety systems that can detect VRUs and issue warnings or actively respond to the information, the trend toward more vehicle automation might lessen the effects of accidents, or, if possible, avert them completely [6]. In order to tackle congestion safety and reliability, this article outlines the infrastructure AI-based systems that make up SSC. To meet SCC issues, sensor systems must be enhanced. This can help vehicles perceive hazards better and support drivers in dangerous situations using Advanced Driver Assistance Systems (ADAS). With the use of sensors and AI, these systems are developing ever-greater intelligence, and there are currently a variety of examples of highly automated vehicle systems As you can see in the below "Figure 2.9: Example of a smart city scenario in which information is constantly transferred between various units to enable applications for automated road vehicles and intelligent traffic management" [6].

Figure 2.9: Example of a smart city scenario.

Article 5 - Smart Cities and the Importance of Smart Traffic Lights [7]

Due to an increase of driving over the past many years, there has been a significant focus on road safety. Driving time is increasing, which not only adds to the commotion but also impacts the environment. Therefore, the creation of new smart technology has taken on significant importance for many businesses, organizations, and researchers. A more intelligent traffic signal system is required by smart cities. The emphasis will be on various types of algorithms and sensors used in smart technology. IoT is a concept that connects commonplace objects to the Internet. Communities gain significantly from this because cities, businesses, and services are made more efficient. Smarter traffic signal systems are required by smart cities, and fortunately, they are compatible with current technological advancements, specifically "wireless technology." “A system utilized in Europe that allows access to Traffic Information Centers at any time to model future events is an illustration of this. Utilizing this network to transmit real-time traffic-related information to drivers and, in some circumstances, vehicles themselves is also being investigated as a way to prevent clogged streets and adverse weather.” [7] These technologies will be accomplished by reducing traffic, pollution, time spent driving, and even preventing accidents.

<u>Article 6 - Design and Implementation of a Smart Traffic Signal Control System for Smart City Applications [8]</u>

Lee and Chiu et al. state that the cornerstone to a smart city is its architecture, which supports V2X capacity, which allows a variety of smart mobility services. Numerous ITS must be created in order to lessen traffic congestion and increase the effectiveness of public transit. “ In this paper, a smart traffic signal control (STSC) system is designed and implemented, it supports several smart city transportation applications including emergency vehicle signal preemption (EVSP), public transport signal priority (TSP), adaptive traffic signal control (ATSC), eco-driving supporting, and message broadcasting.” [8] They suggested STSC system's roadside unit (RSU) controller is its central component, and it also says about its “system architecture, middleware, control algorithms, and peripheral modules.” As per the detail, it may be installed quickly and affordably since it is compatible with current traffic signals. A unique traffic signal system has been created specifically for the EVSP situation. It can alert all nearby cars of both the direction from which the EV is coming, boosting protection and improving traffic flow.

<u>Article 7 - The Development of the Smart Cities in the Connected and Autonomous Vehicles (CAVs) Era: From Mobility Patterns to Scaling in Cities [9]</u>

Campisi, Severino, Al-Rashid, and Pau et al. discussed that the purpose of smart cities is to implement innovation with a variety of tasks and elements, including transportation, resource management for energy, water, and waste, air quality, land use, a service network, construction, as well as the financial system, community interactions, higher employment, and public safety. The growth of smart cities is specifically influenced by a number of elements connected to transportation demand and supply. By outlining a technique that enables the determination of methods for evaluating the optimization of urban transportation with a specific focus on the creation of self driving transportation. This article has also define that the research of published studies on the idea of smart cities and new technology allowed for the examination of their compatibility as well as any potential drawbacks.

Article 8 - Vision-Based Traffic Sign Detection and Recognition Systems: Current Trends and Challenges [10]

S. B. Wali, M. A. Abdullah, M. A. Hassan, A. Hussain, S. A. Samad, P. J. Key, and M. B. Mansor et al. discuss that the creation of intelligent technologies for driver safety depends heavily on studies into the automated TSDR system ADAS the scientific society has expressed a strong interest in studies on vision-based TSDR. A significant portion of TSDR-related approaches has indeed been described over the past decade. Drivers are given crucial knowledge of roadway restrictions and conditions by visual signals, like traffic signs and traffic lanes, in every country on earth.Traffic signs represent indeed an essential component of something like the road infrastructure since they tell drivers on the status of the roadway, as well as about any limits, cautions, or other navigational aids. An incident could be caused either directly or unintentionally by ignoring or neglecting to observe the signs that are placed on the streets. "Traffic sign detection and recognition (TSDR) is an important application in the more recent technology referred to as advanced driver assistance systems (ADAS), which is designed to provide drivers with vital information that would be difficult or impossible to come by through any other means." [11] Because of its conceivable usage in numerous situations, the TSDR system has attracted more attention in past decades. For TSDR, such different road signs provide challenges such as, completely obscured, fading, broken traffic signs and the same moment several signs appear at the same place.

Article 9 - A mobile application for a Smart Traffic System [11]

V. Manolopoulos, S. Tao, S. Rodriguez, and M. Ismail et al. The majority of the information used among traffic surveillance systems is already in use which is gathered from stationary sensors. Latest smartphone advancements have allowed for the creation of Smart Traffic Systems, which offer route assistance using the traffic data obtained via users' smartphones. This article is mostly concentrated upon developing smartphones that have been built on Real Traffic Management Systems that were utilized to collect traffic data as well as to provide drivers feedback and direction. The smartphone app, which collects data in a secure manner and provides users with insights, would be a crucial element of the system. The technology, its security issues, the demand for vehicle routing guiding, and potential remedies are all evaluated in this following article.

3. Design Process

To maximize the amount of workflow efficiency, the design concept that will be used across the two semesters will be one that draws on the skills of each team member. Each team member's function will be decided based on their prior engineering experience acquired through work periods, academic study, or other ways. Afterward, roles and responsibilities were to be decided based on strengths and shortcomings. In our example, based on the course deliverables—a prototype and report simulation—we chose to divide responsibilities into two groups. According to their own skills, each member will finish certain duties in each of these two categories.

3.1 Project Roles

The following table shows each group member's role and responsibilities in the development of the project.

Table 3.1 Project design process and team members who works on each part of the design

Iteration	Project Design Process	Team Member
1	Researching the background of traffic signals	All team members
2	Creating a tree structure of the traffic signals and different intersections	Saro Karimi
3	Research on different traffic signal sensors	Tirth Patel
4	Checks the electro-mechanical signal controller	Vatsal Patel
5	Collecting traffic data and analyze them	Saro Karimi and Tirth Patel
6	Make a demo of an classic traffic signal	All team members
7	Research on traffic signals with machine learning	Saro Karimi
8	Design an image processing system for analyzing data	Tirth Patel and Vatsal Patel
9	Program a basic machine learning system for STS	Saro Karimi and Tirth Patel
10	Create the hardware demo of the STS	Vatsal Patel
11	Implement all of the gathered data and hardware into a traffic signal to create the final STS demo product	All team members

3.3 Design Process

The project will be following an embedded system design since the project has both software and hardware development. Over design approach will be based on Figure 3.1. The process will start off by going through the classic traffic signal. By learning how they work and what they use then we can analyze the components and softwares. After that we will start checking the intelligent traffic signals already built. By knowing how they moved from the old traffic signal and what they use in their system, then we can start designing the STS. Also, in this process we will take note of every problem this device has and try to fix those problems in our system.

The Smart traffic signal will have applications on mobile devices and cars or if the cars and pedestrians did not have the installation option a device will be provided with this software that can connect to other devices. All of this will be used for analyzing the traffic instead of using many sensors installed. More importantly, all of this will be used for our artificial intelligence software that will control all of the traffic flow.

Figure 3.1 Design Process Diagram

4. Scenarios and Use Cases

4.1 Scenarios

Table 4.1 Scenarios and Justification

Id	Scenarios	Justification
1	“Saro arrives at an intersection by driving. Saro sees multiple cars approaching the intersection where the light is red. The other side of the road has lower traffic while the Saro’s side is packed with cars. Therefore there will be more traffic. The STS needs to know how many cars are approaching and calculate the signal time for each traffic signal by connecting to at least five traffic signals. All of this lights turn green together.”	While driving you may arrive at a red light and there are cars stopping behind you and while waiting there will be more. If that light turns green and you continue driving you will face another red light which will give you more wait time. But by connecting the redlights in a certain distance and turning all of them green, we can achieve faster traffic flow and lower stopping time by moving all of the cars at the same time through the traffic lights group.
2	“Tirth is walking on the sidewalk and arrives at an intersection. Tirth wants to cross the intersection and notices an emergency vehicle approaching the intersection. The STS needs to give priority to emergency vehicles over pedestrians and other vehicles.”	The emergency vehicles know their route to reach the destination and it can give a signal to the traffic lights that later it will see. With this signal the STS will prioritize the light for that certain time the emergency vehicle arrives so there will be no pedestrians and cars at the intersection and the light turns green for it before it reaches the light.

3	“Vatsal is driving toward the intersection and wants to do a left turn. There are cars coming from the other side and Vatsal does not have a good view of the opposite side since there is a big truck blocking the view. But the traffic signal detects the cars approaching from the other side and notifies Vatsal when it’s safe to do a left turn so we avoid T-bone accidents.”	Cars face many T-bone crashes caused by left turns since they don’t have a good view of the opposite side. By finding out if there are cars coming or is it safe to do the left turn and signaling it to the driver, we could avoid more T-bone crashes.
4	John is approaching an intersection where the light is red. He does not notice the red light because he is not paying attention to his driving. The STS detects a car driving to the intersection and not slowing down therefore it sends a warning message to the car and it makes the car automatically slow down and stop at the intersection or notify John that he has to stop.”	Others may not pay attention to their driving and pass a red light by looking at their phone, talking, etc. By connecting the traffic signal to the cars, we could warn the driver of the situation or in modern autonomous cars, stop the cars as they reach the intersection.
5	“It’s a sunny day and the sun blocks the view of the drivers. Mike has a sight problem and cannot detect if the light is green or red. Since he has the STS app or device installed on his car, he can see the light status in his car so he would avoid collision.”	On a sunny day many have encountered the problem of seeing a red light's status even if we have sunglasses. We could solve this problem by installing a device that connects to the traffic signal and can be installed on the car and shows the status of the traffic signal to the driver.

4.2 Use Case Model:

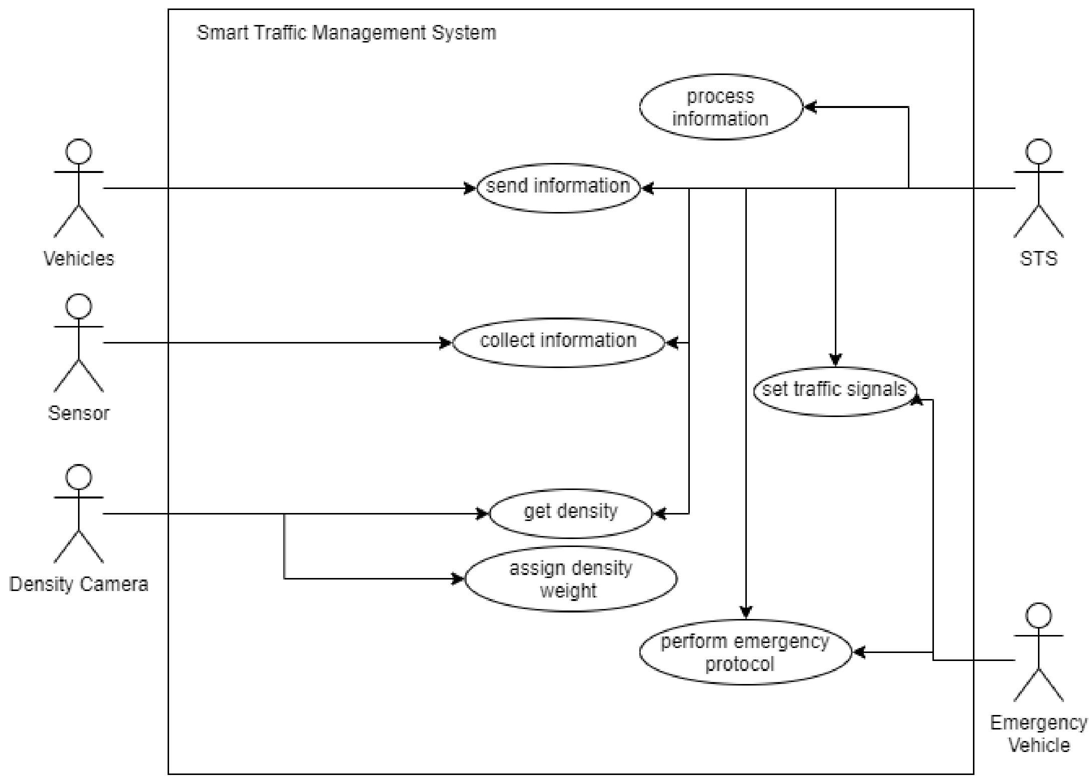

Figure 4.1 Use Case model of STS

4.3 Use Cases:

Table 4.2 Use Cases

Use Case: send information **ID:** UC-1 **Description:** sends information such as speed, distance, lane #, # of cars etc. **Actor:** vehicles, bicycles, pedestrians and buses. **Preconditions:** user is connected to STS app.

Postconditions: STS receives the information and begins processing it.

Ordinary Sequence:

Step 1: Actors arriving at an intersection
Step 2: Actor’s device automatically sends car information to the STS
Step 3: STS processes the information and updates traffic signals.

Exception:

Step 1: if the actor is arriving an intersection at high speed then the STS will send an alert to the user to slow down

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Use Case: collect information

ID: UC-2

Description: detect vehicles and pedestrians

Actor: vehicles, bicycles, pedestrians and buses

Preconditions: actors that are in range of sensors

Postconditions: actors leaving the range of sensors

Ordinary Sequence:

Step 1: detect pedestrian or vehicle
Step 2: send the data to the STS to process it.

Exception:
Step 1: detect an emergency vehicle then send a priority function.

Use Case: get destiny

ID: UC-3

Description: gets the density for each lane

Actor: Vehicles, bicycles and buses.

Preconditions: vehicles approaching the intersection

Postconditions: vehicles stop or exits the intersection

Ordinary Sequence:

Step 1: takes an image
Step 2: processes the image
Step 3: gets the density for each lane
Step 4: send the density to STS.

Exception:

Use Case: assign density weight

ID: UC-4

Description: assigns density weight to each lane

Actor: STS

Preconditions: receiving density for each lane.

Postconditions: ready to receive new data.

Ordinary Sequence:

Step 1: receive density of each lane
Step 2: assign density weight

Exception:
Step 1: if the density contains an emergency protocol then assign it with high priority

Use Case: process information

ID: UC-5

Description: collected information is processed by STS.

Actor: STS

Preconditions: receiving data from sensors and camera.

Postconditions: producing an output

Ordinary Sequence:

Step 1: receive density weight
Step 2: receive emergency protocol
Step 3: running a simulation to figure out the best timing for traffic light
Step 4: send data to traffic lights

Exception:

Use Case: set signals

ID: UC-6

Description: Updating the traffic signal upon receiving data from STS.

Actor: STS and Traffic light

Preconditions: receive signal from STS

Postconditions: updated traffic signal

Ordinary Sequence:

Step 1: receive data from STS.
Step 2: update traffic signal and timings

Exception:

Use Case: perform emergency protocol

ID: UC-7

Description: Emergency vehicles needs to cross the intersection with minimal stop-and-wait condition

Actor: Emergency Vehicles

Preconditions: Emergency Vehicle approaching the intersection

Postconditions: Emergency Vehicle exiting the intersection

Ordinary Sequence:

Step 1: Emergency vehicle detected by the sensor Step 2: sensor activates emergency protocol and sends it to STS Step 3: STS recognizes emergency protocol and prioritizes that lane. Step 4: STS updates the traffic light **Exception:** Step 1: Emergency vehicle not detected then just perform normal operations

5. Stakeholder Requirements and Traceability Matrix

5.1 Stakeholder Analysis:

The table below identifies the stakeholders and their interests.

Table 5.1: Stakeholder and their interests

Stakeholders	**Interests**
Automobile	Decrease in consumption and increase in traveling time
Bus	Less stop-and-wait conditions
Emergency Vehicles	Little to none wait time and stop conditions
Bicycles	Less conflict with other vehicles and good condition bike lanes
Pedestrians	Less waiting time on the intersections and better crossing timing
Pets	Decrease in accidents by cars and crossing the road safer
Municipality	Lowers the numbers of crashes, maintenance costs and

5.1.1 Requirements

ID	Requirements	Classification
1	The STS shall function after a power outage.	Municipality
2	The STS shall include detection.	Municipality
3	The STS should provide efficient signal timing	Municipality
4	The STS shall reduce the maintenance cost.	Municipality
5	The STS shall return the status of the system and any fault data to the control center.	Municipality
6	The STS shall have CPS indicators that show how many seconds are left in the interval for pedestrian change.	Pedestrian
7	The STS shall provide both audible and visual indication of crossing/not crossing intervals.	Pedestrian
8	The STS shall display that it has detected pedestrians or have a manual input such as a push button to inform the STS that a pedestrian is present.	Pedestrian
9	The STS shall reduce waiting time at the traffic lights.	Vehicles
10	The STS shall have a higher priority for transit vehicles than normal vehicles.	Transit Vehicles
11	The STS shall be able to recognize EV and assign highest priority.	Functional
12	The STS shall measure density of each lane	Functional
13	The STS shall adjust the timing based on information gathered by sensors in real-time.	Functional
14	The STS shall include TSC that allows the signal to be sequenced and timed with adjacent signals to provide continuous traffic movement.	Functional
15	The STS shall warn drivers of potential traffic signal violations by acquire data from traffic signals and vehicle systems.	Functional
16	The STS shall include pedestrian signal and timing.	Functional

5.2 Traceability Matrix

5.2.1 House of Quality

Relationships		Weight
Strong	●	10
Medium	○	6
Weak	▽	2

			Functional Requirements							
Relative Weight (out of 100)	**Customer Importance (out of 10)**	**Customer Requirements**	Adjust timing of the signals	Measure density of each lane	Include pedestrian signal and timing	Allow the signal to be sequenced and timed with adjacent signals to provide continuous traffic movement.	Warn drivers of potential traffic signal violations by acquire data from traffic signals	Recognize EV and assign highest priority.	Show the traffic on a road graphically	Dynamically schedule traffic signals based on gathered information
15%	9	Function after a power outage.	○	○	○	●	●	●	○	●
15%	9	Detect vehicles/pedestrians arrving at an intersection	▽	○	●	▽	●	▽	▽	▽
12%	7	Provide efficient traffic signal timing	●	●	○	●	▽	○	▽	●
13%	8	Include CPS indicators that show how many seconds are left in the interval for pedestrian change.	▽	▽	●	▽	▽	▽	▽	▽
15%	9	Reduce waiting time at the traffic lights.	●	●	○	●	▽	○	▽	●
10%	6	Higher priority for transit vehicles than normal vehicles.	●	○	▽	●	▽	○	▽	○
12%	7	Reduce maintenance cost	▽	▽	▽	○	○	▽	▽	○
8%	5	Return the status of the system and any fault data to the control center.	○	▽	▽	▽	▽	▽	○	▽
		Importance Rating Sum (Importance x Relationship)	586.67	573.3	593.3	660	486.67	466.7	293	620
		Relative Weight	14%	13%	14%	15%	11%	11%	7%	14%

Figure 5.1: House of Quality

6. Definition of Acceptance Tests

Table 6.1: Acceptance Criteria for STS

Test Id	Test Description	Expected Results	Functional Reqs Covered
1	Reliability Testing	System is able to function during power outages using a backup battery. Also, recharging the battery using solar panels	1
2	Performance Testing	System must update the traffic lights in less than 30 seconds.	3,9,13
3	Simulation Testing	Simulation is receiving inputs from the sensors, processing it and updating the traffic lights accordingly.	1,2,5
4	Robustness Testing	Simulating the scenarios described in the report and checking if the system functions properly	8

7. Project Plan

A project plan shown below outlines the project's goals, objectives, start dates and completion dates that go along with it. It can change depending on the current project status.

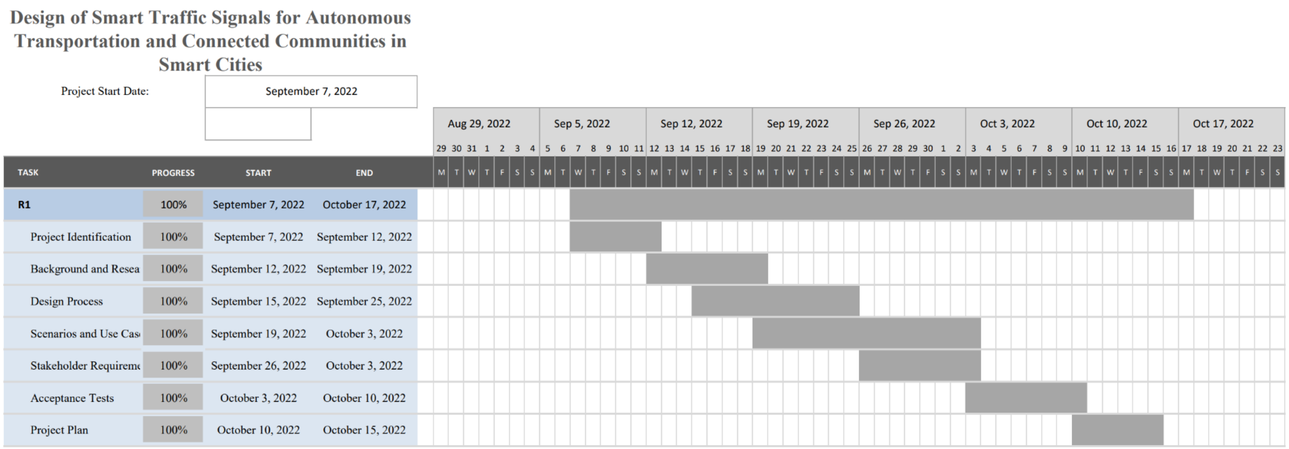

Figure 7.1: Project Plan

8. Contribution Matrix

Table 8.1: Summary of work % contributed by each team member for report 1

Task	People		
Report 1	Tirth Patel	Vatsal Patel	Saro Karimi
	33.33%	33.33%	33.33%

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Appendix A: Team Meeting

Our team members discussed the meeting and to finish the necessary deliverables on time. We would meet the team members on any days of the week to work on the project or if not we have our roles to work. Every week on Mondays, the team members would gather what they did and show it to the project advisor to get comments and more guidance on the project. Our strategy was to make the deliverables ready a week before the due date so we could show it to our advisor and work on it. The below table shows the due dates for the deliverables and our alternative due dates to finish it beforehand.

Table 3.2 shows the due date of the deliverables and its alternative due dates

Deliveries	**When**	**To Whom**
Advisor Review Report R1	11 October, 2022 18 October, 2022	Deliver to Advisor (Dr. Hossam Gaber)
Advisor Review Report R2	1 November, 2022 8 November, 2022	Deliver to Advisor (Dr. Hossam Gaber)
Presentation and Demo	29 November, 2022 - ????	Deliver to Coordinator (Dr. Vijay Sood)
Final Report	6 December, 2022	Delivery to Coordinator (Dr. Vijay Sood)