University of the Philippines Manila
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Efficient Utilization of Traffic Lights in Common Congested Areas in Urban Settings Through Crowdsourcing

A special problem in partial fulfillment
of the requirements for the degree of
Bachelor of Science in Computer Science

Submitted by:

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ACCEPTANCE SHEET

The Special Problem entitled "Efficient Utilization of Traffic Lights in Common Congested Areas in Urban Settings Through Crowdsourcing" prepared and submitted by Angelo Joseph A. Villaluz in partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science has been examined and is recommended for acceptance.

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Abstract

The special problem tackles an important problem in our society, traffic congestion. Traffic congestion, specifically, intersection congestion has been a major issue in urban areas, causing significant impacts on travel time, fuel consumption, and air pollution. Intersection congestion refers to the accumulation of vehicles at intersections, leading to slow and inefficient traffic flow. The special problem produced an adaptive traffic light scheduling system based on the current vehicular volume using mobile crowdsourcing. This spreads out the number of vehicular volumes to each bound of an intersection.

Keywords: Mobile crowdsourcing, Intelligent Transport System, Intersection congestion

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I. Introduction

A. Background of the Study

Traffic congestion has been one of the most concerning and prevalent problems in the modern world. This fast-paced generation, where everyone is continually working to the extent of restlessness, affects one of the factors of traffic congestion. In addition, road construction, road accidents, etc. constitute the fundamental causes of the problem ahead. For so many years, the government in developing countries has been doing lots of work in order to accommodate riders and commuters to have easy and hassle-free transportation. However, traffic congestion remains on the priority list for every government to solve thoroughly. In the Philippines, the Unified Vehicular Volume Reduction Program (UVVRP), better known as the number coding scheme, where the last digit (0 to 9) of the licensed plate numbers of registered vehicles supposedly lessens traffic congestion by evenly distributing these on weekdays (Monday to Friday), were not really made its sole purpose as the private vehicle volume only decreases by 4.3%, as opposed to the expected 20% decreased[1].

Traffic congestion, specifically, intersection congestion has been a major issue in urban areas, causing significant impacts on travel time, fuel consumption, and air pollution. Intersection congestion refers to the accumulation of vehicles at intersections, leading to slow and inefficient traffic flow. This problem results in increased travel time for commuters which leads to frustration and decreased productivity. Additionally, prolonged wait times at red lights in an intersection negatively impact driver satisfaction and also reduces productivity in urban areas.

Global Positioning System (GPS) has been helping every rider to accommodate and help them navigate the daily activities to be accomplished. In developing countries, much research has been conducted, like the implementation of machine learning to predict traffic congestion in a specific area, yet the foundation has not been directly configured. This research aims to utilize the traffic light timings of a specific area where traffic congestion usually occurs. The effectiveness of advantageous usage of traffic lights allows a specific lane within the areas of congestion to flow regularly. GPS-based application, Waze, has been a lot of help to people in everyday commuting. Waze uses real-time information which translates into traffic information and road situations. Data collection was done whenever a user drives on a specific road with the application open which will then further optimize the shortest route to be suggested[2].

Several intelligent transportation systems (ITS) have been developed and adapted to assess traffic situations. In the Philippines, an image processing feature was implemented in an ITS to accommodate traffic congestion. The system was conducted at two different times: daytime and nighttime, to accurately assess the overall reliability of the feature. The image-capturing device was installed in several traffic lights in the intersection of Almar-Zabarte and Camarin, Caloocan City as the intersection has been experiencing notorious traffic congestion in the past years, based on experience. The system averages 92.82% and 85.77% reliability in terms of its functionalities at daytime and nighttime, respectively[3]. However, the system relies on the data collected from the camera which might malfunction over time onto which this paper has sufficed as mobile crowdsourcing was implemented through user's devices.

Mobile crowdsourcing (MCS) refers to collecting significant amounts of data which typically relies on the cloud and smartphone. Smartphones offer a great opportunity for an application to gather a large crowd as its users could be able to participate in a project which contributes to data gathering with ease. MCS has been significantly useful to the device's mobility and its sensing capabilities, as well as human collaboration and intelligence to distribute and perform tasks and further provide cost-efficient applications[4]. A participation model is a type of MCS that has been stated in the study of Kong, et. al. where users or as they refer, workers get involved in the activities conducted by MCS in two forms, (1) Opportunistic and (2) Participatory. In this special problem, participation has been conducted where a worker can consciously submit his/her data to the MCS system. Consent has been one of the priorities of the system to be built as this could breach the user's security in the long run.

B. Statement of the Problem

The lack of real-time traffic information makes it difficult for riders to plan their routes effectively. This also leads to increased travel time and decreases the efficiency of vehicular usage. There are GPS-based mobile applications (e.g. Waze) that show real-time traffic flow through the GPS in mobile devices where the application was installed. However, not all riders use these types of applications as some still prefer traditional navigation methods, and with that lack of real-time traffic data utilization still occurs. Using mobile crowdsourcing helps the utilization of real-time traffic information onto which the system has been adapting.

Currently, some areas in the Philippines do not incorporate adaptive traffic light scheduling systems. Without implementing these types of systems in common congested roads, an increase in vehicular volume would add up to the current problem the country is facing. Within the scope of the study, the adaptive traffic light scheduling system to be implemented through crowdsourcing should be sufficient for the needs of daily commuters in the Philippines.

C. Objectives of the Study

In this study, the main objectives are to:

- Minimize traffic congestion in urban areas where it is most prominent;
- Produce an adaptive traffic light scheduling system based on the current vehicular volume;
- Produce a mobile application that engages users to participate whenever a congested intersection occurs in their everyday commuting experience; and

- Produce an Arduino-compatible microcontroller that simulates a traffic light in an intersection.

In the mobile application, the following specifications are to be implemented:

1. Location detection: The application uses GPS to detect the device's location in real-time.

2. Intersection identification: The application determines whether the device's location is at an intersection by comparing the latitude and longitude to the pre-defined database of the intersection.

3. Traffic light influence: The application communicates with the traffic light within the intersection using an installed Arduino microcontroller to control the timings.

   (a) From users: influences the traffic light timings using the GPS data collected from their devices.

   (b) From server: uses the GPS data to adapt the traffic light timings.

4. User Interface: The application provides a simple, and user-friendly interface for the user to interact. This allows users to report traffic conditions and monitor the status of the traffic light easily.

5. Privacy protection: The application implements anonymity in collecting data to protect the privacy of users.

6. Single-platform: The application is compatible with Android devices.

D. Significance of the Project

The gradual increase in traffic volume depending on the time of the day could greatly affect the daily commuters' experience as to which a proper system could interchange and resolve concurrent traffic problems. The foundation of the research is to overcome the great possibility of influencing the daily cycle of people involved in the study. The proposed system focuses on traffic light management where the highest traffic volume of a specific road within an intersection would be the main beneficiary that could greatly increase the flow volatility since it is dependent on the current vehicular volume in a specific intersection. In addition, the proposed system could exceed the capabilities of the literature as the implementation of the Waze application could be inherited with the idea of better and more efficient data gathering since Waze contains several features which greatly help the overall framework of the system. One possible Waze feature that would certainly improve the potential of the system is the surveying or reporting of the current situation of the user within a specific area. This feature could be adjusted to appropriately compose the data which significantly attracts efficient implementation of the framework. In essence, the system could sufficiently adapt and, possibly, self-propagate through improvements in the future. In essence, the system could sufficiently adapt to the current traffic status and self-propagate through improvements in the future.

Moreover, the system would greatly minimize traffic congestion in urban areas where a gradual increase in vehicular volume is most prominent. The system would be a big step forward toward the innovation and collaboration of its users through mobile crowdsourcing.

E. Scope and Limitations

1. General

- The proposed system benefits only the congested road of the intersection with corresponding traffic lights within a specific urban area. Expressways, however, could not be accommodated and most probably not participated during the experimentation proper. The target intersection is Congressional-Visayas Avenue which complements all the necessary scopes of the project.

- Furthermore, in terms of expenses, whenever the estimation of purchasing an Arduino module and additional technologies have been conducted, the researcher could accommodate a limited amount of money which can be further discussed in future deliberations.

- The proposed system focuses on the cross (+) isolated or single intersection whereas four possible traffic lights on every lane-bound (North, South, East, West) has been installed. Within this area of intersection, the right-turning lanes have not been prioritized as the Philippines implements right-hand traffic. Furthermore, the intersection of Congressional Avenue and Visayas Avenue in Quezon City fits the said characteristics.

2. Mobile Application

- The users involved in participating must be a rider or a commuter currently stuck in a congested intersection with traffic lights.

- Ideally, a user should only be able to increment one traffic data to the system. However, an expensive validation might not be implemented due to its non-resourcefulness. Nevertheless, the mobile application encourages every user to be as fair as possible to gather the ideal data.

- The mobile application uses a network connection that compromises the data between the server and itself. This ensures the adjustment of the tracking state of the device and the traffic light.

3. Arduino

- The proposed traffic light scheduling system has been implemented in NodeMCU ESP8266.

- The study should not be limited to the previously mentioned pre-built frameworks. Nevertheless, several Arduino modules should enable the said functionalities and implement the objectives.

II. Review of Related Literature

This section of the paper revolves around the foundation and sole purpose of the study — to solve traffic congestion. The related literature found in this section defines the methodology of the study that enables the propagation of the traffic light scheduling system to its extent.

Aydinan[5] conducted a study regarding the causes and effects of traffic congestion. The study took place in Cabanatuan, Nueva Ecija, Philippines which the researcher stated as the tricycle capital of the Philippines. The study aims to describe the economic impact of traffic congestion and its causes and its solution to the problem ahead. The data to be used in Aydinan's study were collected from structured questionnaires with a total of 100 survey questions to be answered by various workers in the city. Four major causes of traffic congestion were identified and analyzed using the Relative Importance Index (RRI) which includes the weighted mean of each question handed. Aydinan concluded that among the four major causes of traffic congestion, poor maintenance of the government was one of them. Within these, poor control measures, physical inadequacies, and human errors were among them. Out of the four causes, poor maintenance obtained the highest average weighted mean. Furthermore, we can deduce that several factors were affecting the traffic congestion in the Philippines, even though the study only took up in Cabanatuan City. However, the city holds the fifth most populated city in Central Luzon[6]. So, generalizing the study would not be a dilemma and among the analyzed major causes, we could prioritize solving the poor maintenance/poor governance of the traffic situations.

Arnado and others[7] investigated the regulation and implications of Public Utility Jeepneys (PUJs) in Cebu City, Philippines. An increase in the volume of vehicles most likely resulted in heavier traffic flow. Hence, an uncontrollable increase of PUJs, and none franchise vehicles gained the foundation that formulates the objectives of the study, and dissecting the effectiveness of the governance in Cebu City was one of them. The study utilizes a 5-minute 10-question survey of PUJ commuters, in addition to the data collected from existing records of the Land Transportation Office (LTO), Cebu City Traffic Operations Management (CITOM), and Land Transportation Franchising and Regulatory Board (LTFRB). The results concluded the following: PUJs are not the main reason for traffic congestion. It is the kind of regulation that the government imposes and the unclear provisions of the city ordinances provided for traffic management affect heavy traffic. Again, using the results in the study, we can infer that poor management of traffic situations still came up as we discussed in the previous studies in this section.

Madisa and Joseph[8] conducted a study with the use of Arduino with GSM capabilities to accommodate emergency vehicles (i.e. ambulances). The study was done using an Arduino Uno microcontroller which was connected to a cloud server to monitor the overall system. In addition, an Android application was developed that overrides and resets the traffic light whenever an ambulance needed to cross a junction. The application also monitors the traffic light equipped with GPS which helps distinguish every traffic light easily. Madisa and Joseph concluded that the Android application used by the emergency vehicles allowed ease of transportation to go from town to town. They also stated that the system will be essential for the safety of the people of the society by ensuring the lessening of traffic congestion. This type of system will surely enable the capability of microcontrollers to access and positively manipulate the traffic light scheduling system. Implementation of this leads to the improvement of the overall ITS and lessens traffic congestion.

Nodado and others[3] conducted a study where the improvement of intelligent transportation systems (ITS) was one of the purposes. The study took up at the intersection of Almar-Zabarte, and Camarin Road (both bounds) in North Caloocan City, Philippines where a traffic light was implemented in each and every lane of the intersection. The study used a microcontroller, Raspberry Pi 3, installed inside the Closed-Circuit Television (CCTV) around the area of the intersection for the calculation of traffic density. This study was very similar to the study presented in this paper. However, this study implemented image processing day and night with the help of the microcontroller installed inside the CCTVs. Moreover, an Android-based application (e-Trapiko) was also constructed to be used by the traffic enforcers around the area of the intersection which helps manage the traffic lights automatically and manually. The automatic traffic light scheduling system was conducted inside the mobile application with the use of setting the timer based on the current density of vehicles in each lane of the intersection. The study showed a high accuracy report on daytime and nighttime image-capturing tests. During the daytime, an average of 92.84% accuracy was obtained and 85.77% for nighttime among the four lanes in the intersection. The summary of the entire experiment concludes with almost similar percentages, 92.82%, and 85.77% in daytime and nighttime, respectively, testing on each aspect namely: Android to Traffic Light Control, Android GUI, and Lane Prioritization. Overall, the study successfully eased the workload of traffic enforcement using e-Trapiko and for everyday commuters as the traffic flow was regulated through image processing and adjusting the traffic light schedules. This proves that an adaptive traffic light scheduling system could be a key factor in achieving a better traffic flow and helping every commuter and rider experience less hassle on the road.

The emphasis of this paper is to further improve the efficiency of the usage of traffic light scheduling systems. Moreover, making the traffic light timings adaptive to its area of operation could be a refinement to today's fixed and stable light timings. Hence, a study conducted by Sharma and Indu[9] enables the traffic light timings, specifically the green light, to their maximum extent. The study uses Google's Geocoding and Direction API to point out the area of intersection where traffic congestion might occur. After the identification of the area of intersection, the calculation of the number of cars within each specific lane is to be used on the comparative green light schedulings. The green light timings were calculated with the help of 6 equations equivalent to the 6 traffic phases within the area of intersection. The formula is shown in Figure 1.

$$N_1 = \begin{cases} N_{st} + N_{turn}, & \text{if } N_{st} + N_{turn} \geq N_{st} + E_{turn} \\ N_{st} + E_{turn}, & \text{otherwise.} \end{cases} \quad (2)$$

$$N_2 = \begin{cases} N_{st} + S_{st}, & \text{if } N_{st} + S_{st} \geq N_{turn} + S_{turn} \\ N_{turn} + S_{turn}, & \text{otherwise.} \end{cases} \quad (3)$$

$$N_3 = \begin{cases} S_{st} + S_{turn}, & \text{if } S_{st} + S_{turn} \geq S_{st} + W_{turn} \\ S_{st} + W_{turn}, & \text{otherwise.} \end{cases} \quad (4)$$

$$N_4 = \begin{cases} E_{st} + E_{turn}, & \text{if } E_{st} + E_{turn} \geq E_{st} + S_{turn} \\ E_{st} + S_{turn}, & \text{otherwise.} \end{cases} \quad (5)$$

$$N_5 = \begin{cases} E_{st} + W_{st}, & \text{if } E_{st} + W_{st} \geq E_{turn} + W_{turn} \\ E_{turn} + W_{turn}, & \text{otherwise.} \end{cases} \quad (6)$$

$$N_6 = \begin{cases} W_{st} + W_{turn}, & \text{if } W_{st} + W_{turn} \geq W_{st} + N_{turn} \\ W_{st} + N_{turn}, & \text{otherwise.} \end{cases} \quad (7)$$

$$N_{i(norm)} = \frac{N_i}{S}, \ \text{i = 1,2,...,6} \quad (8)$$

$$S = \sum_{i=1}^{6} N_i \quad (9)$$

$$t_i = N_i * T, \quad (10)$$

Figure 1: Green Light Time Formulas

The 6 equations were normalized to equation (8). Until then, the green light time is calculated using the formula below. The study conducted a simulation using the AnyLogic simulator where it has resulted in a decreased average number of cars when the proposed solution of prioritizing the highest number of cars among the phases within the area of intersection. The formula stated above could be adapted in this paper where the highest number of cars will be prioritized in the green light time calculation. However, if this paper concludes with insufficient amount of time to conduct experiments within the real world, the simulation process done in the study could also be adapted to get expected results from the formulated equations.

The management and effective control of the area of intersection could be a challenge that this paper needs to address. Moreover, several urban areas accommodate a number of traffic lights occurring after one another. This architecture depicts the synchronization of these traffic lights where real-time traffic signals must be inherited in order to achieve a smooth traffic flow. Tomar, et al.[10] suggest that traffic systems must generate a green light for numerous vehicles to accommodate traffic flow. The visualization of the traffic signal control (TSC) used the levels of synchronization which could be solved based on several traffic system methods like the self-synchronization mechanism used for air traffic control (ATC). This method could be adapted in this paper together with an IoT-based mechanism with sensor deployment which further helps the overall methodology and expects a pleasant result. Figure 2 shows the possible implementation in an urban area with several areas of intersections and corresponding traffic lights. This shows that areas alike must have synchronized green light timings in order to achieve a better traffic flow.

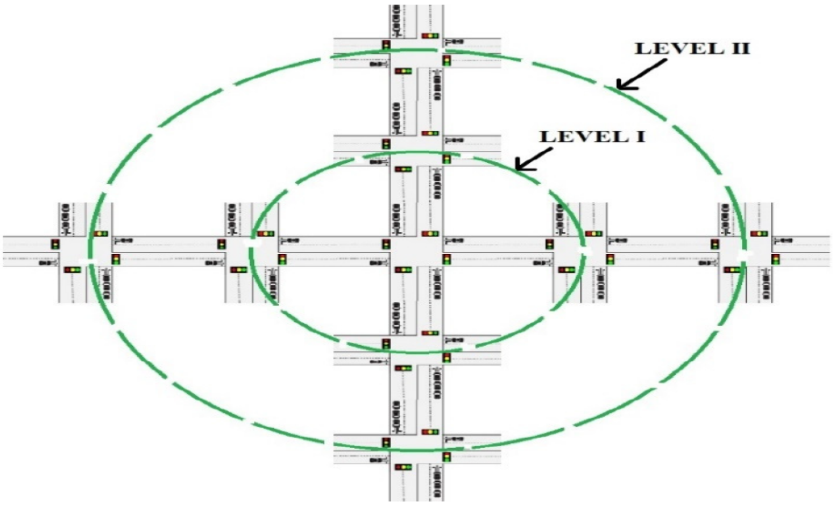

Figure 2: Synchronization Levels

MCS has been enabling smart cities to deal with the potential consequences of environmental pollution, management chaos, and traffic congestion. Kong and others[4] have conducted a study regarding the application and future challenges of MCS. They characterized MCS with three features: mobility, collaboration, and human capacity. The researchers have defined mobility as a utility power that improves the performance of MCS through the mobility patterns and social interactions the smart device carriers have. Second, collaboration enables the crowd workers to collaboratively perform distributive and partitioned tasks which further achieve a global objective. Lastly, the human capacity of MCS enables mobile individuals to utilize their sensing, communication, and processing capabilities[4]. All of these characteristics have been applied to four categories of smart cities: Smart Navigation, Civic Life, Public Services, and Smart Transportation. With regard to this special problem, only public services will be discussed. For that reason, one application mentioned in the study by Kong and others was public administration. They have proven that MCS provides citizens with the opportunity to directly participate in public administration to reduce the barriers between them. Thus, enabling citizens to report traffic conditions which further improves the traffic flow[4]. From this study, it has been proven that MCS could certainly apply to the improvements in traffic management.

Lastly, using GPS-based applications mitigates the overall methodology of the study. Waze APIs could be accessed easily, thanks to Google Developers. Steinbergs and Kligis[2] conducted a study on improving traffic safety using Waze user reports. The study used the Waze report analyzing tool to acquire reports on traffic conditions. The acquired data was then filtered with specificity and aligned to the study. The setting of study took place in Latvia where numerous Waze users participated in the study and reported 64% most of the time versus different communication channels like Facebook, on-call, etc. The study proves that there are several Waze users in different countries. In the Philippines, commuters and riders are using Waze to help ease the modes of transportation. Waze obtains a more accurate location than any other communication channel. This further emphasizes that this paper could utilize the usage of a GPS-based API (e.g. Waze or Google Maps) to improve the overall process of solving traffic congestion.

III. Theoretical Framework

A. Adaptive traffic light scheduling system

Through extensive simulation, Sharma and Indu[9] have found that an adaptive traffic light scheduling system accommodates several lane phase intersections with a low volume of vehicular traffic. The study has been conducted through the AnyLogic simulation modeling tool that runs through specified variables according to the factors affecting congestion. They have concurred that the proposed system greatly prioritizes the most congested lane phase through user data passing to an online central server which will then be processed by the Arduino with a GSM module in each and every traffic light within an area of intersection. However, there were several controlled factors affecting the simulation: the number of cars in a specific direction, the number of cars going in a specific direction, and the total green light time cycle. These specifications could be detrimental when dealing with a real-world situation. Hence, a much better and improved simulation could be applied whenever a study did not come up with real traffic data.

In this special problem, the adaptive green light timing formulas has been implemented to a cross-intersection to accommodate the real-world factor deficiency in the previous study stated. One possible cross-intersection the researcher could think of is the intersection of Congressional and Visayas Avenues. The specifications of the previous study would also be able to assess the traffic situation in the intersection.

B. Mobile Crowdsourcing

A centralized mobile crowdsourcing architecture has been tackled by Phuttharak and Loke[11] which has been following a client-server model where a central server provides services and resources to clients that initiate requests. The centralized architecture is divided into four layers: (a) mobile sensing and gathering; (b) connectivity and network; (c) crowd-processing; and (d) end-user. Mobile sensing and gathering refer to generating and forwarding the data from various sensing devices (e.g. mobile phones) to the main server via wireless communication networks. In this special problem, the data to be collected will be through participatory sensing where data could be used to classify the congestion in an intersection. The connectivity and network layer is responsible for providing network connectivity to mobile devices and transmitting data collected by mobile sensors to the server. It uses various communication networks such as wireless sensor networks, cellular networks, Wi-Fi, Bluetooth, etc. The primary concern of this layer is to establish network links, provide device discovery mechanisms, and minimize costs associated with service charges and resource consumption. The crowd-processing layer is responsible for analyzing, processing, virtualizing, and storing the data and tasks collected from the lower layer. This layer often utilizes cloud computing technology, which provides benefits such as improved data storage, enhanced processing power, and improved reliability. However, cloud computing can also lead to latency issues for real-time processing and highly mobile applications. To overcome these, the concept of fog computing has emerged, which aims to keep data closer to the network edge by using local devices rather than routing everything through a central control center. Lastly, the end-user layer consists of requesters who use crowdsourcing services. These requesters can be individuals, organizations, or even car users. They create crowdsourcing tasks through a user interface (UI) and receive final results from the crowdsourcing back-end server. The UI design plays a significant role in the success of the crowdsourcing task and its results as it affects worker performance and the quality of the results. Simplifying the UI and task instructions and making the content contextual can result in a higher rate of task completion by workers.

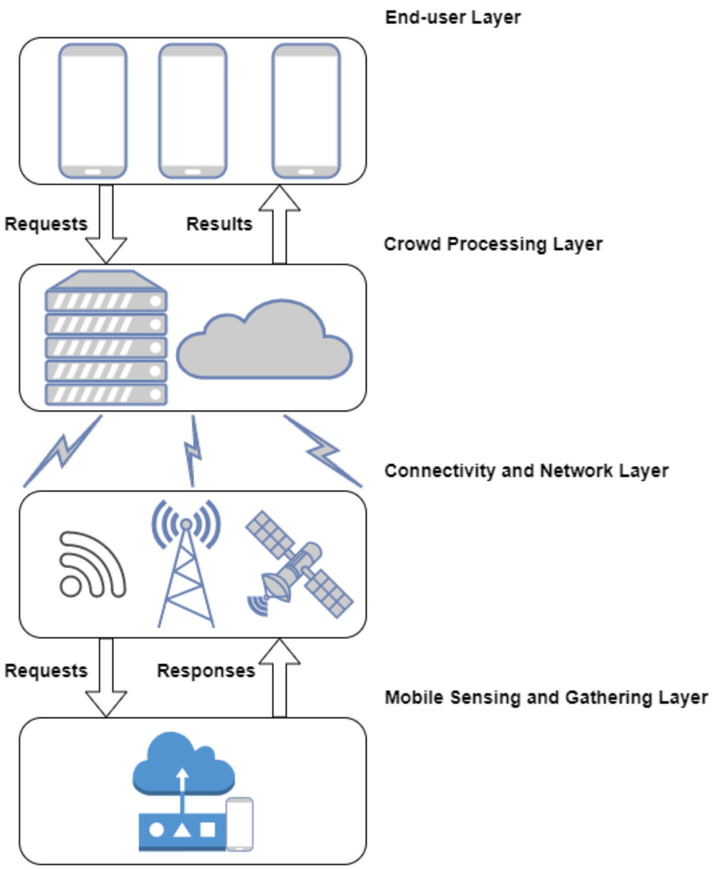

Figure 3: Centralized MCS Architecture

C. Arduino and Cloud-Based Traffic Control System

The traffic light system in the Philippines is currently inefficient and inadaptive in many ways. The green light timings do not coherently calculate based on the current vehicular volume. One possible solution was through installing an Arduino microcontroller linked to a cloud server onto which the user overrides a specific traffic light. The study done by Madisa and Joseph[8] was run through Real-Time Operating System (RTOS) for its high reliability and many deterministic operations. In this essence, Human-Machine Interfaces (HMI) and Supervisory Control Data Acquisition (SCADA) were embedded in the traffic signals to enable communication between the external systems. This study produces a significant theory that Arduino and cloud-based frameworks will effectively control traffic lights. Using Arduino circuits or like would profoundly help the researcher communicate the total traffic light cycles with another external system.

D. Communication Protocol and Traffic Light System

The following are the common communication protocols used to integrate different devices into a traffic light system.

1. Ethernet - a widely used wired communication protocol that allows devices to connect to a network to establish communication. This can be used to connect the traffic signal controller to a central management system that allows real-time traffic data collection and analysis.

2. Serial communication - commonly used in traffic light systems to connect the signal controller to sensors, pedestrian push buttons, or other devices. RS-485 is the most widely used serial communication in traffic light systems.

3. Wireless communication - Wi-Fi, Bluetooth, or Zigbee can be used to allow for remote management and real-time monitoring of traffic signal systems. It can also be used to communicate signal controllers to sensors or other devices.

E. Preliminaries

The researcher has communicated with the MMDA-Traffic Engineering Center (TEC) to acquire insights and suggestions regarding the overall design and implementation of the project. Initially, the researcher asked the resource person several questions regarding the status of the traffic light system in the Philippines. The following are the questions asked of the resource person in the TEC:

1. Do the Philippines implement a standardized/centralized traffic light system? Why or why not?

2. For a specific intersection or area, does it a standard traffic light system?

3. On what percentage does the adaptive traffic light been adopted in Metro Manila?

4. Currently, how do the traffic lights supply the timings for the demand of traffic flow?

The TEC resource person responded with the following, respectively:

1. No, the Philippines do not implement a standardized/centralized traffic system. The reason is due to other cities use different traffic signal systems with different communication protocols.

2. Yes, under MMDA signalization, we use COSMOS System from Korea.

3. 40.54%. This is equivalent to 210 out of 518 signalized intersections.

4. The traffic lights are equipped with loop detectors and we have a tool used in optimizing the signal timing called PTV Vistro.

For clarification and authentication of the feasibility of the project, the researcher requested a follow-up scheduled online meeting with the resource person. The design and implementation below were discussed with the resource person together with the approval of the system. The insights given were the assurance of the usage of the Arduino microcontroller and its connections to the traffic light and mobile application. In addition, the system must be implemented at an isolated or single intersection which the target intersection (Congressional-Visayas Avenue) is an example of. This is due to the synchronization of multiple traffic light intersections will be a much more complex feature of an adaptive traffic signal system.

IV. Design and Implementation

A. System Architecture

Figure 4 below shows the architecture of the distributed systems composed of several lone systems. First, a client application has been implemented to interact with a user. The client application is a mobile application with local storage that is compromised of the user's data and communicates with the web server. Another system that incorporates the overall distributed system is the web server. The server takes up all the necessary endpoints that a user could infiltrate. Every endpoint communication is synchronized to align with the data within the server's database and the mobile application's local storage. The next system will be the microcontroller which uses MQTT to communicate with the web server. A single microcontroller handles a single bound in an intersection. Every microcontroller connects to the MQTT Broker in the cloud. This helps to the synchronization of the overall system.

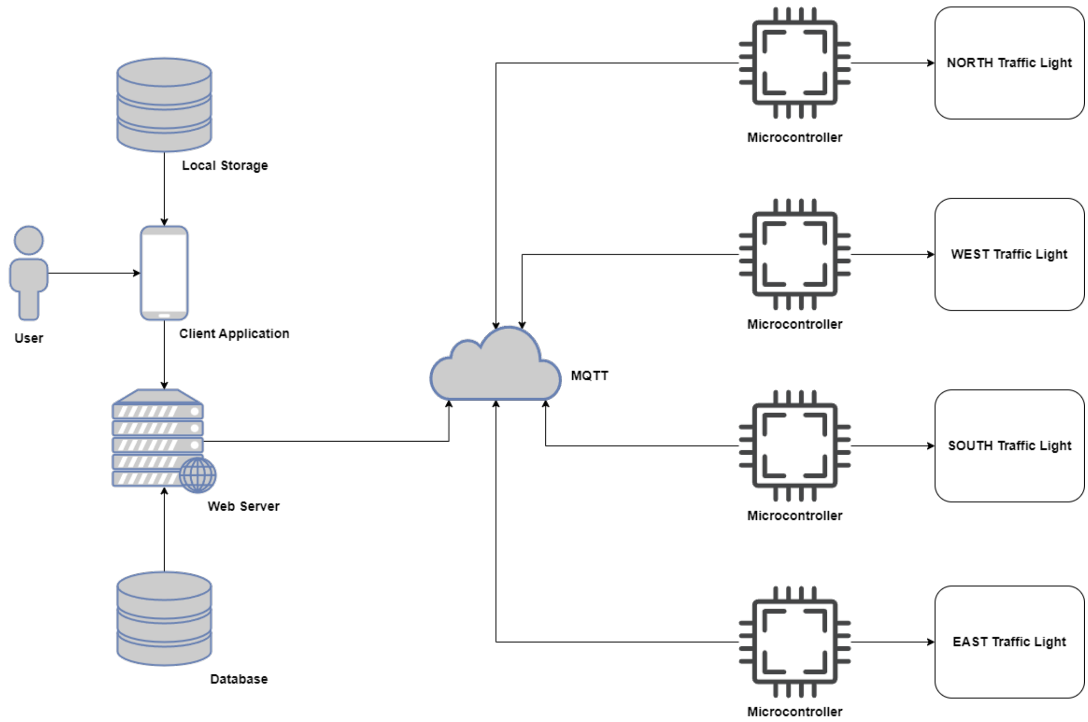

Figure 4: System Architecture

B. Traffic Light Scheduling System

An ideal traffic light scheduling system must be adaptive to the current traffic situation. Whenever the threshold for the vehicular volume has been reached, the traffic light must adapt to the congestion of an intersection. In this paper, the threshold for a lane-bound to be considered a slow and heavy traffic situation will be 60 and 120, respectively. The numbers calculated were considered in a 3-lane highway, so the threshold must be a factor of the n-lane highway. The adaptive green light calculation inhibits the current vehicular volume gathered from the mobile application. The algorithm for calculating green light timings is implemented based on the formulas in Figure 1 and shown below. The formula accumulates all the vehicular volume in each lane phase, illustrated in Figure 5.

$$N_i = \text{turning left} + \text{going straight}, i = 1, 2, \ldots 6$$

$$S = \sum_{i=1}^{6} N_i$$

$$N_i(normalized) = \frac{N_i}{S}$$

$$t_i = N_i(normalized) \cdot T$$

$$T = \text{STANDARD TIME FOR } RED + YELLOW + GREEN$$

$$g_i = t_i - \text{STANDARD TIME FOR } YELLOW$$

$$r_i = T - t_i$$

where

N_i is the number of users in a bound

S is the number of users in an intersection

t_i is the calculated time for a bound

T is the total time cycle for each traffic light in an intersection

g_i is the green light time for a bound

r_i is the red light time for a bound

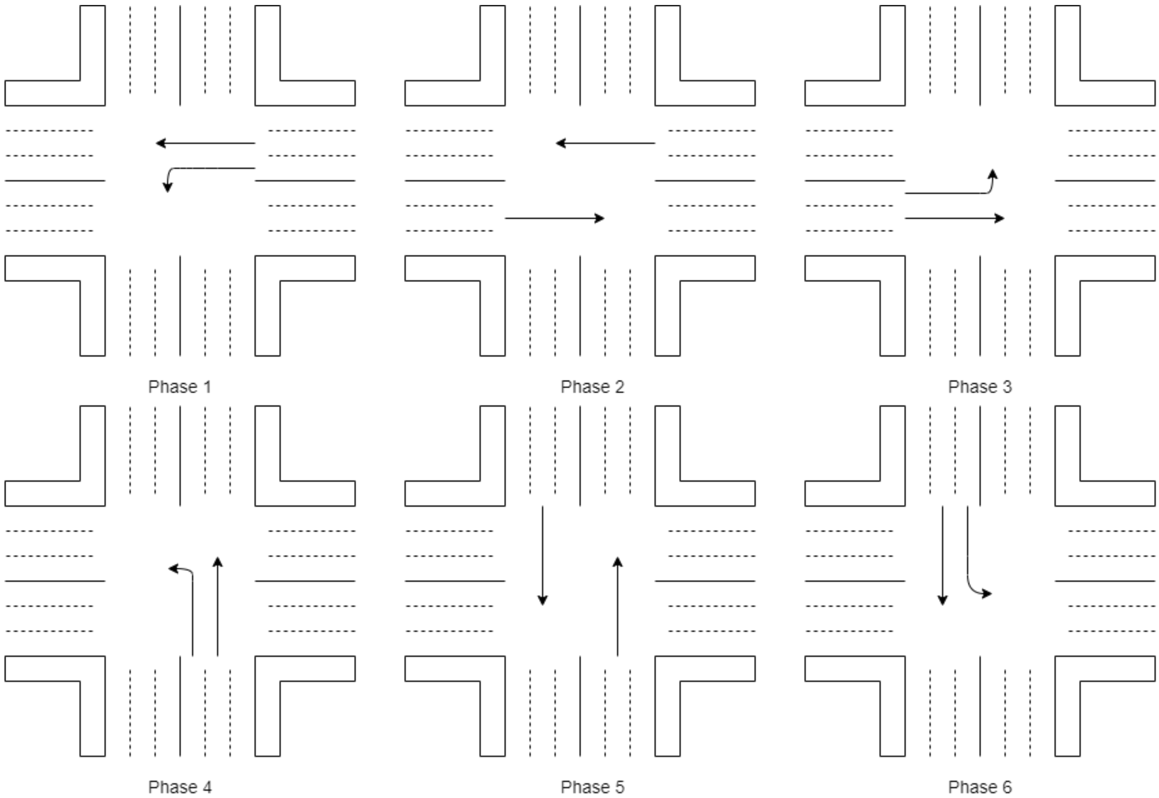

Figure 5: Traffic Lane Phase

The default lane phase complements the actual phasing of traffic on the target intersection (Congressional-Visayas Avenue) stated in the scope above. The only phase not inherited in the target intersection was phase 5, however, phase 5 was still illustrated for the standardization of the traffic lane phase for a 3-lane road. For the demonstration of the system, only phases 3 and 4 were implemented, since the resources are limited. These phases were chosen as it also complements the counterclockwise traffic light cycle at the target intersection.

C. Application Development

1. Language and Frameworks

1. Android Studio

   - It is the standard Integrated Development Environment (IDE) for Android development.

- It comes with a Gradle-based build system that includes a fast and feature-rich emulator which helps ease of testing an application. [12].

2. Spring Boot

   - An open-source Java-based framework used to create a micro Service application, an architecture that develops and deploys services independently.
   - Can also be used to create server-side applications.

2. Database

1. Room

   - It is a persistence library that is also an abstraction layer over SQLite
   - Room reduces boilerplate codes as it converts data from SQLite to Data Transfer Object (DTO).
   - It is a component of the Android Architecture that provides observable data for the synchronization of interface and storage. [13]

2. PostgreSQL

   - An open-source object-relational database system that extends the Structured Query Language (SQL).
   - Fault-tolerant and highly extensible.

3. Network Protocols

1. Message Queueing Telemetry Transport (MQTT)

   - It is the most commonly used messaging protocol for the Internet of Things (IoTs).
   - An event-driven and communicates between machines using publish/-subscribe (Pub/Sub) pattern, where events could be published and subscribed as Topics. [14]

2. Socket IO

    - A library that is built on top of Web socket protocol which provides a low-latency, bi-directional, and event-based communication between a client and a server. [15]
    - It provides real-time data synchronization between a client and a server.

3. Hypertext Transfer Protocol (HTTP)

    - It is the foundation of exchanging data on the Web.
    - Uses a request-response pattern where a client requests data, then a server will send back the data as a response.

D. Arduino Microcontroller and Mobile Crowdsourcing Application

In the target intersection (Congressional-Visayas Avenue), the traffic light system is still unknown. Generalization on what type of communication protocol to the existing system could be fatal in the development of the special problem. To ensure the process and methodology, an Arduino microcontroller has been installed on-site to ensure the connection between the mobile application to the traffic light system. Before developing the APIs in the microcontroller, it should, first, be able to install properly the traffic signal system in the intersection. Necessary communication interfaces, such as Wi-Fi, Bluetooth, or cellular network, must be present in the microcontroller to ensure the data transfer from the mobile application to the microcontroller to the traffic lights.

V. Results

A. Mobile Application Screenshots

The following screenshots show the mobile application's behavior throughout its lifecycle, captioned with corresponding descriptions.

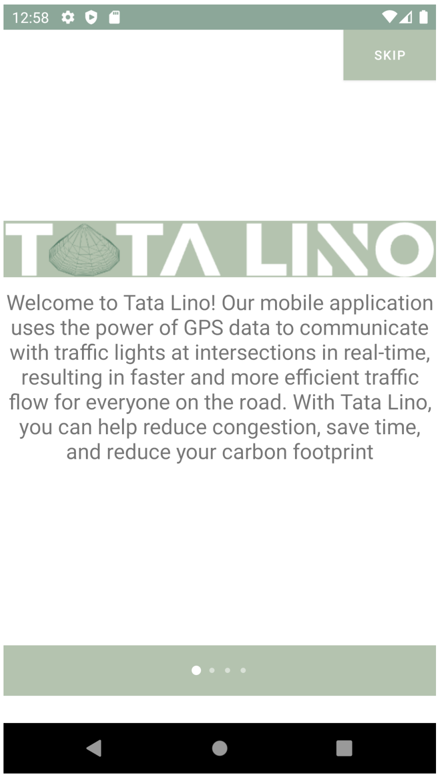

Figure 6: Landing Page

This is the landing page of the application where four swipable contents are implemented. Each content introduces the mobile application and its purpose.

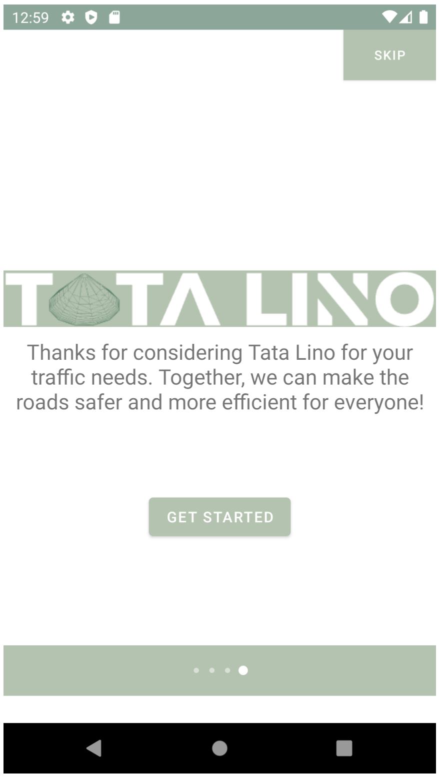

Figure 7: Get Started Page

This will be the last content of the landing page. As we can see, the buttons "Get Started" and "Skip" could be clicked to navigate to the mobile application itself.

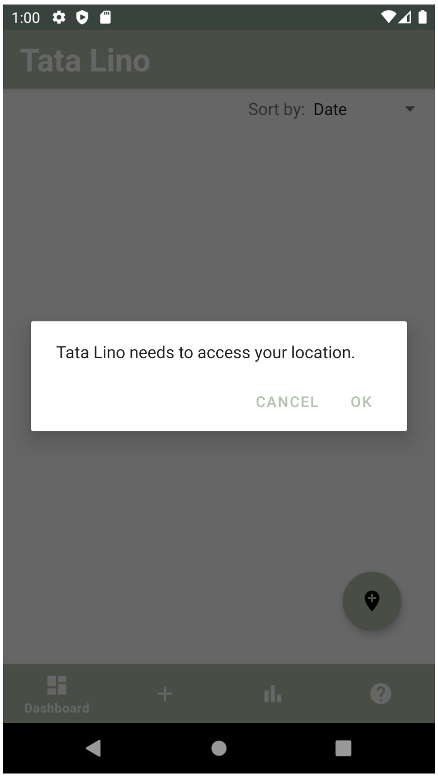

Figure 8: Location Permission

This will be the dialog that will ask the user to access the device's location. Clicking "OK" will navigate the user to the permission settings of the application.

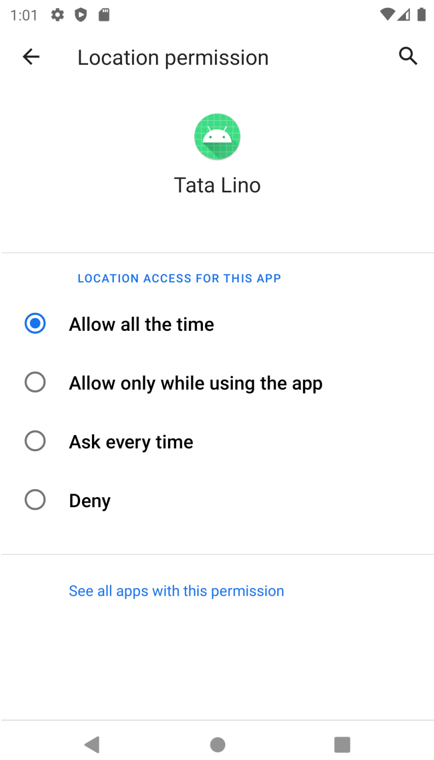

Figure 9: Location Accessed

This screenshot pertains to the permission settings of the application. The application needs to access the location all the time as background tracking will be implemented throughout its lifecycle.

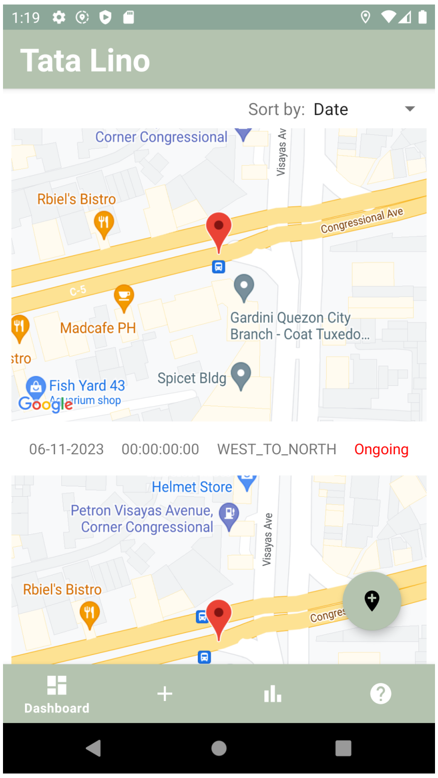

Figure 10: Dashboard Page

This is the dashboard page of the application. This will only be accessed when the application has already been permitted to access the device's location all the time. The dashboard page contains all the tracking history of the user. The floating action button on the lower-right part of the page will navigate the user to the track user page. Whenever the tracking state is "Ongoing", the user could click the map snapshot to navigate back to the tracking page.

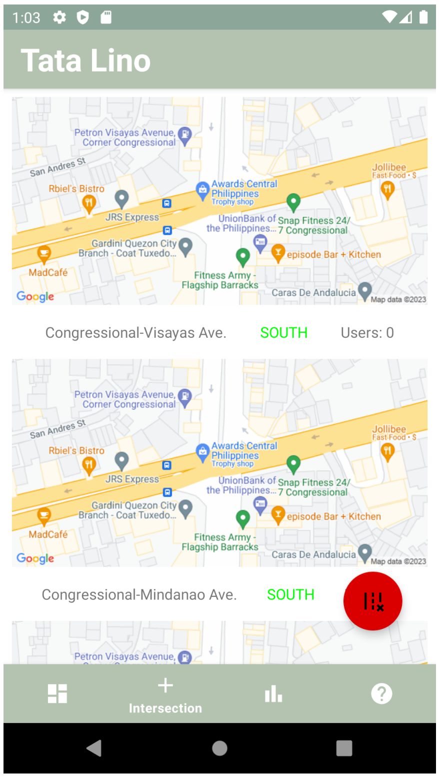

Figure 11: Intersection Page

The intersection page contains all the available intersections in the server's database. Initially, navigating to this page will load the data from the server. The user could also monitor the current number of users in a particular intersection. Also, the stoplight state will be fetched whenever this page has been refreshed.

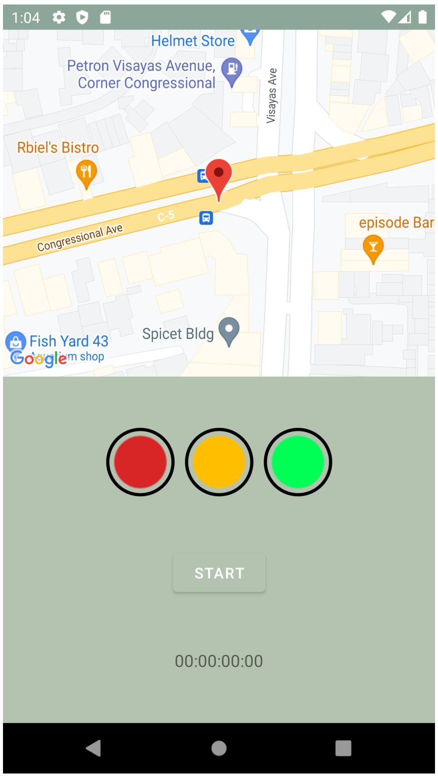

Figure 12: Track User Page

The track user page contains the map with the user's location. The user could also monitor the stoplight status of its bound whenever the tracking has started.

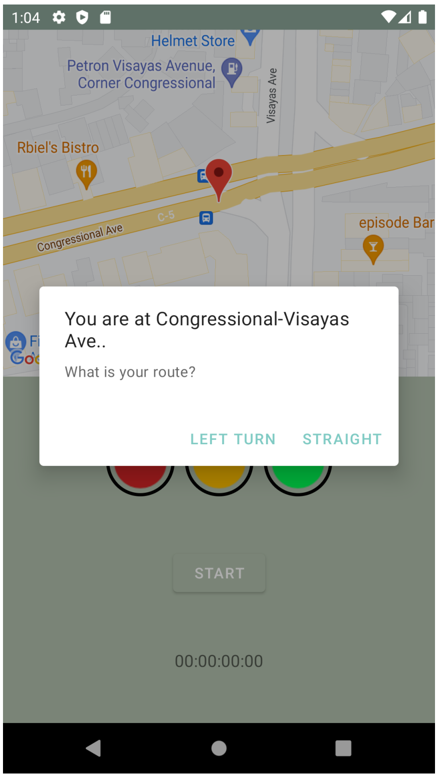

Figure 13: Route Dialog

This dialog will confirm whether the user is turning left or going straight ahead of the intersection. Clicking either of the choices will increment to the server and current number of user in that bound and intersection will be updated in real-time.

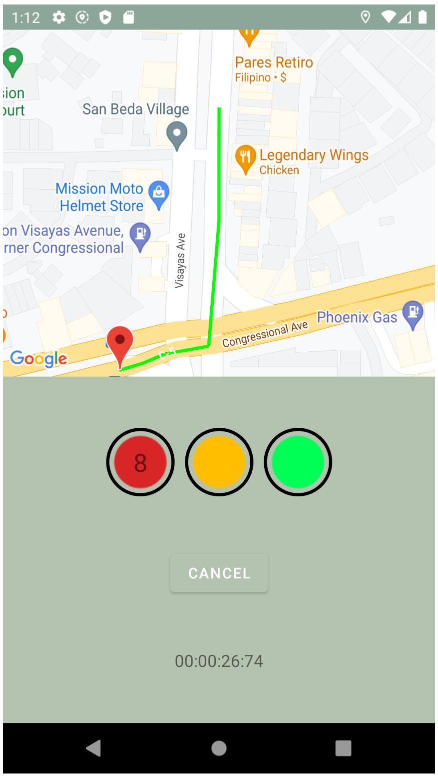

Figure 14: Tracking User

The tracking page of the application will move the map snapshot to the user's location in real time. Also, the monitoring of the stoplight of the user's bound will be updated in real-time. The user could cancel the tracking to erase all the data from the server.

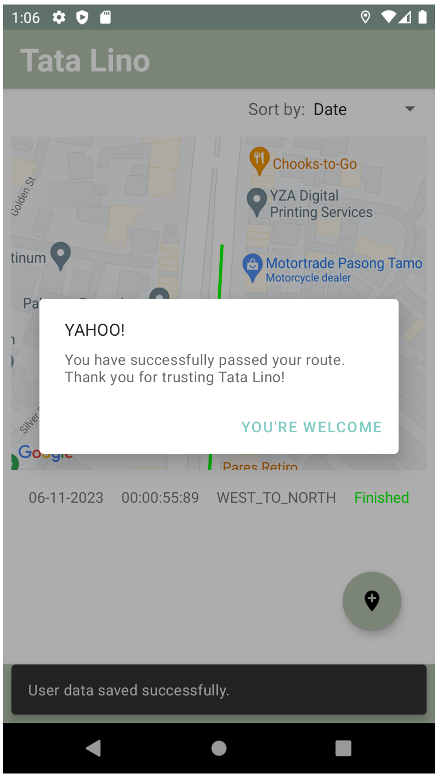

Figure 15: User Passed

The user will be navigated back to the dashboard page after crossing the intersection. Then, the dialog will appear on the screen.

B. Traffic Light Mock-up

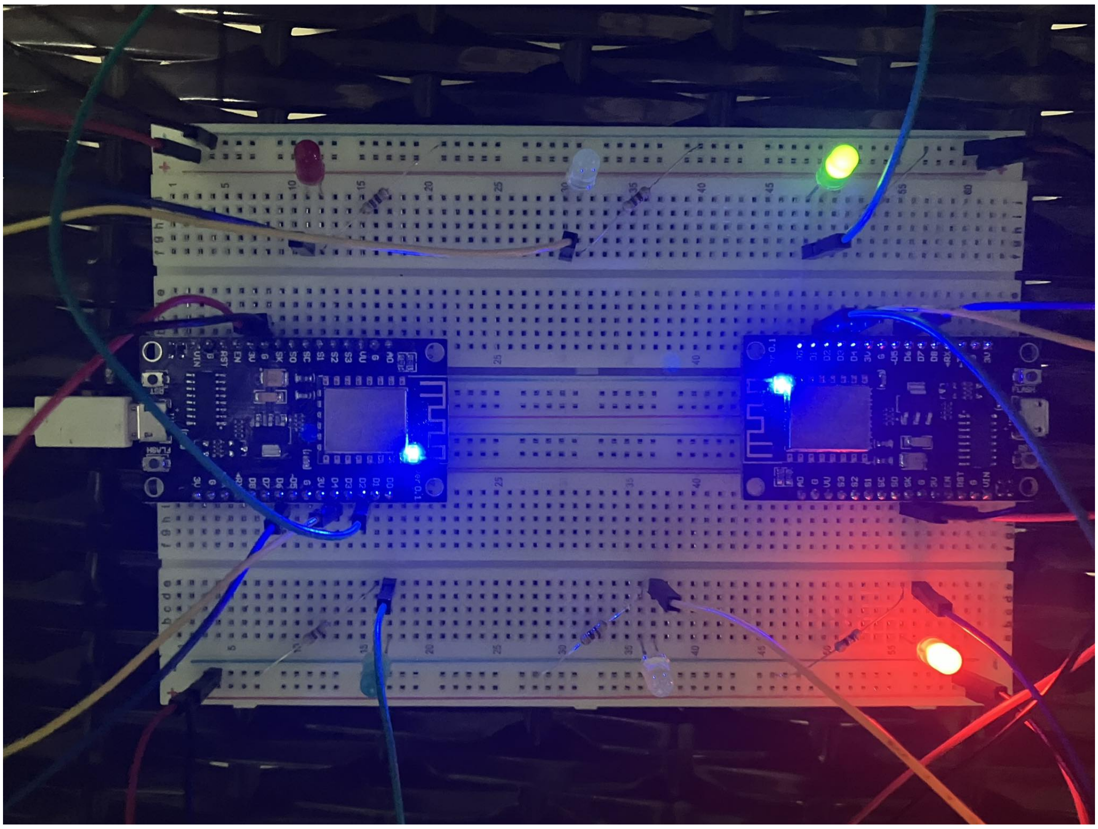

Figure 16: Stoplights

Figure 16 shows the mock-up stoplight used for the simulation of a stoplight that communicates with the server using the MQTT broker. The stoplight consists of a microcontroller and LEDs that basically inhibits a real-world stoplight. The microcontroller contains a Wi-Fi connection to be able to exchange data with the MQTT broker. The mock-up only contains two bounds for an intersection. The stoplight seen on the upper part of the board is westbound, while the southbound is seen in the lower part of the board.

VI. Discussions

The special problem has developed an adaptive traffic light system. The system heavily relies on a network connection to minimize the delay in monitoring the traffic situation at an intersection and the overall interface. This includes the real-time tracking of the user's device, the traffic light status of the user's bound, and the current number of users in an intersection. The system will adapt to the current number of users to adjust the corresponding timing of each traffic light in an intersection. For example, if the current number of users on westbound is higher than those on southbound, a corresponding green light time will also be higher on westbound. Each time a user has started the tracking state, the data will be appended to the server and updated after crossing the intersection.

A. Distributed System

The distributed system composes of several lone systems. First, the mobile application acts as the client application and communicates with the server for data exchange. The mobile application enables the user to interact with the whole system. Next, the server application is considered the intermediary between the mobile application and the mock-up traffic light. The server communicates with the mobile application through network protocols, HTTP, and Socket IO. As previously mentioned, a reliable network connection must be inherited for the whole system to be fully functional. The communication between the server and the traffic light would be exchanging data through an MQTT broker. Each time a traffic light phase has changed (i.e. green to red or red to green), the server will update the corresponding time and status of each traffic light. This will ensure the adaptiveness of the scheduling system based on the current number of users in that traffic light bound.

B. Issues and challenges

The main issue for the distributed system was caused by the network connection. Whenever a user has a bad connection, there would be delays, and inaccurate time and state would be seen in the interface. With that, the researcher made the data exchange between the mobile application and the traffic light through the server. This allows the mobile application to adjust to the corresponding time and state of the traffic light. Even if delays have occurred (e.g. the time and state advances in the interface), the mobile application will still adjust whenever a traffic light phase has changed. For example, the interface shows that the traffic light is already green with 8 seconds in time, but the mock-up traffic light is still red. As soon as the mock-up traffic light changes from red to green, a corresponding time will be updated on the interface.

C. Contribution

The system helps to overall problem of travel time, fuel consumption, and air pollution. This allows every commuter or rider to efficiently move towards their destination. This also lessens the work of a traffic enforcer who manually facilitates the traffic situation in an intersection.

VII. Conclusions

In conclusion, by addressing the objectives of minimizing traffic congestion in urban areas, producing an adaptive traffic light scheduling system, developing a mobile application for user engagement, and creating an Arduino-compatible microcontroller simulation for traffic lights, we have made significant progress in tackling the challenges associated with traffic management. By adopting innovative approaches and leveraging technology, we aim to create a smarter and more efficient transportation infrastructure.

Through the implementation of advanced algorithms and real-time data analysis, our adaptive traffic light scheduling system can dynamically adjust signal timings based on the current vehicular volume. This will help optimize traffic flow and alleviate congestion in the most prominent urban areas where traffic congestion is a persistent issue.

Furthermore, our user-engagement mobile application empowers commuters to actively participate in reporting congested intersections during their everyday journeys. By involving users as real-time traffic reporters, we can gather valuable data and insights to further enhance traffic management strategies.

To facilitate the development and testing of traffic management solutions, we have created an Arduino-compatible microcontroller that accurately simulates a traffic light in an intersection. This allows for efficient prototyping, experimentation, and evaluation of different control algorithms and strategies.

By combining these efforts, we strive to create a comprehensive ecosystem that addresses the challenges of traffic congestion in urban areas. Our ultimate goal is to enhance the efficiency, safety, and sustainability of transportation systems, improving the quality of life for both residents and commuters alike. Together, we can pave the way toward smarter and more livable cities.

VIII. Recommendations

Based on the discussions and achievements outlined in the previous sections, we can identify several areas where enhancements can be made to the application system, thereby improving its functionality and user experience. These recommendations can serve as a valuable guide for future students who will be working on their SP (Special Problem) related to traffic management and mobile application development.

1. Enhanced Real-time Data Analysis: One area of improvement lies in enhancing the real-time data analysis capabilities of the mobile application. By leveraging machine learning and artificial intelligence techniques, future developers can explore advanced algorithms to process and analyze the traffic data collected from users. This can enable more accurate congestion detection, predictive traffic modeling, and efficient route suggestions for users.

2. Gamification Elements: To further engage and incentivize users, integrating gamification elements into the mobile application can be considered. This can include introducing leaderboards, rewards, challenges, and achievements based on user participation and contributions in reporting congested intersections. Gamification can encourage a sense of competition, making the application more appealing and encouraging sustained user engagement.

3. Integration with Navigation Apps: Collaborating with established navigation applications, such as Google Maps or Waze, can enhance the overall user experience. Integrating our application with these platforms can provide users with seamless navigation options and real-time traffic updates, combining the benefits of both systems. This integration can also allow for the exchange of data, enabling our application to contribute to the accuracy of navigation instructions and traffic predictions.

4. Community Features and Social Networking: Building community features and social networking capabilities within the application can foster a sense of

community among users. This can include features such as user profiles, messaging systems, forums, and the ability to connect with fellow commuters. Creating a platform where users can share experiences, tips, and information related to traffic conditions can enhance user engagement and encourage a collaborative approach toward traffic management.

5. Expansion to Additional Cities and Regions: While initially focusing on specific urban areas with prominent traffic congestion, expanding the application's coverage to include other cities and regions would be a valuable future enhancement. This would require integrating with data sources and traffic management systems from different locations, enabling users from various areas to benefit from the application's features. This expansion can help address traffic congestion challenges on a broader scale and provide a more comprehensive solution.

By considering these recommendations, future BSCS students working on their SP can explore new avenues for improving the mobile application system. These enhancements aim to further optimize traffic management, enhance user engagement, and contribute to the overall effectiveness of the solution. The researcher encourages students to conduct thorough research, consider user feedback, and iterate on these recommendations to shape the future of traffic management applications and create meaningful impacts in urban transportation systems.

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