Monitoring of Illegal Removal of Road Barricades using Intelligent Transportation Systems in Connected and Non-Connected Environments

Final Report

by

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November 2022

Center for Connected Multimodal Mobility (C^2M^2)

Clemson University

Benedict College · The Citadel · SC State University · University of South Carolina

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ACKNOWLEDGMENT

The project is funded by the Center for Connected Multimodal Mobility (C^2M^2) (Tier 1 University Transportation Center) Grant, from the U.S. Department of Transportation's University Transportation Centers Program and administered by the Transportation Program of the South Carolina State University (SCSU) and Benedict College (BC)
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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems in Connected and Non-Connected Environments		**5. Report Date** 11/18/2022 **6. Performing Organization Code**
7. Author(s) Frank C. Ngeni; ORCID: https://orcid.org/0000-0002-7181-6184 Judith L. Mwakalonge, Ph.D.; ORCID: https://orcid.org/0000 0002-7497-6829; Gurcan Comert, Ph.D.; ORCID: https://orcid.org/0000-0002-2373-5013; Saidi Siuhi, Ph.D.; ORCID: Varghese Vaidyan, Ph.D.; ORCID:		**8. Performing Organization Report No.**
9. Performing Organization Name and Address South Carolina State University 300 College Street NE, Orangeburg, SC 29115		**10. Work Unit No.** **11. Contract or Grant No.** 69A3551747117
12. Sponsoring Agency Name and Address Center for Connected Multimodal Mobility (C2M2) Clemson University 200 Lowry Hall, Clemson, SC 29634		**13. Type of Report and Period Covered** Final Report (August 2021 - November 2022) **14. Sponsoring Agency Code**
15. Supplementary Notes		

16. Abstract

Illegal removal of road barricades without notice of road emergency officials and road users has resulted in fatalities, injuries, and property damages. It is only after an incident has occurred or someone noticed the removal and alerted the authorities for the barricade to be placed back at its intended location. Due to this event, traditional barricades must be equipped with mechanisms to alert emergency officials and warn road users of impending danger. This research utilized the Global Positioning System (GPS) module, and Radio Frequency (RF) modules to detect barricade movements, and alert emergency officials and road users. The barricade movements were estimated from the haversine distance formula, corrected for errors, and then compared with the distance threshold value for the road users within a geofenced area to be alerted. The geofenced area radius was estimated to be *1.04 miles* from the barricade location using the American Association of State Highway and Transportation Officials (AASHTO), National Safety Council (NSC), and TransGuide ITS manuals. The non-parametric bootstrapping method was used to estimate the GPS position error to *10.5 feet* and corrected the measured distances. Experimental data of the system from a clear sunny day shows that low-cost GPS modules have the best response to barricade movements compared to a cloudy day where movements can't be explained easily. This system can communicate with Road-Side Units (RSUs) and On-Board Units (OBUs) and is expected to warn road users and alert emergency officials.

17. Keywords	18. Distribution Statement
barricades, illegal removal, ITS, GPS module, RF module, RSUs, OBUs, traffic safety	This report or any part of this report is restricted to publication until prior permission from the authors.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		NA

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EXECUTIVE SUMMARY

Illegal removal of road barricades without the notice of road emergency officials and road users has resulted in fatalities, injuries, and property damages. It is only after an incident has occurred or someone noticed the removal and alerted the authorities for the barricade to be placed back at its intended location. Due to this event, traditional barricades must be equipped with mechanisms to alert emergency officials and warn road users of impending danger.

In the first part of this report, the non-connected environment utilized Wireless Fidelity (Wi-Fi) together with the Global Positioning System (GPS) module to monitor and detect barricade movements. Barricade movements were estimated from the haversine distance formula, corrected for errors, and then compared with the maximum distance threshold value for the road users within a geofenced area to be alerted after approval from the emergency officials. The geofenced area radius was estimated to be *1.04 miles* from the barricade location using the American Association of State Highway and Transportation Officials (AASHTO), National Safety Council (NSC), and TransGuide Intelligent Transportation System (ITS) manuals. The non-parametric bootstrapping method was used to estimate the GPS position error to *10.5 feet*.

To facilitate communication in the connected environment part of the project, Radio Frequency (RF) modules were used. Radio waves offer signal transfer and comprise a transmitter and a receiver whereby the transmitter encodes/modulates the information by varying frequency, and the receiver receives the information from the transmitter once tuned at the same frequency through decoding. The RF modules worked in collaboration with the GPS module and micro-controllers to monitor the location of barricades and information was smoothly shared with emergency officials through emails. The GPS continuously geolocates the barricade and updates google maps through Google JavaScript APIs and if any movement is detected, the transmitter sends information to the receiver at the monitoring station. Road users within a geofenced area were alerted when the threshold distance that endangers safety was exceeded and approved by emergency agencies through text messages. Experimental data of the system from a clear sunny day shows that low-cost GPS modules have the best response to barricade movements compared to a cloudy day where movements can’t be explained easily. This system can communicate with Road-Side Units (RSUs) and On-Board Units (OBUs) and is expected to warn road users and alert emergency officials.

PART ONE

Non-Connected Environment

CHAPTER 1

Introduction

1.1 Background

During emergencies, emergency management officials use barricades to protect the traveling public from impending danger. Barricade(s) may be set up to stop traffic from a washed-out or flooded roadway or bridge. In early October 2015, South Carolina experienced devastating flooding as heavy rain hammered the region. Eighteen people were killed because of weather-related incidents as reported by emergency officials (Yan & Sanchez, 2015). Seven were killed in traffic incidents and twelve were killed in drowning incidents after driving through high water. Interstate 95 was one of the hundreds of roads that were closed due to flooding with some roads being completely washed away (Yan & Sanchez, 2015).

Cases of barricades marking washed-out roadways being illegally removed are not unfamiliar during emergency conditions (Rae, et al., 2016). In June 2011, barricades marking a washed-out municipal road were illegally removed in Brandon, Manitoba and no suspects were identified, and no one was charged. Similarly, during the 2015 historic floods in the Eastern United States, on Congaree Road in Lower Richland County, South Carolina, barricades placed to limit people crossing were displaced before a truck with five railroad employers on duty for maintenance went off the road into the flooding water resulting in two fatalities (WIS-Staff, 2015).

1.2 Methods of Traffic Control

According to Federal Highway Administration (FHWA) before road/lane closures, data on geometric characteristics, existing traffic conditions, environmental characteristics, proposed work activity, and work duration need to be evaluated (Datta, et al., 2016). Roads are usually full, partially or lane closed to control traffic in work zones or around incident areas. During working on the fully closed road, traffic is usually detoured, allowing roadworks to proceed. This can lead to constructive public sentiment, productivity increase, project duration overrun control, improved safety, cost savings, and a reduced risk period. (FHWA(2), 2022). Furthermore, full road closure can be in terms of a real full road closure, weekend closures, and other closures due to limited capacity, night-time, off-peak or ramp controls. Apart from full road closure, partial closure of a road can be achieved by the closure of one side of the road where traffic is channelized rather than being detoured to the other roadside. In lane closure, a specific lane can be closed and usually authorities prepare policies and conduct thorough studies on traffic before implementing the strategy by determining daily permitted lane closure times (FHWA(2), 2022).

During traffic control, the Manual on Uniform Traffic Control (MUTCD) recommends that Traffic Control Devices (TCDs) must command attentiveness to drivers, and deliver an unblemished and simple message. Also, TCDs are expected to command traffic respect and provide thorough time for an immediate response within a Temporary Traffic Control (TTC) zone (FHWA(3), 2009). TTC zones are divided into four areas that can be used to alert drivers which include the advance area, the transition area, the activity area, and the termination area (FHWA(4), 2022). These zones need to be ascertained for the positioning of suitable traffic control signs.

In road short-term and long-term closures, different practices can be implemented to ensure traffic safety. Tapers, Portable Changeable Message Signs (PoCMS), Permanent Changeable Message Signs (PerCMS), and the pilot car method are some of the methods used (FHWA(3), 2009). Furthermore, warning signs and queue warning systems, pavement markings, arrow panels, and channelizing devices can be used jointly with other methods to ensure the safety of road users (FHWA, 2009). The use of channelizing devices such as cones, tubular markers, vertical panels, drums, barricades, longitudinal channelizes, and raised islands are more common in TTCs (FHWA, 2009). Table 1-1 below shows the summary of different traffic control practices that can be used and their corresponding disadvantages.

Table 1: Summaries of the Traffic Control Practices

S/No.	Practice	Advantages and Disadvantages of Illegal removal
1	Tapers	Can be used temporarily and is easy to be compromised without notice.
2	Portable Changeable Message Signs (PoCMS).	Can be used temporarily and is movable. It’s not easy to be compromised compared to tapers. Also, it requires power to function.
3	Permanent Changeable Message Signs (PerCMS)	Can be used permanently to input different warning instructions to road users, can’t be compromised easily but needs electric power to function.
4	Warning signs and queue warning systems	The best way to warn road users on a highway and a series of arrangements make them not easy to compromise. They can also be used at any time of the day.
5	Pilot Car Method	Best to instruct a vehicle queue through the TTC zone in a short duration and cannot be compromised easily.
6	Pavement markings	Best when there is inadequate safety personnel on-site. It cannot be compromised easily but road users may tend to ignore them.

7	Arrow panels	Similar in practice to warning signs but can't be used alone to shift traffic to other locations. They need other traffic control devices to function properly.
8	Channelizing Devices (cones, tubular markers, vertical panels, drums, barricades, longitudinal channelizes, and temporary raised islands)	Best way to channel traffic during both daytime and night-time but is easy to be compromised. They also need other traffic control devices to function properly. A periodic review of the TTC plan is necessary to improve safety over a long project duration.

1.3 Types of Barricades

Barricades have been used for decades to improve safety and not every barricade can be used at any incident or any place without satisfying the minimum standard requirements (FHWA, 2009; Shi, et al., 2009). They grouped into three classes based on the MUTCD. Type I barricades are used on conventional roads or urban streets and Type II or Type III barricades are used on freeways and expressways. Based on the traffic volume, Type I or Type II barricades are used to direct traffic flow when traffic is minimum while Type III barricades can also be used to close or partially close a road on higher-volume highways.

Also, barricades can be classified as pedestrian barricades, traffic barricades, and expanding-length barricades (Warehouse, 2018). To improve the effectiveness of these barricades, technology can be used to track and monitor their position

1.4 Main Objectives of the Study

The general goals of this study were:

1. To conduct comprehensive review literature on practices commonly used for road/lane(s) closure and summarize the key findings.
2. To identify the problems of the current non-smart barricades used for road/lane(s).
3. To propose smart road/lane closure monitoring and warning systems that support connected and non-connected vehicles to improve safety.
4. To recommend the best road/lane(s) closure monitoring and warning systems to support connected and non-connected vehicles.

1.5 Specific Objectives of the Study

In this study, a low-cost barricade monitoring system using a GPS module was proposed. The contributions can be listed as:

1. The motion detection and alert algorithms were developed to assist in the continuous monitoring of barricades when any illegal movements are detected.
2. The GPS positional error was estimated and corrected using the non-parametric data bootstrapping method.
3. The effects of cloudy and sunny weather conditions on the low-cost GPS module's response were noted.
4. The coverage distance of alerting was estimated using the American Association of State Highway and Transportation Officials (AASHTO), National Safety Council (NSC), and TransGuide Intelligent Transportation Systems manuals.
5. Alerts were sent to the authorizing agent through emails and once approved, alerts were sent to road users in a geofenced area on highways to alert them of impending dangers due to barricade displacement.

CHAPTER 2

Literature Review

In many of the reported cases where the barricade was removed, the duration at which the barricade was moved is unknown. During the last few decades of technological developments, different asset-tracking technologies have been used to track and monitor objects. Barricades can be tracked and monitored using the Global Positioning System (GPS), Radio-Frequency Identification (RFID), Near-Field Communication (NFC), or Bluetooth (Paul & Wan, 2008).

2.1 Asset Tracking Technologies

RFID systems employ electromagnetic waves to automatically identify, and track objects attached with RFID tags. When the tags are triggered by an electromagnetic pulse from an RFID tag reader, it transmits digitized data in form of a number back to the reader. RFID system requires an infrastructure to be established for the tags' information to be ascertained (PcsInfinity, 2019). Another method of asset tracking is barcodes which represent data in visually and digitally readable formats. Barcodes are equipped with data represented by width varying and lines arranged in parallel. The most current, two-dimensional (2D) alternatives use dots, rectangles, hexagons, and matrix codes. The disadvantage with barcodes is they need to properly align a scanner to get information and when the barcode got tampered with, they become inefficient (PcsInfinity, 2019). Furthermore, NFC can be employed which is a communication protocol between two electronic devices over *4 cm (11⁄2 in)* or less. NFCs don't have to focus on assets to scan but just by taking it closer, it can be read automatically (PcsInfinity, 2019).

For indoor asset tracking, Wi-Fi can be incorporated with other technologies like Long Range (LoRa) using a minimum-power network modulation technique. Also, Bluetooth termed a short-range technological standard can be used for data transfer between devices using Ultra High-Frequency (UHF) radio waves (PcsInfinity, 2019). Bluetooth has been aimed at novel applications throughout the world in the medics, fitness, security, and entertainment industries. To locate an object via Bluetooth or LoRa, the received signal strength indicator and time of arrival are used to compute a distance to the transmitter utilizing trilateration and triangulation principles. These methods of asset tracking are only limited to some applications even after adding customized tracking algorithms to improve their efficiency. All these methods have limitations with the range of coverage and accuracies.

The most used and reliable way of asset tracking is the GPS which is usually embedded in many electronic devices. Vehicle tracking relies on the battery for power generation or is wired directly to a vehicle's electrical system. The need-to-know real-time data dictates the quality, size, or type of GPS asset tracker required for the operation (PcsInfinity, 2019). It is well documented that many tracking devices become unresponsive due to *Faraday effects* but due to advanced technology, enough signal strength from GPS satellites makes it more reliable. GPS module connected to a Global System for Mobile communication (GSM) module can be used to track vehicle movements by continuously monitoring and reporting the status of the vehicle, but this requires an internet connection (Maurya, et al.,2012, Hasan, et al., 2009). Nowadays, many devices are being equipped with GPS trackers such as phones and they are capable to track thefts (Tandon, et al., 2021). With the need for real-time tracking in the connected environment and non-connected environment becoming a reality, efficient tracking is necessary especially when the lives of people on highways need to be ensured (Jalayer, et al.,2016).

2.2 Barricades Monitoring Technologies

Barricades are key road assets for delineating a safe drivable area (Kim & Song, 2016) but their use has not been developed to incorporate means to automatically track and monitor them (FHWA, 2009). The employment of current technology such as RFID technology combined with GPS technology that can track the location of barricades may minimize or alleviate fatalities (Paul & Wan, 2008). With the current artificial intelligence technology, a better way to detect misplaced barricades without physical presence such as computer vision approaches utilizing machine learning models can be useful (Chian, et al., 2021). Other technologies such as cloud-enabled Building Information Modeling (BIM) and Bluetooth Low-Energy (BLE) mobile tracking sensors can also be used to continuously detect unsafe conditions (Park, et al., 2017).

2.3 Experimental Analysis of Barricades Monitoring Technologies

In the experimental analysis of the event, the illegal barricade removal alerts using the microcontroller and the GPS module can be generated to assure the safety of road users and transportation agencies at a low cost (Indukuri & Kottursamy, 2020). It can be achieved with the GPS that locates the barricades and sends their location coordinates through GSM or General Radio Packet Service (GPRS) modules (Indukuri & Kottursamy, 2020; Maurya, et al., 2012; Sunehra, et al., 2021; Shinde & Mane, 2015; Jalayer, et al., 2016). As an example, the detection of road conditions such as potholes is capable of being marked by coordinates and uploaded to google maps to alert road users (Sulistyowati, et al., 2020). During real-time information sharing to the servers, the servers may be embedded with a GPRS module that is capable to locate periodically the transmitted information and converting them into a format that is suitable for the Google Earth software application (Hasan, et al., 2009; Chadil, et al., 2008).

2.4 GPS and RFID Applications in Monitoring Illegal Movements

According to the Texas Transportation Code, Title 6, Chapter 472.022, a person commits an offense if he disobeys displayed signals, instructions, warnings, or road markings or drives around a barricade (USLaw, 2022). Due to this tendency especially when the road is closed, Aucxis (2022) has discussed how transportation agencies have looked for solutions that would enable their staff to efficiently identify and geolocate their barricades. European companies such as Qeos and Safetybloc have managed to have real-time, accurate monitoring of their concrete blocks and ascertain their location using RFID sensors (Aucxis, 2022). Apart from RFID sensors, GPS sensors are capable to track and monitor movements since RFID sensors are constrained to the easiness of manipulation of their output data. GPS receivers support different formats such as Receiver Independent Exchange (RINEX) and National Marine Electronics Association (NMEA) that contain information such as latitude, longitude, time, speed, elevation, and Position Dilution of Precision (PDOP) that can be customized to many uses (Shoab, et al., 2013).

2.5 GPS Accuracy

From the collected sensor data, Ranacher, et al. (2015) showed that these data are usually subject to noise errors that interfere with the accuracy, but they came up with how these data can be spatially and temporally autocorrelated to provide a quality estimate (Ranacher, et al., 2015). Apart from the sensor accuracy problem, Raghunath et al. (2011) suggested how the performance of the GPS is hindered by ionospheric errors such as poor spacecraft ephemeris caused by right ascension, altitude, and declination (Raghunath, et al., 2011). Different scholars have tried to study statistical methods of GPS error distribution that seem to be adequate in applications and Abbous & Samanta (2017) managed to use the Mean Least Square Estimation (MLSE) statistical method to correct positional errors during data processing in real-time. They established a cost parameter that can be optimized in both real-time and post-processing (Abbous & Samanta, 2017). The model was validated in different environments to study the positional error distribution and a higher correlation was observed in geolocating the same places.

2.6 GPS for Safety Assurance

Apart from sensor accuracy problems, the safety of the system needs to be reliable. Olokun (2021) proposed a vehicle accident detection and alert system using GSM and GPS modules that are capable to sense accidents using vibrational sensors and micro-controllers that had a decent accuracy at a low cost (Olokun, 2021). Also, Nanda et al. (2019) proposed a system that can help to detect and locate accidents using GPS and GSM modules and inform authorities through text messages (Nanda, et al., 2019). The system developed was capable to check the driver in drowsy and verify their driving license through an embedded RFID on license plates. These systems lack one thing in common which is alerting the road users within the geofenced area and lack communication with the roadside infrastructures.

2.7 Benefits of Barricades Monitoring System

The proposed barricades monitoring system will enhance the performance and reliability of driving assistance technology in Intelligent Transportation Systems (ITS) such as Driver Assistance Systems (DAS) and alert individuals on highways of the illegal removal of barricades. It can be used together with systems like forward collision warning, Adaptive Cruise Control (ACC), and lane departure warning systems that require accurate positioning data of roadside infrastructures to improve the safety of road users (Kim & Song, 2016). By seamlessly integrating this system into vehicles and roadside units, the communication capabilities with road infrastructures, individuals, and authorities can achieve smart movements (Guerrero-Ibáñez, et al., 2018).

From the literature review, it has been observed that the GPS module has monitoring capabilities but is subject to different errors such as positional errors that need to be corrected. Also, the barricades monitoring system can be embedded in driver's assistance technologies to improve safety since their lightweight property makes them easily compromised without notice. Furthermore, the literature review shows there are inadequate studies on alert systems for road users within a geofenced area. This study will propose efficient ways to track the illegal movement of the barricades in real-time and alert individuals and authorities hence improving safety and reducing property damages.

CHAPTER 3

Methods

This section briefly explains how the GPS module was integrated with a motion detection algorithm, and alert algorithm to generate google maps of an area where the barricade has been displaced. The system shows how alerts were sent to authorized agents and approved before being sent to the road users in a geofenced area.

3.1 The Radius of the Geofenced Area

The radius of the geofenced area was defined as the total of three distances, the *Critical Safety Distance (CSD)*, the *Stopping Sight Distance (SSD)*, and the *Extra Buffer Distance* (EBD). The first distance from the traffic barricade location is the CSD which has been defined by the National Safety Council (NSC) such that the final warning sign should be placed *25 feet* from the end-point of operation or traffic incident. NSC also has suggested the "*Men Working*" sign be placed at *500 feet*, the "*Road closed*" sign at *1000 feet*, and the "*Road Construction Ahead*," or "*Barricade Ahead*," sign at *1500 feet* from the incident (NSC, 2016). The CSD was considered as *25 feet* due to the critical nature of the event of barricade illegal removal.

The next distance considered from the traffic barricade location is the SSD which is estimated after drivers have noticed the incident and it is defined as the minimum sight distance required for drivers to stop the vehicle after seeing the incident on their paths without hitting it (Garber & Hoel, 2009) (AASHTO, 2011). This is the sum of the perception-reaction time distance and braking distance given by the equation below.

$$SSD = 1.47ut + \frac{u^2}{30(\frac{a}{g} \pm G)} \quad \text{(1)}$$

where *SSD* is a stopping sight distance in *feet*, *u* is the design speed of the road section(*mph*), *t* is the braking reaction time that is estimated to be *2.5 seconds* and *a* is the deceleration rate in ft/s^2. Also, *g* is the acceleration due to gravity ($32.17\ ft/s^2$) and *G* is the grade of the road section (*decimal*).

The farthest distance is the *EBD* which has not been defined in manuals but was estimated using knowledge from the system-level performance requirements for TransGuide Intelligent Transportation System. In the guide, the Dynamic Message System (DMS) update has been recommended to be accomplished within *15 seconds*. This time and vehicle speed generate a distance corresponding to the AASHTO braking distance whose estimation can be done by considering the posted speed limit of the highway section.

Figure 1 below shows a section with a posted speed limit of *70 mph* (for freeways) to compute the corresponding three distances discussed above.

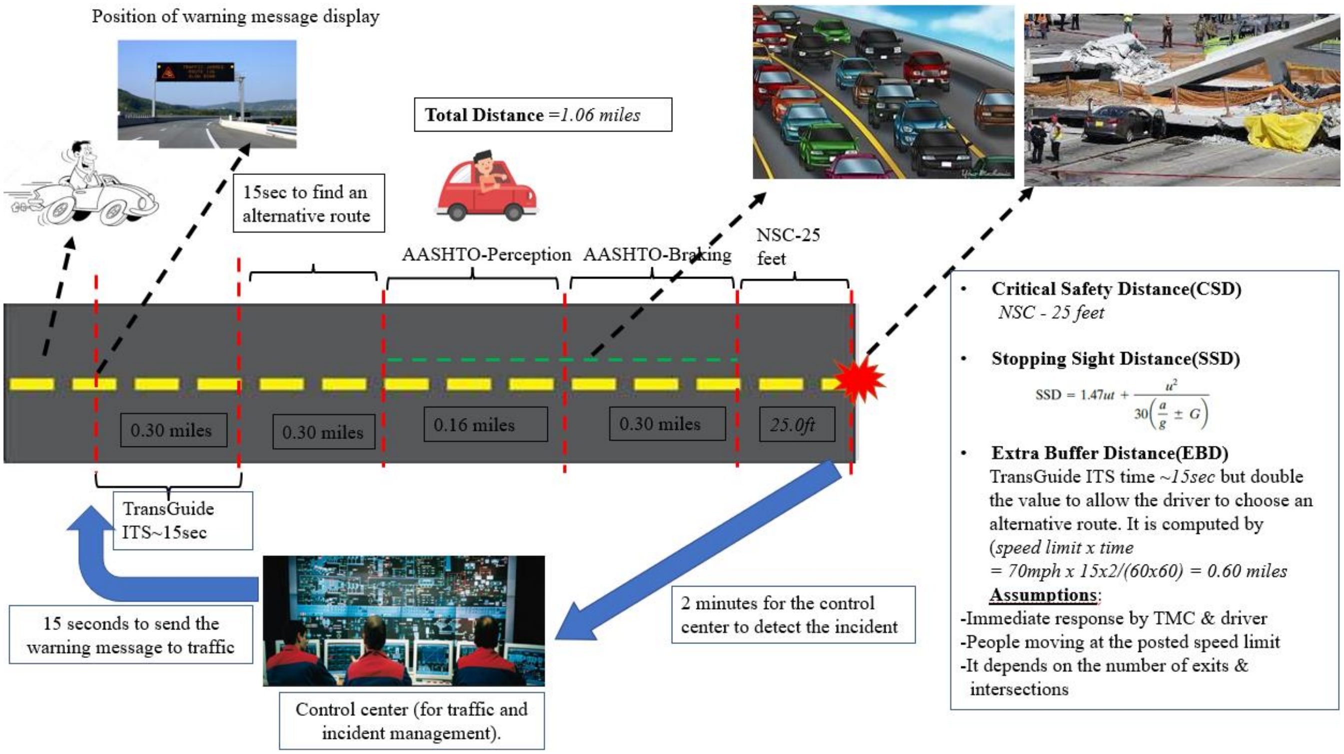


Figure 1: Radius of Geofenced Area Estimations

$$EBD = Design\ speed\ x\ time \qquad (2)$$

But for the effectiveness of the computations, immediate response by Traffic Management Center (TMC) and drivers need to be assumed and at least one exit or intersection needs to be nearby for the driver to choose an alternative route. Hence to consider the risk to the traffic, our total distance is the summation of CSD, SSD, and EBD which leads to the radius of the geofenced area. Figure 2 below shows the radii of the geofenced area spatially. This geofenced area was approximately *1.04 miles* from the barricade location.

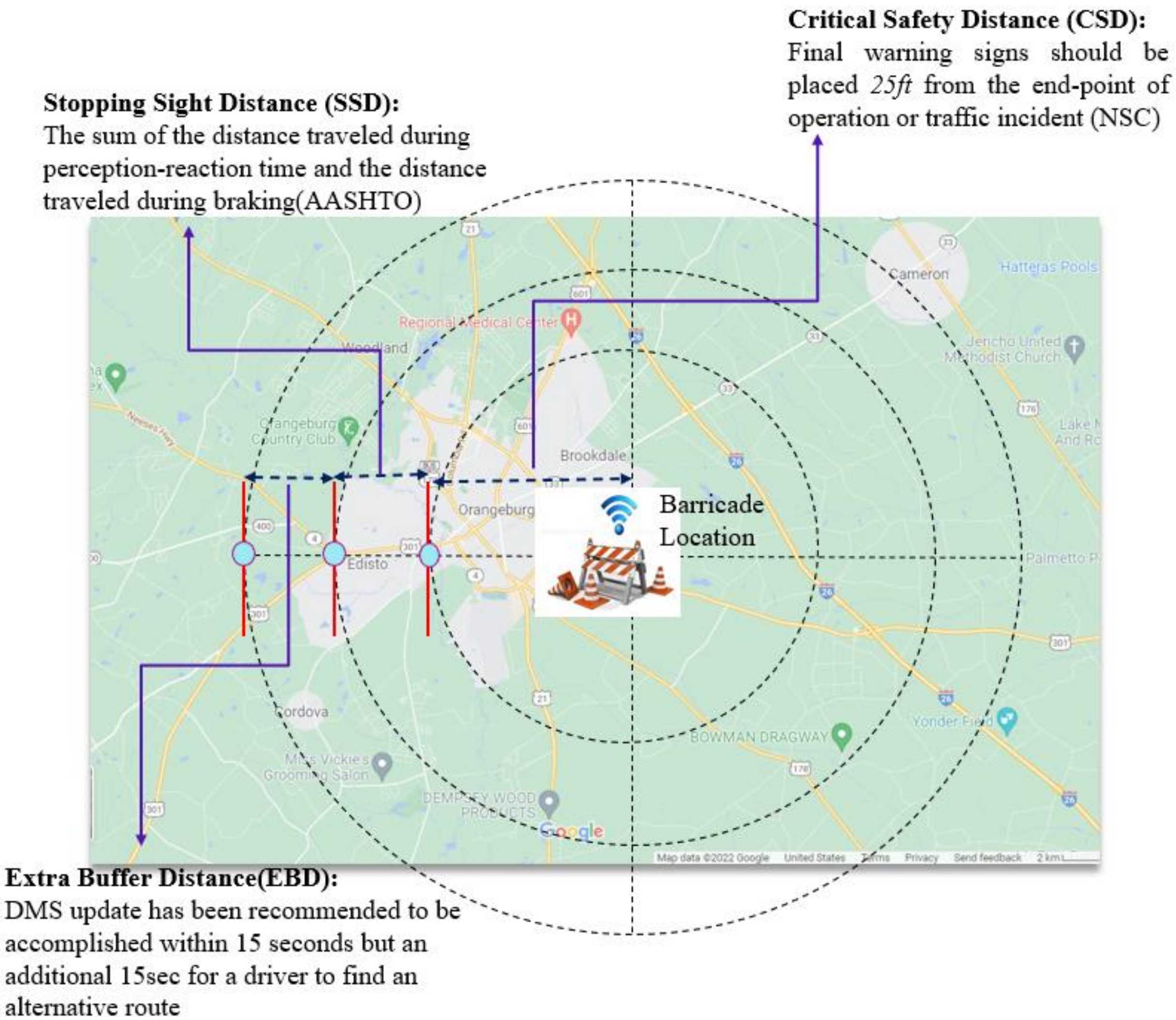


Figure 2: Coverage of Geofenced Area

3.2 GPS Setting, Motion Detection, and Alerting

During the project execution, a *raspberry pi 3 model B Vi.2* was configured, and a GPS module was attached to collect the real-time NMEA data. The GPS module generates timestamps, latitudes, and longitudes which were necessary for our use. These data were temporarily stored in the excel database and once any movement was detected by using the motion algorithm, it was checked if a threshold value was exceeded. The threshold value used was from the smallest dimension of the vehicle in the market called *Renault Twizy*, an electric ultra-compact vehicle with a *1.19m (3.9 feet) width* (SRL, 2020). This assumption was made to ensure any displacement of a barricade that can allow passage of the smallest assumed vehicle width can trigger alerting to the authorities as it will make vehicles and drivers unsafe. Figure 3 below shows the Renault Twizy model that has the smallest width within the current generation of car models.

Table 2: The Smaller Car Width in the Current Generation of Car Models

S/No.	Car Model	Width Dimensions(m)
1.	Renault Twizy	1.19
2.	1948 British Lamar	0.7
3.	Messerschmitt KR	1.22
4.	Mahindra Reva-i	1.324

Figure 3: The Renault Twizy Model

Figure 4 below shows the flow chart that was developed in this study to illustrate the flow of information. Input from the GPS real-time NMEA data was used with latitudes, longitudes, and timestamps whereby threshold motion will need to be achieved for the alert system to be triggered. From the Smart Barricades Monitoring (SBMo) algorithm developed, the output expected is google maps and alerts to authorized agencies and road users.

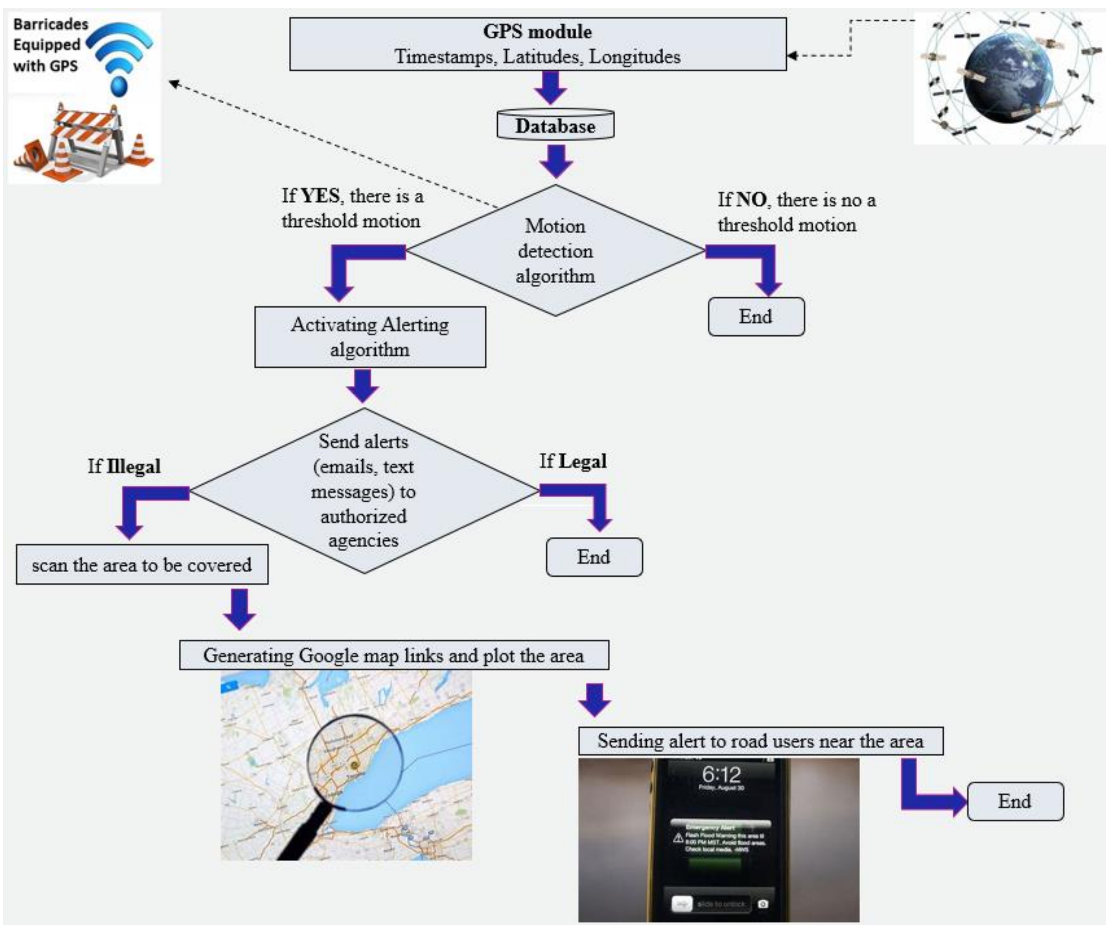


Figure 4: The Flow Chart of the Proposed Smart Barricades Monitoring (SBMo) System

3.3 Distance Measurement

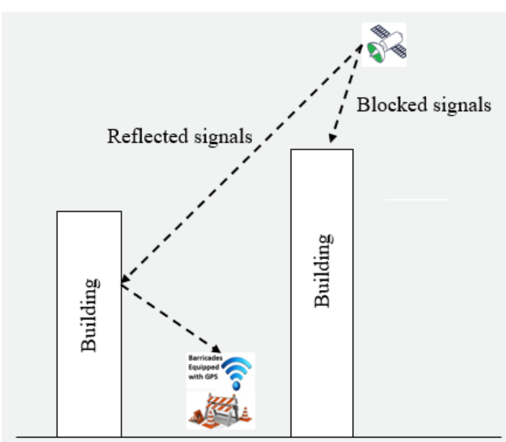
Before any detection to trigger alerting, the location need was ascertained using latitudes and longitudes, then the distance was computed using the Haversine formula in real-time between two consecutive geolocations. The haversine formula used to determine the great-circle distance between two points on an Earth's sphere is not accurate because it assumes the Earth to be a perfect sphere through its oblate spheroid, but it is among the best possible ways to measure distance on the Earth's surface. Distance is computed using the formula (1) below.

$$= 2r\arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \quad \text{.....................................(3)}$$

Where:

r = Earth's radius ~ 6471km
φ1, φ2 are the latitude of point 1 and latitude of point 2,
λ1 and λ2 are the longitude of point 1 and the longitude of point 2.

Distance between two consecutive geolocations was measured to keep track of the distance every second and data were generated with a large error reported due to sensor noise and satellite positioning errors. The main sources of GPS errors can be caused by satellite position, GPS receiver features, and surrounding effects on the incoming signals. It is expected that the more the Global Navigation Satellite System (GNSS) frequency bands a GPS receiver can support, the better the accuracy. Figure 5 below shows how signal transmission can be affected.



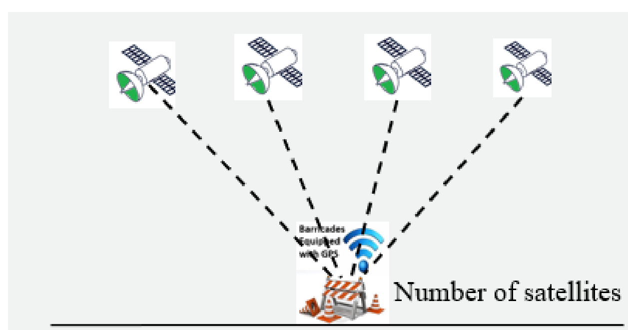


Figure 5: The Effects of the Surrounding Environment on the Signal Transmission

3.4 Data Bootstrapping to Determine GPS Positional Error During Localization

To correctly measure the GPS positional accuracy, the data bootstrapping method was used. The GPS module was left to run for 11 hours continuously, and the latitudes, longitudes, and distances were recorded while the GPS was stationary. To correct the GPS positioning error, the non-parametric bootstrapping method was used. Bootstrapping of data can be defined as the sampling with replacement from real data to estimate the variation in the statistic of interest which may be the mean, median, or standard deviation. One of the applications of bootstrap is in assessing the accuracy of an estimate based on a sample of data from the population. The variation in the calculated distance using the Haversine formula indicated high positional errors. To filter the error, the mean of the bootstrapped data was calculated using the non-parametric data bootstrapping. The following were the procedures used in the process.

Data were resampled by sampling with replacements from the original distance data $(x_1, x_2, \dots \dots, x_S)$ such that each bootstrap sample has M observations where $x_S < M$ hence the matrices for the n sample bootstrap will appear as.

$$Bootstrap\ matrices = \begin{bmatrix} x_{11} & \cdots & x_{1M} \\ x_{21} & & x_{2M} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nM} \end{bmatrix} \quad (4)$$

After GPS positional error correction, the SBMo directly interfaces with the threshold value. Once the motion does not exceed the threshold value, nothing happens but once it exceeds the threshold value, the alert algorithm is activated.

3.5 Alert Algorithm

The alert system comprises two parts whereby the first is for alerting the authorities in charge of the barricades' safety and once the situation has been verified with the authorities, a signal is sent to alert all drivers within a geofenced area. These drivers will be on highways and a layer of highways from google maps was extracted to be geofenced. Authorities will be alerted through the email address and once the approval to alert users have been granted, the messaging will be triggered. The triggering of this email involves the verification of the distance exceeding the threshold distance set within the system and once the incident has been verified, alerts are sent to mobile phone users within the geofenced area.

CHAPTER 4

Data Analysis

4.1 Data Bootstrapping Results

From each bootstrap sample, estimates θ were calculated and denoted $\hat{\theta}^*$ hence a total of n values $\hat{\theta}^*$ were obtained: $\{\hat{\theta}^*{}_1, \hat{\theta}^*{}_2, \dots \dots .., \hat{\theta}^*{}_n\}$. The mean and standard deviation statistics were computed using $\{\hat{\theta}^*{}_1, \hat{\theta}^*{}_2, \dots \dots .., \hat{\theta}^*{}_n\}$ data. Figure 6 and 7 below shows the mean distances before bootstrapping data and after bootstrapping data with $n = 10{,}000$ combinations, respectively. After bootstrapping the data from varied movements were presented in Table 3, the GPS measurement positional error was determined. The value was approximately *3.2 meters (10.5 feet)*.

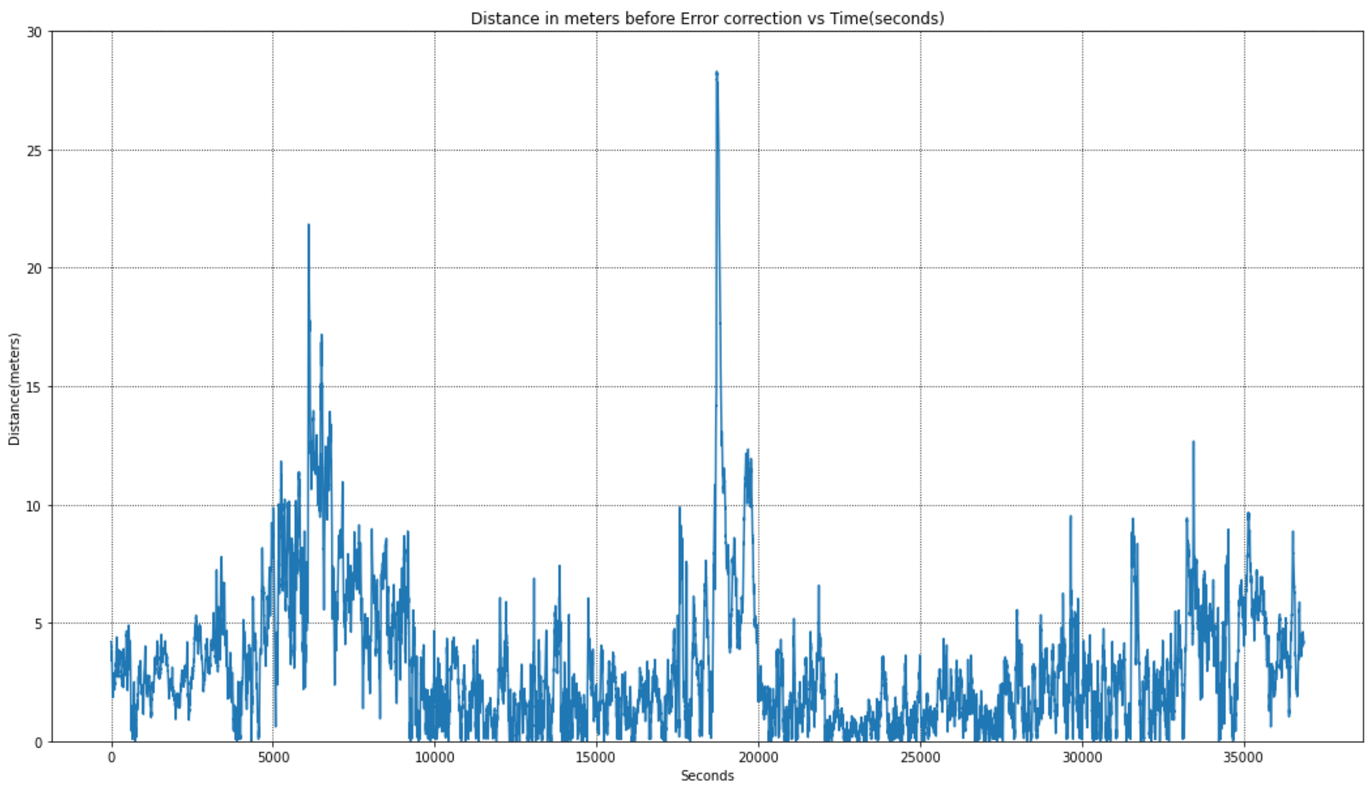


Figure 6: Mean Distance (meters) before Bootstrapping the Data

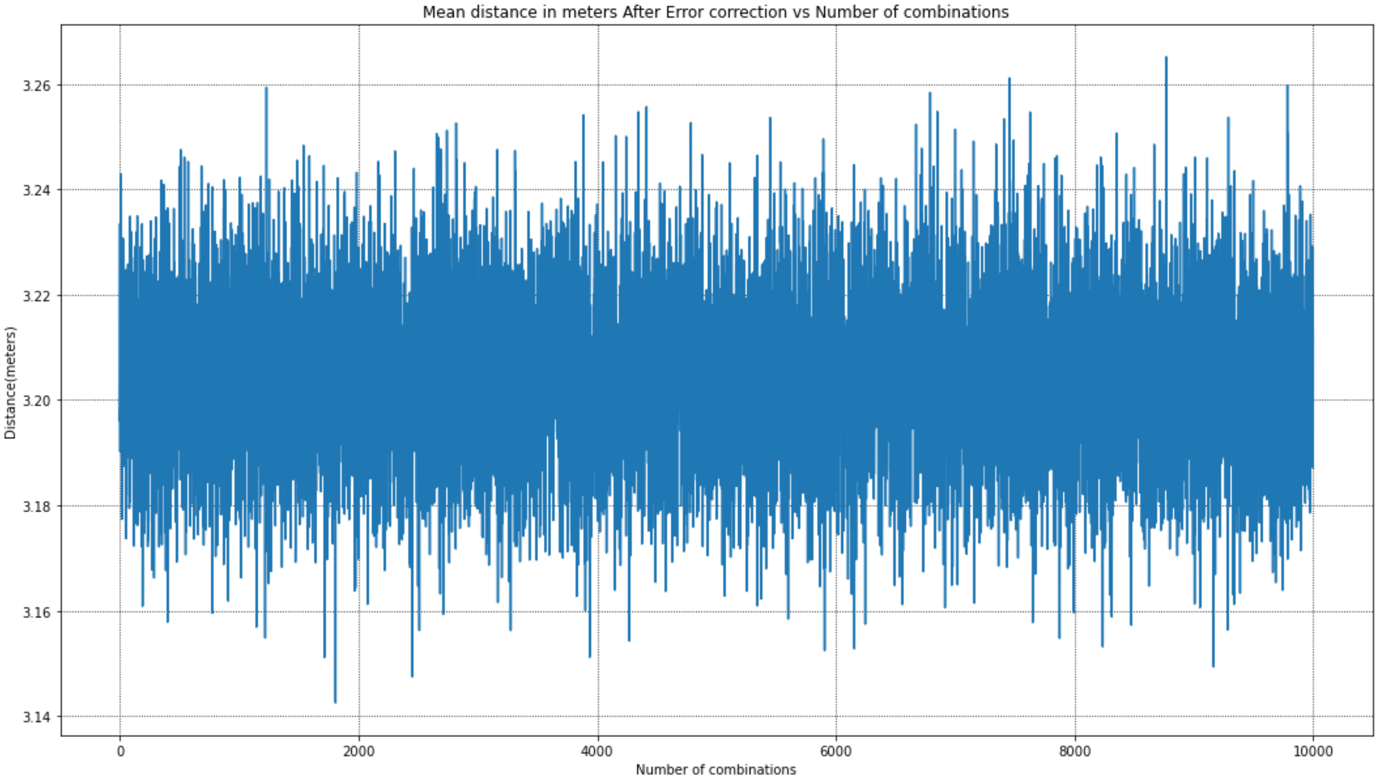


Figure 7: Mean Distance (meters) after Bootstrapping the Data

Table 3: GPS Error during Localization

Distances	Latitudes	Longitudes	Distance(meters)
Point +0.00	**.49957306119927	***.856297181292	3.204471520291802
Std Dev.	$1.93786058152934 \times 10^{-7}$	$2.03430276002898 \times 10^{-7}$	0.0154570551489699
Movements			
Point +1.00	**.49954945615861	***.85627567619393	3.205542711411834
Point +2.00	**.499549451939835	***.85627568267905	3.204673121251192
Point +3.00	**.499532325901654	***.85626621422949	3.208452550474691
Point +4.00	**.499581174901614	***.85629939177933	3.206421531233605
*** and *** have been used for the privacy of my location*			

4.2 Experiment with Varying Barricade Movements

Positional errors due to the GPS module used can be easily corrected and computed from the measured distance. After determining the GPS positional error, an experiment was carried out to estimate the response/instance of the GPS sensor to the varied distance movements in different weather conditions. The recording was carried at the instants of *1m, 2m,* and *3m* movements with the return of the device to the reference point after every instant recorded. Below were the procedures.

i. The device was left for one hour at the reference point before starting the stopwatch to stabilize and lock enough satellites.
ii. The stopwatch was started when the device is at the reference point and left for extra *5 minutes*.
iii. The device was moved *1m* and left for *5 minutes* and then returned to the starting point and left there for *10 minutes*.
iv. This was repeated for three more trials in a movement of *1 meter*, five trials for a movement of *2 meters*, and 3 trials for a movement of *3 meters*.

Figure 8 below shows the response of the distance movements with the GPS positional error already corrected and noise data filtered out during a cloudy day.

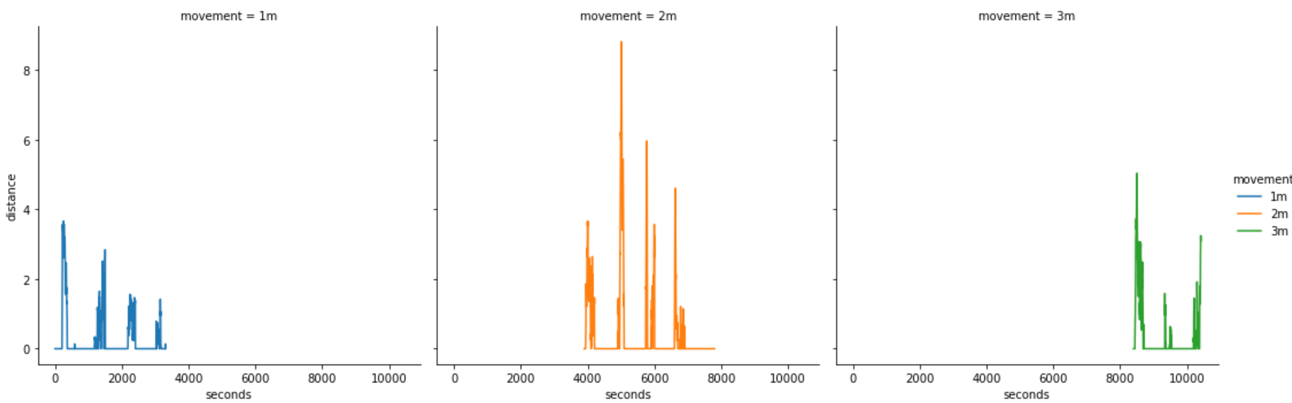


Figure 8: GPS Distance Signature

4.3 Experiment on Alerting

During alerting, another experiment was done to determine how the pulse is generated and communicated to the authorizing agents through emails. Figure 9 below shows the distance movements in the instants of one meter and two meters and Figure 10 shows the corresponding alerting pulses during the experiment on a clear sunny day. The instants recorded were only two for one meter and another two for two meters hence two pulses per movement were expected after filtering the noise. Furthermore, Figure 8 and Figure 9 both show the response of a device to different barricade movements and in different weather conditions where Figure 8 was during a cloudy windy day and Figure 9 was during a clear sunny day. The response to barricade movements on a clear sunny day is easily differentiated from the response during a cloudy day.

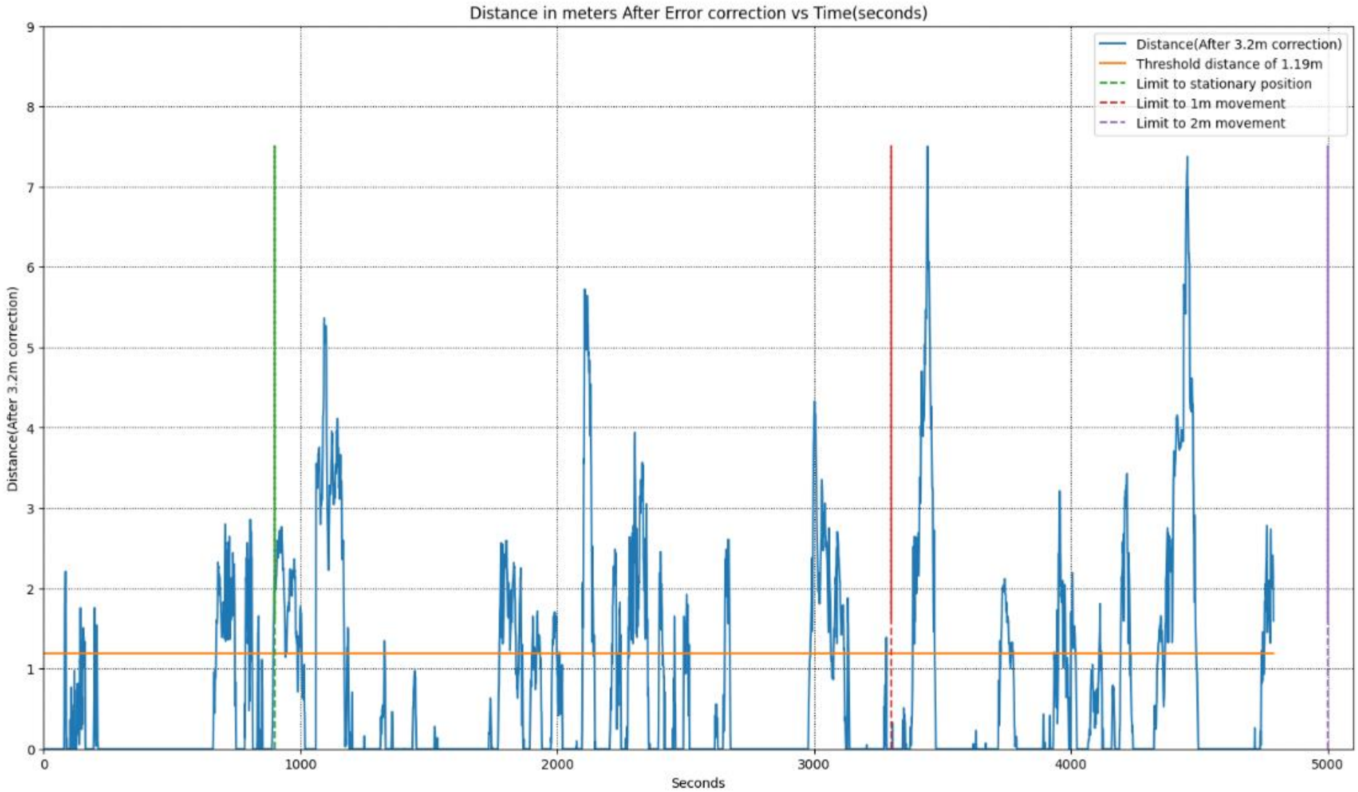


Figure 9: GPS Distance Signature during Alerting

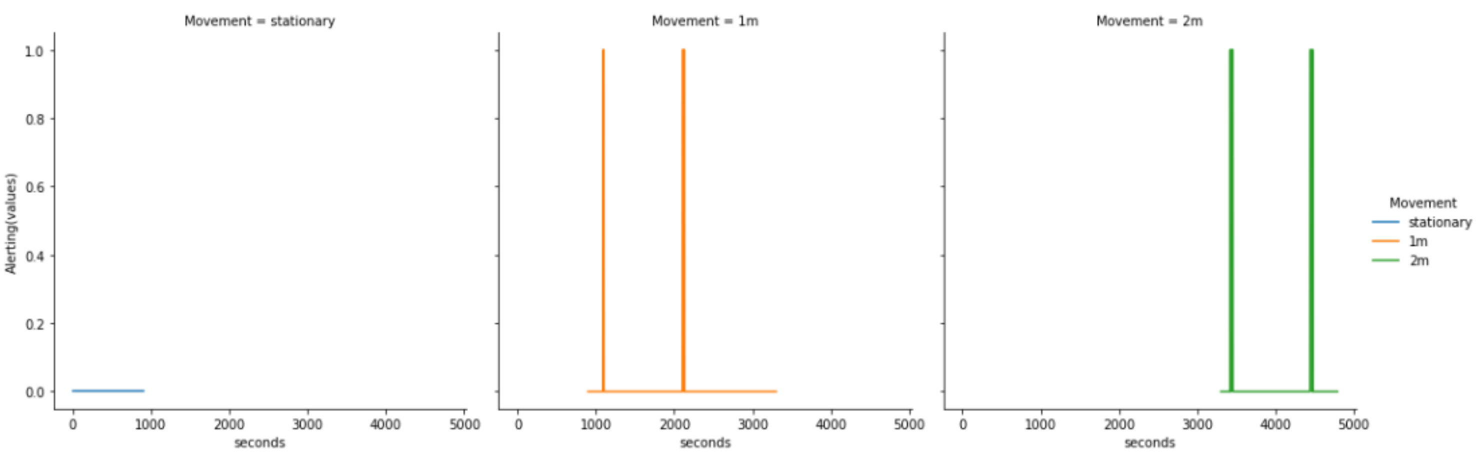


Figure 10: Alerting Pulses after Exceeding the Threshold Values

4.4 Real-time Data Publishing and Google Maps Setting

PubNub is a real-time communication platform for data streaming that is used to publish and subscribe to messaging API built on a global data stream network. With its extensive data network centers, it is widely used, and the streamer enables real-time geolocations to be published directly to the webpage hence improving communication safety. PubNub was used to generate publish and subscription keys which were locked to our application. Figure

11 below shows how PubNub works and how it streams data and verification of the data to be published was done by generating publish time tokens. Also, Figure 12 shows the PubNub publication summary of streamed data.

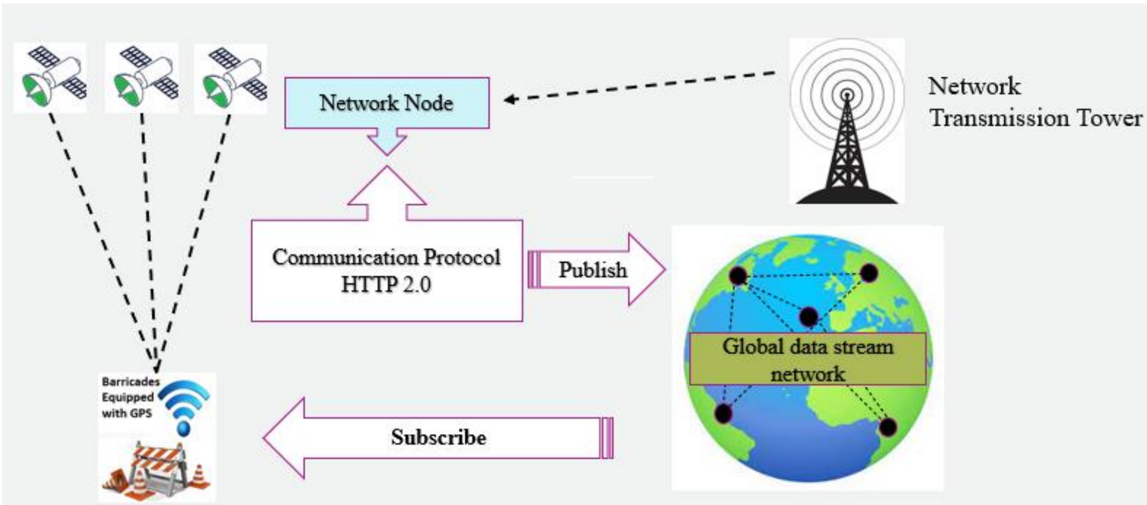


Figure 11: PubNub Communication Protocol

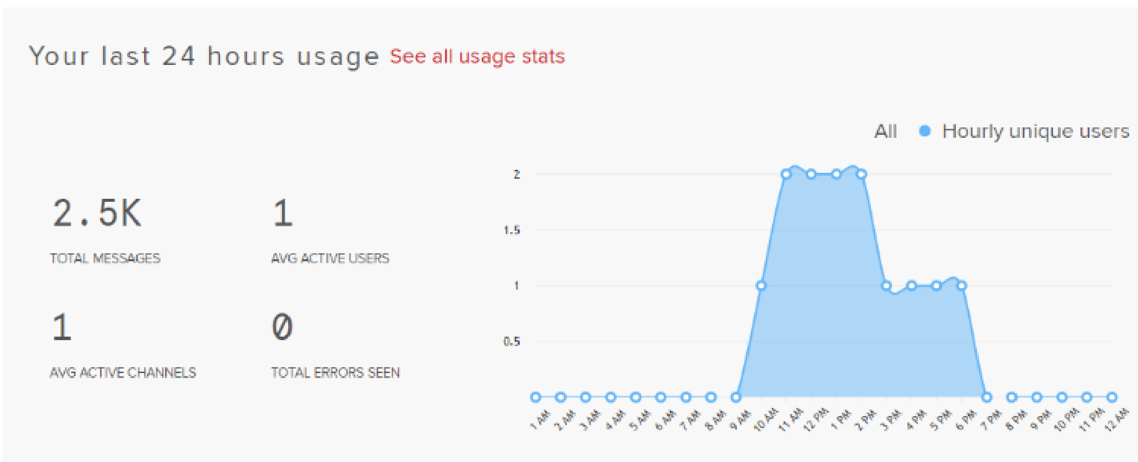


Figure 12: Data Publication Summary

After publishing geolocations on the map, a real-time GPS tracker web was established, and hence any movement can be shown directly from the map. The generation of the map was enabled by using the Google APIs that were also locked in our system.

CHAPTER 5

Findings

This research has studied how monitoring can be done on barricades and provided the potential for future studies. It was aimed at solving the illegal removal of barricades' risky behavior that happens without notice of road emergency officials and road users. Road users are usually prone to fatalities, and injuries while assets are prone to damage. The introduction and literature discussed how this is essential and how different scholars have used different technologies in monitoring to achieve safety. The research fills the gap in road assets monitoring technologies for easy communication between road infrastructures, authorities, and road users. It has a detailed explanation of the GPS setting and error correction, generation of detection after a threshold distance equivalent to the smallest dimension of the car in the market, and alert algorithms to GPS position broadcasting within a road geofenced area. The following are the findings from the study.

1. Using a non-parametric data method, the GPS sensor's mean positional error of *3.2 meters (10.5 feet)* was filtered.
2. The estimation of geofenced radius for alerting the public was estimated using the summation of three distances, the *Critical Safety Distance (CSD), the Stopping Sight Distance (SSD),* and *the Extra Buffer Distance (EBD).* The CSD was defined by the NSC as such that the final warning sign should be placed *25 feet* from the end-point of operation or traffic incident. The SSD is defined as the sum of the perception-reaction time distance and braking distance from AASHTO. The EBD was defined as the system-level performance requirements for TransGuide Intelligent Transportation System where the DMS updates. This geofenced radius was approximately *1.04 miles* estimated when the posted speed limit is at *70mph* and the provision of extra distance for the driver to decide on the alternative route.
3. Data from a clear sunny day shows the best response since the difference in barricade movements can be seen for *1m* and *2m* movements compared to the cloudy day where movements can't be easily explained. This might be caused by ionospheric effects where refraction and diffraction in the atmosphere change the apparent speed of satellite signals.

For illegal barricade movements, detection of illegal movements, alerting the authorizing agencies and road users, and updating the system for easy tracking is essential for the system to reduce fatalities and property damages. It is from these systems that safety can be assured.

CHAPTER 6

Limitations of the Study

The study has a higher potential to be extended in areas where there is little network coverage and cover large distances using suitable sensors. Also, it can be applied in the ITS industry and driver assistance systems development that aims to ensure the safety of road users. Moreover, alerting on large scale requires authorization by the federal government, and a proper chain of command needs to be laid.

Also in this study, the relationship of GPS positions on a barricade to GPS accuracy was not studied such as on top, at the edge, and in the middle. Similarly, the nature of enclosing material to the GPS accuracy was not studied. It is expected further studies on these positioning will have a significant influence on GPS accuracy. With the expected monitoring system, contractors and the Department of Transportation are resting assured when working on highways as any illegal movements can be traced, or accidents that displace the barricades can be noticed at any time in a remote area.

PART TWO

Connected Environment

CHAPTER 1

Introduction

1.1 RF Modules for Connected Environment

Vehicle sensors have developed to the extent that autonomous vehicles need them to connect to the surrounding environment in ensuring traffic safety. This has prompted transportation authorities to install roadside units like cameras and other sensors to gather data about the environment and report on the road conditions to achieve smart transportation systems (Guerrero-Ibáñez, et al., 2018). To ensure the traffic safety of road users, the Manual on Uniform Traffic Control Devices (MUTCD) has highlighted how barricades and other signs should be positioned as a temporary measure to control traffic (FHWA, 2022). But it is well documented that the use of barricades is usually not attached with smart monitoring devices to monitor their illegal removal that may cause loss of life and property damages. The development of different sensors such as Radio Frequency (RF) modules offers easy ways to monitor them in non-connected environments where there is no Wireless Fidelity (Wi-Fi).

The Radio Frequency (RF) modules have been used in different applications such as in car parking management systems (Ibrahim, 2020), tracking of truckloads placement of Hot Mix Asphalt (HMA), and real-time measurement of pavement temperature (Schwartz, et al., 2014) in the pavement construction. The extended application of RF modules can be in ensuring the safety of road users. The use of RF modules for secure transmission comprises a transmitter and a receiver that exchange information at predefined desirable distances (Dudak, et al., 2019). The transmission of data is usually in a free bandwidth that makes it possible to collect and read sent data (Dudak, et al., 2019).

1.2 RF Modules with Micro-controllers

Two micro-controllers can be configured by one carrying the transmitter and the other carrying the receiver and then spaced within allowable distance to transfer the message (Andhale, et al., 2020). For the geolocation of a barricade, a Global Positioning System (GPS) module will need to be configured to one of the micro-controllers with a barricade which will be tracked (Noman, et al., 2018). The GPS is capable to track any movement anticipated to be illegal when properly configured with a Global System for Mobile Communications (GSM) module that will enable communication with phone users (Al-Khedher, 2011; Hannan, et al., 2011).

With the complete assembly of micro-controllers, the GPS module, the RF modules, and spacing adequate to initiate communication, illegal movement alerts can be generated hence assure road users and transportation agencies of safety when using highways. It is usually necessary to keep track of barricades to avoid fatalities (Chian, et al., 2021). For example, in Australia, data shows that reckless driving has been a leading cause of flood disaster fatalities with people driving their vehicles ignoring floodwaters, warning signs, and road closures installed (Rae, et al., 2016). With these tendencies, barricades are subject to being illegally removed and may cause serious effects on the incoming traffic.

1.3 Study Objectives

The objectives of this study were to improve the safety of barricades by incorporating an Intelligent Transportation System (ITS), and particularly the preparation of the communication framework of RF modules with Road-Side Units (RSUs) and On-Board Units (OBUs). Furthermore, the system was designed to warn road users located within a geofenced area on highways and alert emergency officials of any impending danger due to the illegal removal of road barricades. Google maps were generated through continuous broadcasting of geolocations of a barricade from the GPS module on site and if any movement was detected at the monitoring station that exceeds the threshold value, the alert system was triggered.

The study is organized into five sections. Section 2 is about the literature review of how the RF modules, the GPS, and the micro-controllers have achieved monitoring of the incidents. Section 3 describes the model layout and Section 4 discusses the conclusion, recommendations, and limitations of the study.

CHAPTER 2

Literature Review

Noman et al.(2018) demonstrated how a single unit of GPS, GSM, and RF modules can be used to track vehicles subject to theft. The model showed effectiveness by detecting any breakdowns on windows or doors and any in-vehicle movements. The system can trigger alerts to vehicle owners via a message sent containing vehicle location through the GPS-GSM modules (Noman, et al., 2018). Furthermore, Al-Khedher (2011) demonstrated how the GPS-GSM architecture was essential in tracking vehicles to locate their current position (Al-Khedher, 2011). The model utilized the Google Earth applications and transferred information by using the GSM module where the GPS coordinates were filtered to enhance their positional accuracy using the Kalman filter.

2.1 Radio Frequency (RF) Technology

Radio Frequency (RF) technological evolution has accelerated the use of radio frequency systems in train tracking (Santos, et al., 2005). Santos et al.(2005) presented a radio communication system for a location problem in tracking trains with a low budget. Through this technological alerting system, communication has been simplified with proper configuration when there is any illegal movement of barricades. The units can be configured in such a way that they carry different microcontrollers such as Arduino and Raspberry pi (Andhale, et al., 2020). Andhale, et al. (2020) showed this capability through a receiver attached to one microcontroller and a transmitter attached to another microcontroller.

2.2 Radio Frequency (RF) Technology with Safety

Safety is a major concern due to the rise in the number of kidnappings and road accidents (Shyam, et al., 2015). Shyam et al.(2015) demonstrated how RFID and GSM were used by parents to track their children's location in real-time, but the solution can be extended to tracking road assets. Not only road assets but the system can be used to control vehicle speed (Jahan, et al., 2013). Jahan et al.(2013) showed how the system may be incorporated with a LED flashing indicator that flashes at a pre-determined frequency when speed exceeds the threshold value. Furthermore, the On-Board Unit (OBU) sensors can be configured to detect blind spots when driving. In connected autonomous vehicle development, Road-Side Units (RSUs) offers smooth Vehicle-to-Vehicle (V2V) and vehicle-to-Infrastructure (V2I) communication. RF modules, Ultrasonic sensors, Raspberry pi, and GPS modules can be used to study these communications on small scale (Ghatwai, et al., 2016).

2.2 Radio Frequency (RF) Technology with RSUs and OBUs

After collecting this information from either OBUs or RSUs sensors, data can be published through google maps. Live traffic stream data in several forms are usually fed to the maps through a secured link enabled by the respective Google maps JavaScript Application Program Interfaces (APIs) (Mishra, et al., 2018). This can also be achieved using Microsoft SQL Servers and Active Server Pages Network Enabled Technologies (ASP.NET) to track the real-time locations on a specific map (El-Medany, et al., 2010). Since the information will be sent to road users in a location, the geofencing capabilities of the system will need to be assessed by triggering alerts to the users on the pre-defined boundary (Abbas, et al., 2019).

From the literature reviews, the GPS modules, the GSM modules, the RF modules, and the micro-controllers can all be configured to assure the safety of road users without using Wi-Fi, especially in remote areas. The system is capable to track any incident and generate alerts to road users and authorities. Hence the illegal removal of barricades that may render safety has been tackled by enhancing the monitoring of road assets.

CHAPTER 3

Methods

3.1 RF Modules Configurations in Connected Environment

In the model designs and implementations, an RF module of 433 MHz frequency, the GPS module, and the microcontroller were utilized. The RF module consists of two units which are the transmitter and the receiver. To set up the environment, two sites were designated which are the site and the monitoring station. The transmitter and the GPS module were embedded in a microcontroller at the site. The GPS was used to broadcast continuously the geolocations of the barricade on site and once any movement that exceeds the threshold value was detected, an alerting system at the monitoring system was triggered.

Antenna Length

Since the microcontroller was subject to a lot of noise, information transfer through a transmitter was not accurate enough without attaching the antenna. The length of an antenna that needs to be harmonic to the wavelength was computed by dividing the speed of light *(299 792 458 m/s)* by the frequency of the module *(433 000 000Hz)* which resulted in 692.36 mm. The distance becomes sensible and implementable after two iterations to divide by two and the length becomes 173 mm.

3.2 Barricade Site with the GPS Module and the Transmitter

The GPS module locked the satellites and published the National Marine Electronics Association (NMEA) data that were captured and sent via a transmitter on site. The data package sent via transmitter was sent with a packet signature to check the validity of reception in case of transmission/reception corruption. Basic data encryption on transmission was formulated with a similar encryption key in the receiver and transmitter code. This was done to control the invalid packet data received that have not been sent by the system.

3.3 Monitoring System

The monitoring station consists of the receiver module connected to the raspberry pi's General-Purpose Input/Output (GPIO) pins. Multiple algorithms are running at the monitoring station.

1. The receiving data algorithm validates the information received through matching with the packet signature and then decrypts the information received that was sent after conversion to bytes before displaying the data packet.
2. The data received also contains the NMEA data from the satellite that is formatted to extract the longitudes, latitudes, and timestamps. This information is continuously broadcasted and continuously updated on google maps. These

maps are used by the authorizing officials in monitoring the barricade's position in real time.

3. The NMEA data is also used to estimate the distance between two consecutive geolocations and when the distance exceeds the threshold value, the alerting algorithm is triggered.
4. The alerting system works in the manner that it first alerts the authorizing officials via emails if any barricade movements are detected. Authorizing officials will determine if the information received is legal or illegal.
5. If the authorizing officials determine the barricade movement is illegal, information sharing to the public via text messages is activated to alert the road users. Road users considered are those located in a geofenced area

Figure 13 below shows the summary of events in the whole system layout. The system consists of the barricade site algorithm that generates data (top) and the monitoring system algorithms(bottom).

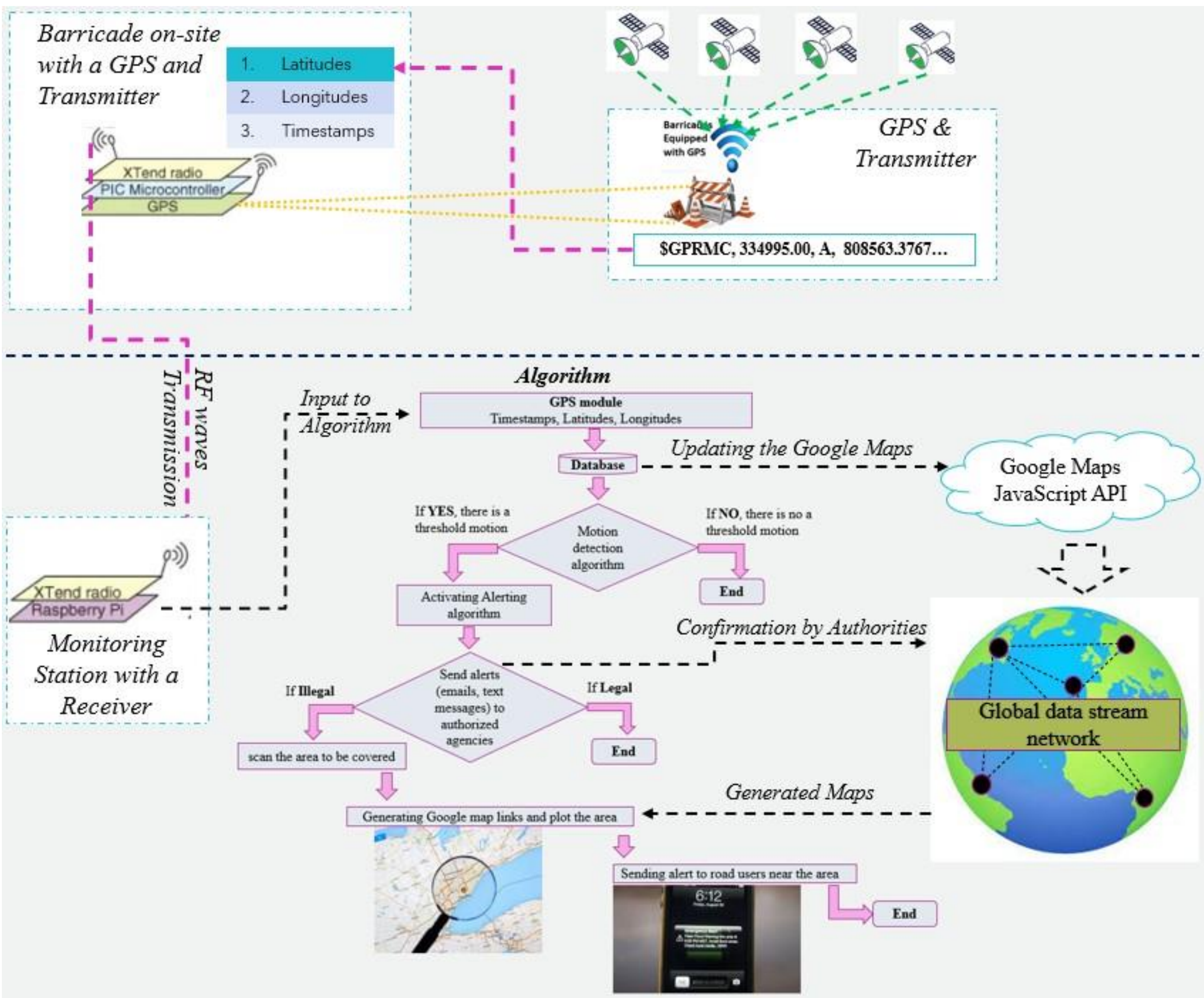


Figure 13: Schematic Communication Algorithm using RF Modules

3.4 On-Board Units (OBUs) Framework

Figure 14 below shows the communication framework between a barricade equipped with monitoring sensors on site, the monitoring station, the monitoring cloud, and the OBU of the vehicle. The control unit of the vehicle is capable to inform the driver of any incident after the emergency official has verified the information received from the barricade via the monitoring cloud. The monitoring cloud is continuously updated by the GPS from the barricade on site and the control unit of the vehicle via the Google JavaScript APIs.

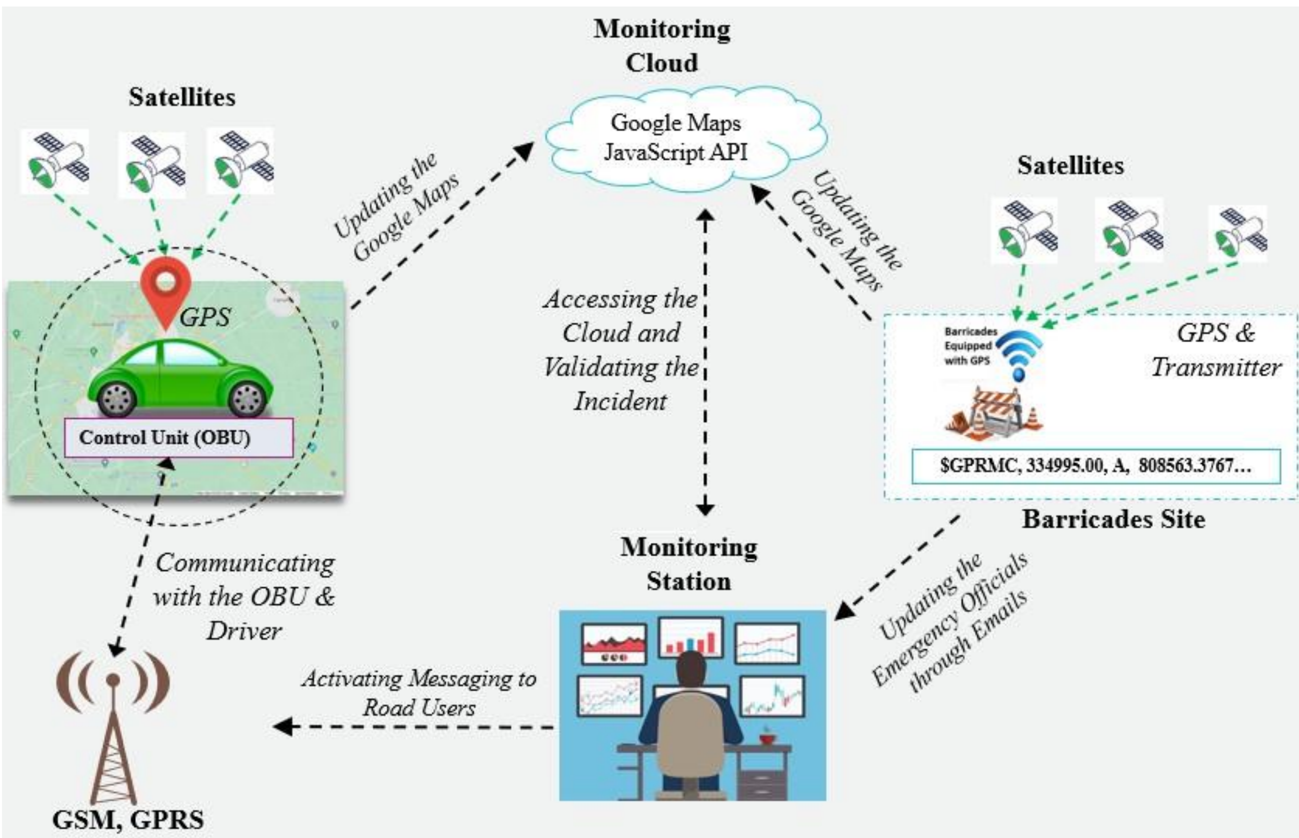


Figure 14: Schematic Communication Algorithm between Barricade and OBUs

3.5 Road-Side Units (RSUs) Framework

To have the secure information transfer between the barricade on site and the Roadside Units (RSUs), there is a separation between these two parts. The emergency officials offer a link to these parts by first receiving the information from the barricade on site and validating the information received by accessing the monitoring cloud and confirming the illegality. Once the emergency official verifies the incident, alerts are communicated via the Roadside Units (RSUs) and the GPRS system by sending text messages to road users' phones within a geofenced area. The RSUs have limitations in their coverage hence they need to be spaced at a more adequate distance. The RSUs are devices that offer communication in Connected Autonomous Vehicles (CAVs) by sharing data between vehicles referred to as Vehicle-to-Vehicle (V2V) and infrastructures referred to as Vehicle-to-Infrastructure (V2I). Figure 15 shows the communication framework with the RSUs.

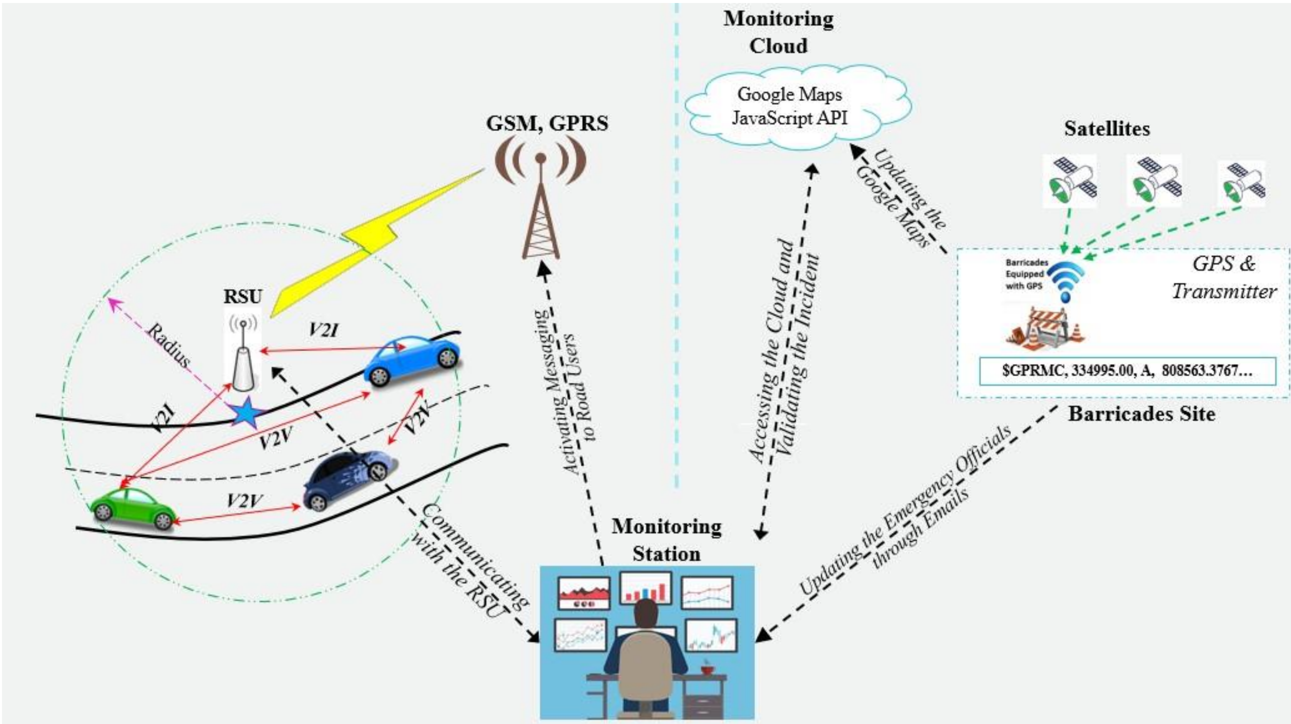


Figure 15: Schematic Communication Algorithm between Barricade and RSUs

CHAPTER 4

Conclusions

This study presented an RF communication system designed to alert on the illegal removal of road barricades and prepared the frameworks for the Roadside Units (RSUs) and On-Board Units (OBUs) communication. The secure communication was achieved using symmetric encryption in the transmitter at the barricade site and receiver at the monitoring station. Furthermore, a signature was embedded in the data packet transmitted to control the type of data transmitted. These data packet signatures were matched in the transmitter and receiver algorithms for the information received to be decrypted. The following are the advantages of the proposed monitoring system in ensuring the safety of road users.

(i) The proposed communication through the RF module is capable to be used in rural areas where GSM and GPRS system coverage is limited.

(ii) The system is capable to work with RSUs and OBUs to enhance communication in a limited connected environment.

(iii) The system offers secure communication between road users, emergency officials, and the barricade on site due to the presence of an encryption layer between the RF transmitter and RF receiver.

(iv) Safety for road users during barricades' illegal removal is assured at a low cost and property damages are reduced.

REFERENCES

AASHTO, 2011. *A policy on Geometric Design of Highways and Streets 6th Edition.* Washington, DC: American Association of State Highway and Transportation Officials.

Abbas, A. H. et al., 2019. GPS-based location monitoring system with geofencing capabilities. *AIP Conference Proceedings,* Volume vol. 2173, p. 020014.

Abbous, A. E. & Samanta, N., 2017. A modeling of GPS error distributions. *2017 European Navigation Conference (ENC),* pp. 119-127.

Al-Khedher, M. A., 2011. Hybrid GPS-GSM Localization of Automobile Tracking System. *International Journal of Computer Science and Information Technology, Vol. 3, No. 6,* pp. 75-85.

Al-Khedher, M. A., 2011. Hybrid GPS-GSM Localization Of Automobile Tracking System. *International Journal of Computer Science & Information Technology (IJCSIT), vol. 3, no. 6.*

Andhale, S. et al., 2020. RFID-based Smart Ticketing System. *5th International Conference on Communication and Electronics Systems (ICCES),* pp. 530-535.

Aucxis, 2022. *Safetybloc: tracing of safety barriers.* [Online]
Available at: https://www.aucxis.com/en/e-trade/cases/safetybloc-tracing-of-safety-barriers/e-trade
[Accessed 18 September 2022].

Chadil, N., Russameesawang, A. & Keeratiwintakorn, P., 2008. Real-time tracking management system using GPS, GPRS, and Google Earth. *5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications, and Information Technology,* Volume vol. 1, pp. 393-396.

Chian, E., Fang, W., Goh, Y. M. & Tian, J., 2021. Computer vision approaches for detecting missing barricades. *Automation in Construction Volume 131,* p. 103862.

Datta, T. et al., 2016. *A Guide to Urban Work Zone Temporary Traffic Control,* Detroit, Michigan, USA: Federal Highway Administration (FHWA).

Dudak, J., Gaspar, G. & Tanuska, P., 2019. Implementation of Secure Communication via the RF Module for Data Acquisition. *Journal of Sensors,* Issue Article ID 7810709, pp. 1-10.

El-Medany, W. et al., 2010. A Cost-Effective Real-Time Tracking System Prototype Using Integrated GPS/GPRS Module. *6th International Conference on Wireless and Mobile Communications,* pp. 521-525.

FHWA(2), 2022. *Work Zone Management Program.* [Online] Available at: https://ops.fhwa.dot.gov/wz/traffic_mgmt/tcg.htm#general

FHWA(3), 2009. *Manual on Uniform Traffic Control Devices (MUTCD).* Washington, D.C: USDOT-FHWA.

FHWA(4), 2022. *Chapter 6F. Temporary Traffic Control Zone Devices.* [Online] Available at: https://mutcd.fhwa.dot.gov/htm/2003r1/part6/part6f3.htm [Accessed 18 November 2022].

FHWA, 2009. Figure 6F-7. Channelizing Devices. In: *Manual on Uniform Traffic Control Devices for Streets and Highways.* Washington, DC USA: USDOT FHWA, pp. 604-606.

FHWA, 2022. *Chapter 6F. Temporary Traffic Control Zone Devices.* [Online] Available at: https://mutcd.fhwa.dot.gov/htm/2003r1/part6/part6f3.htm

Garber, N. J. & Hoel, L. A., 2009. *Traffic and Highway Engineering Fourth Edition.* Virginia, USA: Thomson West.

Ghatwai, N., Harpale, V. & Kale, M., 2016. Vehicle-to-vehicle communication for crash avoidance system. *2016 international conference on computing communication control and automation (ICCUBEA),* pp. 1-3.

Guerrero-Ibáñez, J., Zeadally, S. & Contreras-Castillo, J., 2018. Sensor Technologies for Intelligent Transportation Systems. *Sensors (Basel),* pp. 1-24.

Hannan, M., Arebey, M., Begum, R. & Basri, H., 2011. Radio Frequency Identification (RFID) and communication technologies for solid waste bin and truck monitoring systems. *Waste Management Volume 31, Issue 12,* pp. 2406-2413.

Hasan, K. S. et al., 2009. *Cost-Effective GPS-GPRS Based Object Tracking System.* Hong Kong, China, IIMECS 2009, pp. 398-402.

Ibrahim, D., 2020. Chapter 20 - Car park management system. In: *Arm-Based Microcontroller Multitasking Projects.* s.l.:Elsevier Ltd, pp. 397-412.

Indukuri, C. L. & Kottursamy, K., 2020. Advanced Accident Avoiding, Tracking and SOS Alert System Using GPS Module and Raspberry Pi. *Artificial Intelligence Techniques* *for Advanced Computing Applications,* p. 167–178.

Jahan, A. S., Hoq, I. & Westerfeld, D., 2013. GPS-enabled speed control embedded system speed limiting device with display and engine control interface. *2013 IEEE Long Island Systems, Applications, and Technology Conference (LISAT),* pp. 1-7.

Jalayer, M., Zhou, H. & Zhang, B., 2016. Evaluation of navigation performances of GPS devices near interchange areas pertaining to wrong-way driving. *Journal of Traffic and Transportation Engineering (English Edition),* pp. 593-601.

Kim, T. & Song, B., 2016. Detection and Tracking of Road Barrier Based on Radar and Vision Sensor Fusion. *Journal of Sensors,* p. https://doi.org/10.1155/2016/1963450.

Maurya, K., Singh, M. & Jain, N., 2012. Real-Time Vehicle Tracking System using GSM and GPS Technology-An Anti-theft Tracking System. *International Journal of Electronics and Computer Science Engineering,* Issue V1N3-1103.

Mishra, S., Bhattacharya, D. & Gupta, A., 2018. Congestion adaptive traffic light control and notification architecture using google maps APIs. *Data, 3(4), 67,* p. https://doi.org/10.3390/data3040067.

Nanda, S., Joshi, H. & Khairnar, S., 2019. An IoT-Based Smart System for Accident Prevention and Detection. *Fourth International Conference on Computing Communication Control and Automation (ICCUBEA),* pp. 1-6.

Noman, A. T. et al., 2018. Design and Implementation of Microcontroller Based Anti-Theft Vehicle Security System using GPS, GSM, and RFID. *4th International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT),* pp. 97-101.

NSC, 2016. *Barricades and warning devices for highway construction work.* [Online] Available at: https://www.nsc.org/getmedia/0d06a78e-983f-4ca0-a980-3e0b1acebb44/barricades-and-warnin-devices-for-highway-construction-work.pdf.aspx#:~:text=Final%20warning%20signs%20and%20barricades,feet%20beyond%20the%20repair%20zone.

Olokun, B., 2021. Design and Construction of Microcontroller based Vehicle Accident detection and reporting System. *International Journal of Engineering and Information Systems (IJEAIS),* pp. 13-24.

Park, J., Kim, K. & Cho, Y. K., 2017. The framework of Automated Construction-Safety Monitoring using Cloud-enabled. *ASCE Journal of Construction Engineering and Management,* pp. 10.1061/(ASCE)CO.1943-7862.0001223, 05016019.

Paul, A. S. & Wan, E. A., 2008. Wi-Fi-based indoor localization and tracking using sigma-point Kalman filtering methods. *2008 IEEE/ION Position, Location and Navigation Symposium,* pp. 646-659.

PcsInfinity, 2019. *7 Most Common Methods Used for Asset Tracking.* [Online] Available at: https://www.assetinfinity.com/blog/asset-tracking-methods

Rae, E. et al., 2016 . *Preventing flood-related fatalities–a focus on people driving through floodwater.* Brisbane, Australia, Bushfire, and Natural Hazards CRC ISBN: 978-0-9941696-6-2, p. 151.

Raghunath, S., B.L.Malleswari & Sridhar, K., 2011. Analysis of GPS errors during different times of the day. *International Journal of Research in Computer Science,* pp. 45-48.

Ranacher, P., Brunauer, R., SPEK, S. v. d. & Reich, S., 2015. GPS error and its effects on movement analysis. *Instrumentation and Detectors.*

Santos, A., Soares, A., Redondo, F. d. A. & Carvalho, N., 2005. Tracking trains via radio frequency systems. *IEEE Transactions on Intelligent Transportation Systems (Volume: 6),* p. DOI: 10.1109/TITS.2005.848369.

Schwartz, C. W., Khan, J. S., Pfeiffer, G. H. & Mustafa, E., 2014. *Radio Frequency Identification Applications in Pavements,* College Park, Maryland, USA: National Technical Information Service, 5301 Shawnee Road, Alexandria, VA 22312.

Shi, J., Li, Z. & Snyder, M., 2009. *Highway Work Zone Safety Audits at the Construction Stage.* Washington D.C, TRB Journal of Transportation Research Record.

Shinde, P. A. & Mane, Y., 2015. Advanced vehicle monitoring and tracking system based on Raspberry Pi. *2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO),* pp. 1-6.

Shoab, M., Jain, K., Haq, M. A. & Shashi, M., 2013. *Development and implementation of NMEA interpreter for real-time GPS data logging.* Ghaziabad, India, IEEE 3rd International, pp. 143-146.

Shyam, N., Kumar, N., Shashi, M. & Kumar, D., 2015. SMS-Based Kids Tracking and Safety System by Using RFID and GSM. *IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2,* pp. ISSN, 2348-7968.

SRL, S. N., 2020. *RENAULT Twizy 2012 - Present.* [Online]
Available at: https://www.autoevolution.com/cars/renault-twizy-2012.html#aeng_renault-twizy-2012-urban-45-5-hp

Sulistyowati, R., Suryowinoto, A., Sujono, H. A. & Iswahyudi, I., 2020. Monitoring of road damage detection systems using image processing methods and Google Maps. *IOP Conference Series: Materials Science and Engineering,* pp. https://doi.org/10.1088/1757-899X/1010/1/012017.

Sunehra, D., Sreshta, V. S., Shashank, V. & Goud, B. U. K., 2021. Raspberry Pi Based Smart Wearable Device for Women Safety using GPS and GSM Technology. *2020 IEEE International Conference for Innovation in Technology (INOCON),* pp. 1-5.

Tandon, S., Singhal, S., Khan, S. & Kumar, P., 2021. GPS System-based Tracking model for Mobile phones. *2021 6th International Conference on Communication and Electronics Systems (ICCES),* pp. 814-821.

USLaw, J., n.d. *2019 Texas Statutes Transportation Code Title 6 - Roadways Subtitle Z - Miscellaneous Roadway Provisions Chapter 472 - Miscellaneous Provisions.* [Online]
Available at: https://law.justia.com/codes/texas/2019/transportation-code/title-6/subtitle-z/chapter-472/subchapter-c/section-472-022/
[Accessed 18 November 2022].

Warehouse, C.-C., 2018. *Which Type of Barricade Do I Need? A User's Guide.* [Online]
Available at: https://www.crowdcontrolwarehouse.com/blogs/blog/which-type-of-barricade-do-i-need-a-user-s-

guide?msclkid=72012a72aa3111ecb43a6089493cd771
[Accessed 18 November 2022].

WIS-Staff, 2015. *Sheriff: Somebody else moved the barricade before the truck drove off.* [Online]
[Accessed 7 October 2015].

Yan, H. & Sanchez, R., 2015. *South Carolina flooding: Dams breached, more trouble ahead.* [Online]
Available at: https://www.cnn.com/2015/10/06/us/south-carolina-flooding/
[Accessed 29 July 2022].