An Emergency Real-Time Route Avoidance System for IoT-Enabled Vehicles

A Thesis

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School of Applied Computing, Faculty of Applied Science and Technology

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Abstract

For emergency responders (ERs), every delay in reaching their destination could be the difference between life and death for those involved in accidents, which is why they must reduce their arrival time as much as possible. ERs are legally permitted to exceed speed limitations, run red lights, and ignore stop signs, all of which put them and nearby civilian drivers at risk of accidents. The traditional use of emergency lights and sirens is ineffective in negotiating traffic and increases congestion. In this thesis, we describe an innovative route avoidance system and report on real test case scenarios. The system, built upon vehicular ad-hoc networks, vehicles enabled with dedicated short-range communication, and a centralized server, enabled ERs to temporarily reserve roads to their destination, detouring connected civilian drivers along the path to reduce traffic volumes, reduce ER arrival times, and improve safety for all drivers.

Keywords: vehicular ad-hoc networks, dedicated short-range communication, emergency responders, traffic routing, reducing arrival time, traffic volume, road safety, centralized server.

Thesis Supervisor: Dr. Richard Pyne
Title: Professor, School of Applied Computing

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Chapter 1

Introduction

Emergency responders (ERs) are persons with specialized training who arrive first at scenes of emergency and typically include law enforcement officers (LEOs), firefighters, and emergency medical service (EMS) technicians [1]. Given the time-sensitive nature of emergencies, ERs need to quickly and safely reach their destination [2]. They thus are authorized the ”code three running” option permitting the use of warning lights, sirens, exceeding speed limits and crossing against stop signs and red lights to minimize travel time [1, 2, 3].

As traffic volumes continue to rise, both the arrival times to emergencies and the risk that ERs become involved in accidents also increase [4]. For ERs, crash-related fatalities are up to 4.8 times more likely than any other driving-related occupation in the United States, given that they operate under stressful driving conditions, time pressure, and multitasking activities [1]. The relevant causative factors attributing to these crashes include complicated urban intersections [1, 5], high traffic volumes [1, 4], lack of recognition by other drivers [1, 4, 6], and human error [3, 6].

In the United States, there were more than 37,600 LEO injuries between 2004 and 2006 [1], 17,000 firefighter injuries in 2015 [1], and 1,500 EMS technician injuries in 2009 [1], all related to preventable crash-related incidents. Additionally, each year there are approximately 100 LEO fatalities [1, 7, 8], 45 EMS technician fatalities [1, 7], and 15 firefighter fatalities [1, 7] as the result of these accidents. Furthermore, there are 60 civilian fatalities each year due to ER-related accidents [1]. These accidents incur many lawsuits that cost the cities millions of dollars every year due to injuries, property damage, and life loss [1].

1.1 Statement of the Problem

The Ministry of Transportation in Canada is dedicated to moving people safely, efficiently, and sustainably through promoting innovative technology and infrastructure. When it comes to emergency calls, ERs are equipped with sirens and lights, and there are laws in place that dictate how civilian vehicle (CV) drivers should respond to nearby ERs. For instance, failure to slow down and make room for parked ERs with activated lights or failure to maintain at least 150 meters from a travelling ER could result in fines between $400 to $2,000 and three demerit points in Ontario based on Section 159(2) and (3) of the Highway Traffic Act [9, 10].

Unfortunately, the traditional methods used by ERs (i.e., lights and sirens) have been proven ineffective at attaining attention and negotiating traffic. By the time CVs recognize the signals, they have difficulty identifying the ER's direction and distance, thereby not having enough time or context to react effectively [11].

Continuing with the reliance on human perception-based warning signals results in additional traffic chaos and accidents [11]. Developing a more sophisticated and assistive system for ERs and CVs could help the Ministry of Transportation reduce the risk for ERs by reducing traffic volume around their vehicles (i.e., helping CVs maintain a minimum distance) when responding to calls.

1.2 Purpose of the Study

The study will be limited to IoT-enabled vehicles (hereafter referred to as "connected vehicles") operated by ERs and civilians). For our system to consume traffic data and communicate with the connected vehicles, our mobile application will use cellular data to connect with our centralized server. For the system to avoid route collisions, both drivers need to enter their destinations and follow the routes provided by our mobile application. This study explores the relationship of localized traffic volume around ERs to reduce accidents involving ERs responding to calls within urban areas such as Toronto, Ontario.

1.3 Outcomes & Contributions

The study by [12] uses a centralized traffic control server to improve road safety and reduce arrival times for ERs. The server notifies CV drivers instructing them to pull over and halt for approaching ERs, and generates the ER's optimal routes using real-time traffic information collected from RSUs installed at every intersection. This approach relies too heavily on high penetration rates of RSUs in the infrastructure of urban areas, resulting in inconsistent communication between the vehicles and the server. Additionally, research shows that warning drivers of approaching ERs results in panicking the driver, increasing the risk of further accidents with the ER or neighbouring CVs [3, 6].

In this research, we will focus on preemptively assisting CV drivers in avoiding the path of ERs. Our emergency route avoidance system aims to discreetly guide CV drivers to maintain a 300-meter distance (twice that of the legal minimum distance) from active ERs. This distance helps reduce traffic volume around and ahead of ERs, combined with the discrete guidance to minimize the anxiety of nearby CV drivers helping to lower the chance of accidents while responding to calls.

This research aims to provide vehicle manufacturers with our emergency route avoidance system to employ as standard within their IoT-enabled motor vehicles, helping navigate drivers to maintain a safe distance from active ERs in urban areas.

1.4 Research Question

The topic of this study explores the use of real-time route guidance for CVs during emergencies. This study's factors include the distance between CVs and active ERs and the ER arrival times. The populations that this study will explore are CV drivers and ERs in urban areas, such as the city of Toronto. This study aims to answer the research question: Does guiding CVs away from ERs such that a distance of 300-meters is maintained reduce arrival times and risk for ERs responding to calls?

1.5 Significance of the Study

By leveraging cloud computing and IoT technologies, CVs will overcome human perception limitations and more effectively avoid ERs responding to calls by maintaining a minimum distance of 300-meters. Maintaining this distance ensures a reduction in traffic volume around ERs, resulting in fewer threats and obstacles that could cause delays and further accidents, creating a safer and faster commute.

1.6 Overview of Methodology

Our experiment will be performed with human participants after developing a centralized server and complementary GPS-enabled navigation mobile application on Android. The experiment involves a minimum of two participants divided between two types; one as acting ER driver and the other as acting CV. Each driver type has a dedicated version of the application that generates a route between an origin and destination location of their choosing, provided by our server. When the server generates the ER route, it searches for any possible path collision with the ER. It uses the respective vehicle's current location and speed to estimate whether the vehicles could collide (i.e., appear within 300-meters of each other). The application periodically updates the server with the vehicle's speed, location, and heading data, enabling the server to update its predictions. If a collision is likely, an alternative route is generated for the CV such that the distance between the vehicles remains greater than the threshold.

1.7 Definition of Terms

1. Emergency: Any situation that poses an immediate risk to health, life, property, or environment.
2. Traffic flow: The total number of vehicles passing a given point in a given time.

1.8 Organization of the Thesis

This chapter introduced our topic and the problem we will be studying. We looked at why we need to study this and how we will benefit from it. In chapter 2, we will be exploring the review of related literature. Chapter 3 will incorporate the methodology that we are going to use to conduct our experiments. Chapter 4 is going to report on our findings. Chapter 5 is going to give our conclusions and recommendations.

Chapter 2

Literature Review

In 2019, the U.S. Department of Transportation (DOT) reported more than 36,000 fatalities and 4.4 million critically injured individuals due to vehicle accidents [13], making road traffic accidents the third leading cause of death in the United States [14]. Among these reports, 90% result from human error (i.e., the improper reaction to impending danger) [15]. As urbanization continues to grow, so does the expected number of drivers on the road, ultimately increasing traffic congestion and the risk of increased traffic accidents [16] given the reduced space and time needed to identify and safely react to emergencies. Additionally, the increase in traffic congestion due to inefficient traffic flow increases commute times for urban drivers, which drastically and irreversibly damages our environment from the emissions of each car [17]. Some of the main factors contributing to road traffic accidents related to human error include biological limitations, such as perception, communication and processing outlined below:

1. Perception is the ability to sense and identify emergencies. While humans rely on various biological senses to navigate the world, only a select few provide relevant data while operating a vehicle, such as sound and sight. Drivers generally only use sound to identify honking and sirens; they filter out most other noises. Sight is the most used sense by drivers, but every vehicle has an ar-

ray of blindspots and many threats live outside the line-of-sight (LOS), usually obstructed by other vehicles, buildings, trees, and poor weather conditions [6];

2. Communication is the ability to perceive neighbouring drivers' intentions unambiguously and clearly express your intentions. Standard vehicles are equipped with few external indicators, including a monotone horn, signal lights, and brake lights. But the use of these indicators varies between cultures;

3. Processing is the ability to plan strategies for avoiding or preventing dangerous situations by collecting environmental context and assessing the surroundings. Drivers already have potentially high cognitive workloads given many factors such as unfamiliar roads, poor weather conditions, and multitasking, to name a few. Even in optimal conditions, drivers often only have a few seconds to react given the high speeds they travel at, and the decisions they make tend to be ill-informed guesses that often lead to accidents [3].

One of the leading prospective solutions to improving road safety and traffic efficiency is a cooperative vehicle safety system that uses the Dedicated Short-Range Communication (DSRC) in Intelligent Transportation System (ITS) for Vehicular Ad-hoc Networks (VANET) [12, 18, 19].

2.1 Intelligent Transport Systems

VANET is considered the most trusted and intelligent transport system [20]. Vehicles in VANET, referred to as Connected Vehicles (CVs), establish communication networks in both short and medium-range proximity using Wireless Access in Vehicular Environments (WAVE) broadcasting services. There are three components to VANET:

1. Onboard Units (OBUs) that are installed within the vehicle

2. Trusted Authorities (TA)

3. Roadside Units (RSUs) are IoT devices strategically places around roads such as in traffic lights [20]

CVs communicate by periodically broadcasting messages every 300 milliseconds (ms). Each message is created as WAVE short messages (WSMs), which DSRC broadcasts over the 802.11p beacon frame [21]. The message contains their speed, acceleration, location, and heading [20, 18].

DSRC, also known as IEEE 802.11p, is a protocol enabling VANET Vehicle-to-Everything (V2X) communication. V2X also includes other specific types of communication: 1) Vehicle-to-Vehicle (V2V), 2) Vehicle-to-Pedestrian (V2P), and 3) Vehicle-to-Infrastructure (V2I) communications [12, 20, 18].

Throughout the last decade, many countries have been investing in standardizing traffic management communication infrastructure to increase the demand for CVs [12]. Nevertheless, despite the promising results in the literature, CVs are not yet highly available on the market, and their safety and assistive features are yet to be fully realized [22, 23]. However, with the recent growth of popularity surrounding autonomous vehicles over the last decade, the growing demand for vehicular safety features, and stringent government rules for improved traffic management, more comprehensive implementation of CVs is inevitable [24, 25, 6].

2.2 VANET in Accident Prevention

Drivers of regular vehicles (RVs) rely too heavily on LOS to perceive their surroundings, often having difficulty seeing or sensing obstacles obstructed by other vehicles, buildings, trees, or weather conditions [6]. Even with the technological advances in modern cars' sensors, such as LIDAR, radar, and cameras, each relies on LOS and performs poorly in terrible weather conditions [6]. This review highlights three problem areas that, when addressed, could significantly increase road safety, including non-line-of-sight (NLOS) pedestrian sensing [6], NLOS vehicle sensing [26], and cooperative lane changing [27].

2.2.1 NLOS Vehicle Sensing

In 2018, there were more than 12 million reported car-related accidents in the United States [28], with more than 36,000 involving fatalities [28]. The root of many of these accidents stems from the obstructed vision of drivers, either due to blind spots, poor weather conditions, or any number of other causes. NLOS vehicle sensing enables CVs to sense each other despite obstacles that would otherwise hide their presence [26]. One study by [3] focused on law enforcement officers' safety, hereafter referred to as emergency response vehicles (ERVs). Many ERVs reported driving more than 5 million miles a year and often operated under heavy visual, mental, and cognitive workloads, potentially driving at high speeds through difficult traffic and weather conditions [3]. ERVs traditionally rely on sirens and lights to draw attention but are inefficient at preventing dangerous situations and ultimately lead to travel time delays as they navigate through the congested traffic. The warning is often recognized too late and confuses the drivers about the position and direction of the ERVs [3]. Multiple studies leveraged V2I communication by installing RSUs alongside major highways and using a centralized server to disseminate ERVs' telemetry information through them via DSRC [3, 12]. As a result, CVs with graphical user interfaces (GUIs) (e.g., mounted smartphones) could be visually informed of the ERV's position and desired route, providing context on how to safely and efficiently avoid ERVs. The drawback to this approach is that it relies heavily on high CV penetration rates.

2.2.2 NLOS Pedestrian Sensing

The second problem area is similar but relates to sensing pedestrians instead of vehicles. While collision threats are seemingly identical, the sensing mechanism requires an entirely different set of approaches. For instance, pedestrians can roam both roads and sidewalks, and they may not carry smartphones. Vehicle accidents involving pedestrians account for more than 6,500 deaths each year and continues to rise sharply [29]. The cause of many of these accidents stems from the driver's inability to notice the pedestrians in time to avoid collisions safely. In the study by

[6], a group of pedestrians were provided DSRC-enabled smartphones that made it possible for the CVs to sense them with DSRC technology. The smartphones could communicate directly with the CVs via V2P communication or with nearby RSUs that would relay their telemetry information to the CVs via V2I communication. Although their experiments were performed on autonomous vehicles, their approach to predicting NLOS pedestrian movement and suggest maneuvers for the vehicle to safely drive around the pedestrian is highly transferable to the drivers of controlled CVs. The drawback to this research is that the experiments assumed all pedestrians possessed a powered-on, DSRC-enabled smartphone. Even with higher penetration rates of DSRC-enabled smartphones, the dependency that the smartphones need to be powered-on will always pose a deployment issue.

2.2.3 Cooperative Lane Changing

Lane changes are among the most fundamental processes for drivers. However, they account for about 5% of traffic accidents [27] and 10% of traffic congestion [27]. Among these reported accidents, 75% of them were caused by human error [27]. With the advances in CVs in VANET, more optimized lane changing planning and speed control strategies can be advised to the driver. There are many studies on cooperative lane changing algorithms. One proposes a multi-vehicle cooperative lane change strategy in which the decision making control is decentralized [27]. This approach creates a more comfortable experience for the involved drivers than unaided lane changes while simultaneously increasing traffic flow efficiency and road safety. Unfortunately, the research failed to consider the perceived errors, delays in communication, and systems response times. Additionally, this approach requires a high penetration rate of CVs, which is yet to be seen globally. A DSRC-based freeway merging assistant system was developed [23]. Various lane merging scenarios were tested using a smartphone as a GUI for displaying advisory messages and three CVs. Although the tested scenarios were basic, involving only single-hop broadcasting, they were performed in an uncontrollable environment, demonstrating that real-world cooperative lane changing is feasible and effective even at complex interchanges. In the third study, authors [22] focused on improving and maintaining traffic flow during emergency evacuations. The experimenters varied the penetration rate of CVs from zero-percent (i.e., base scenario) to 30-percent (i.e., the predicted rate by 2018). The algorithm suggested which lane and speed to maintain based on neighbouring CVs' traffic flow data. The study results demonstrated that increasing the percent of CVs present in an emergency evacuation led to significant traffic delays early into the situation and that the delay benefits would become positive only after approximately 1/3 of the overall time. It also demonstrated that the amount increase is proportional to the penetration rate of CVs. The study's limitations were in the assumptions that drivers of CVs would obey every suggestion of the algorithm.

2.3 VANET in Road Optimization

2.3.1 Route Guidance

Route guidance is defined as the problem of computing an optimal route (either by distance or time) between an origin and a destination and having it adapt to real-time traffic updates while guiding the driver on how best to avoid congested traffic. Given the time-sensitive nature of emergencies, ERVs need to reduce travel times by maintaining high speeds and avoiding unnecessary delays. In addition to the high accident risk, other drivers' wrong behaviour also slows down the emergency vehicle and prevents it from reaching the emergency scene earlier. For example, in traffic jams, confused drivers often do not know how and where to form a suitable corridor to let the emergency vehicle through [3]. The study, [30], uses real-time traffic information with the intent of avoiding congested road sections. The proposed model takes the approach to minimize prerequisite infrastructure by using CVs within a VANET as information servers instead of relying on RSUs.

In the second study, [12], the use of a centralized server controls all traffic lights and traffic information. It is also responsible for computing the shortest-time plan and alternative routes, based on distance and average expected speeds, for emergency response vehicles (ERVs). The first issue addressed is the ability to compute the fastest route from the source to the event (destination) for these ERVs and adjust this route based on real-time traffic. The second challenge is to disseminate the warning messages to nearby CVs along the ERVs route, advising them to move or stay put to avoid collisions with the ERVs. The study [21] implements the best-lane strategy (BLS) algorithm, which sits on top of the DSRC/WAVE protocol stack. The algorithm is designed to guide ERVs through congested traffic networks by advising periodical lane changes ensuring it travels in the lane with the highest utility.

2.3.2 Traffic Light Preemption

Many factors contribute to the increasing congestion of traffic in urban areas, but intersection traffic lights play a significant role in regulating traffic flow. Traditional approaches use inefficient timer-based decision logic, merely toggling the right-of-way (i.e., green light) signal between the competing directions at a fixed interval. Unfortunately, traffic flow for most of the time is not symmetric, resulting in unnecessary traffic congestion. One study implemented DSRC-actuated traffic lights using off-the-shelf hardware and software to reduce traffic congestion by prioritizing CVs [31]. The significant reduction in traffic congestion despite a low CV penetration rate, combined with a cost-effective implementation, makes this approach easily deployable. Another approach makes use of a centralized ITS server that preempts all traffic lights (i.e., displaying a red light to all directions) when an ERV is approaching [4]. The intent is to stop all traffic such that no driver will collide with the ERV.

Consequently, they cannot control traffic flow without traffic lights and may only cause more chaos in nearby roadways. Similarly, another approach entails giving the direction of an approaching ERV the right-of-way (i.e., displaying a green light) such that vehicles can move and clear a path [3]. This approach does not warn drivers of an approaching ERV, and it also relies heavily on the presence of traffic lights to control traffic flow.

2.4 Unique Applications

Aside from the clear use-cases in safety and assistive applications, there is extensive literature on other use-cases such as toll road collection [32, 33], fleet management [24], and parking management [24].

Chapter 3

Methodology

3.1 Introduction

Given the average driver's biological senses, they only have a few moments to react upon acknowledging the warning signals from ERs. Within these moments, the drivers must identify the ER's location and heading, understand their maneuver options, and safely execute their plan. Unfortunately, ERs are often upon the drivers (i.e., within 150-meters of them) before they can clear a path, causing chaos and congestion. These increases in traffic volumes around and ahead of ERs constitute a significant cause for delays when responding to emergencies and increase the risk of other accidents [1, 3, 4, 6]. By creating an emergency route avoidance system, we aim to proactively guide civilian drivers away from ERs such that they maintain a distance greater than 300-meters at all times. This chapter will outline how the data is collected, how we designed the software, and how the experiments will be performed.

3.2 Participants

Volunteers will be involved in this experiment. All participants must have a valid driver's license and an insured vehicle. The participants must also be willing to commute to Oakville, Ontario, Canada. We planned to have the participants sampled from Sheridan College's population in Oakville. Unfortunately, with the introduction of remote learning due to COVID-19, we opted for convenience sampling. Each participant will be told that the experiment would involve using vehicular GPS tracking and evaluates how they react with a vehicle in the presence of an active ER. We also inform them that they only need to complete an even number of the six total variations, and we will compensate them for their time and gas.

3.3 Research Design

Before the emergency guidance experiment in this thesis can begin, a mobile application and centralized server are needed. The server will facilitate route generation for CV and ER vehicles communicated to the driver through the application.

We chose the origins and destinations to mimic a fire-related emergency and a student commuting to school. The ER representing a firetruck originates near a fire station (2028 Madden Blvd, Oakville, ON L6H 3L6) and travels to two possible locations based on the scenario. In one instance, the destination is a plaza (1130 Eighth Line, Oakville, ON L6H 2R4), and in the other instance, it is along the side of the road somewhere along the route of the CV. Simultaneously, the CV, a student driver, starts from a representation of home (2163 Sixth Line, Oakville, ON L6H 3N7) and commutes across town to school (1430 Trafalgar Rd, Oakville, ON L6H 2L1). We chose these locations to ensure Google Maps would return the same overlapping routes, as shown in Figure 3-1.

The application will only be developed for the Android platform to keep development times short and minimize costs. To avoid possible compatibility issues and to reduce setup times when configuring the participants' phones, we will instead provide them with a phone preconfigured for our experiments.

3.4 Data Collection Methods

We provide the participants with a mobile phone equipped with our application and the required features such as GPS and cellular data to communicate with our server.

Figure 3-1: A example of overlapping routes for ERs and CVs.

The phone is to be mounted on their vehicle's dashboard, enabling them to read the display while driving safely.

The application tracks the vehicle's position in real-time using the GPS module built into the mobile phone, providing longitude and latitude values. We deduce the vehicle's speed and heading by calculating the differential between their current location and the previous location.

The server provides the client (ER or CV) with their route based on their origin and destination coordinates. The server also tracks and uses the client's current location, speed, and heading to predict when and where a CV and ER are likely to collide (Figure 3-2). If a collision is predicted, the routes for any involved CVs will be updated, guiding them away from the collision site.

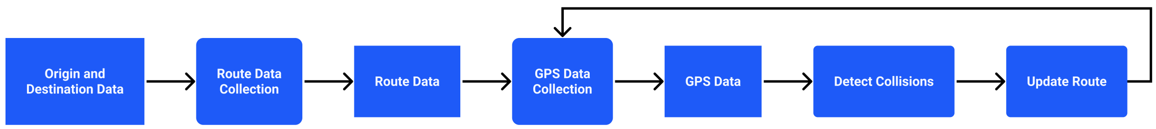

Figure 3-2: Main pipeline used to build Route Avoidance System using GPS.

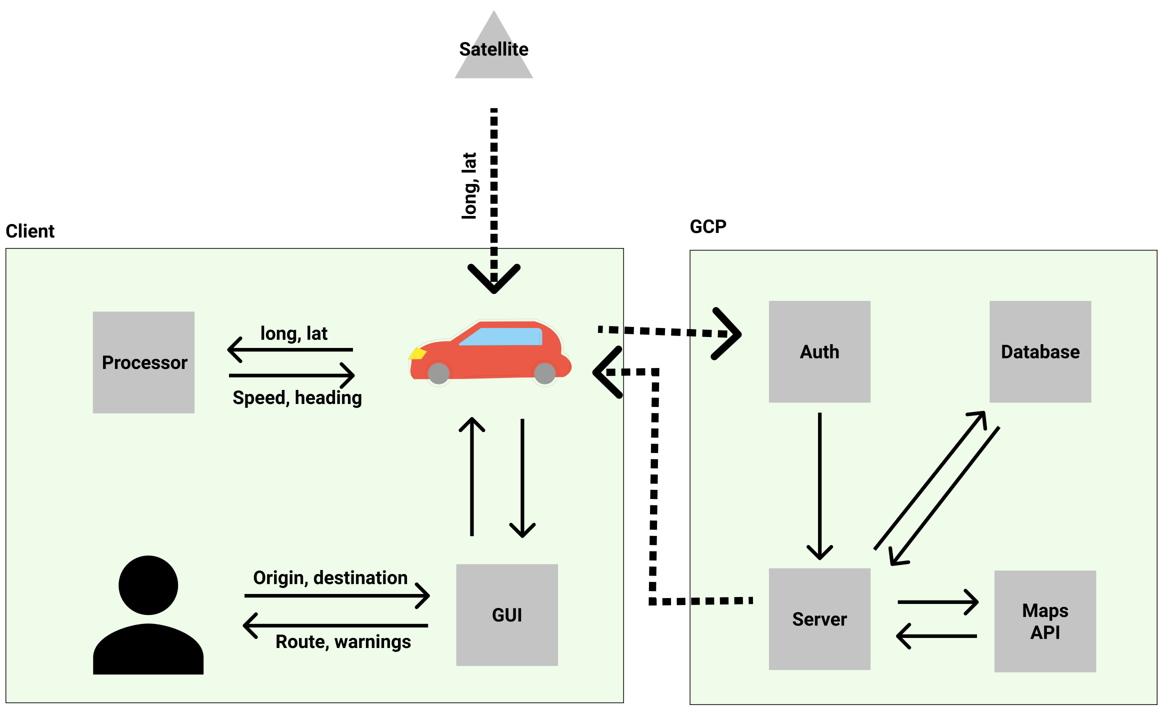

Figure 3-3: Software System Design Diagram.

```
function FindCollisionPath(er_polyline, cv_polyline, er_steps, cv_steps)
    overlaps = []
    overlaps.append(findPathOverlaps(er_polyline, cv_steps))
    overlaps.append(findPathOverlaps(cv_polyline, er_steps))
    overlapPolyline = generatePolyline(overlaps)
    return {overlapPolyline, overlaps}
end function

function FindPathOverlaps(polyline, steps)
    result = []
    for step in steps do
        overlapPosition = locationIndexOnEdgeOrPath(step, polyline)
        if overlapPosition > -1 then
            result.append({step, overlapPosition})
        end if
    end for
    return result
end function
```

Figure 3-4: Pseudocode for path collision detection between the routes of an ER and CV.

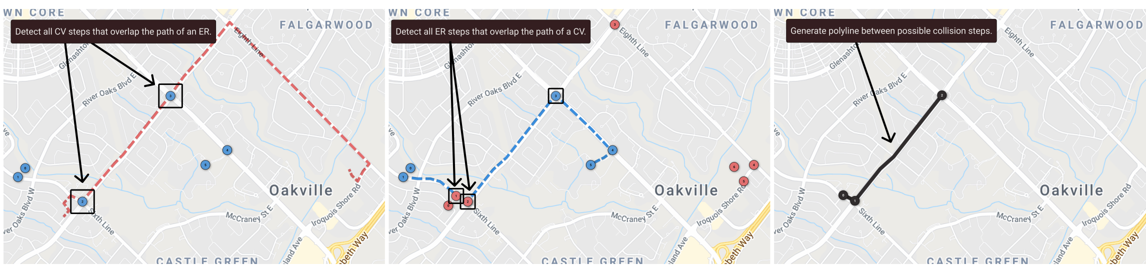

Figure 3-5: Illustration of the path collision detection algorithm between the routes of an ER and CV.

3.5 Software & Technology Related Design

As shown in Figure 3-3, the system is composed of a mobile client application and various Google Cloud Platform (GCP) services for authentication, database, Maps API, and server hosting. We will use the NodeJS runtime environment to develop the server and the Flutter SDK and Dart language to develop the mobile application.

The server is responsible for predicting when and where CVs might collide with active ERs and decide how best to avoid the collision. The pseudocode in Figure 3-4 elaborates on the process of detecting all possible collision points, and Figure 3-5 visualizes the process. The Directions API by Google Maps provides an array

```
function ComputeDetour(collisionPath, cv, er)
    stepsToAvoid = []
    waypoints = GenerateWaypoints(collisionPath.polyline)
    for step in waypoints do
        cv_arrivalInMinutes = CalculateArrivalTime(step, vc.currentSpeed, vc.currentLocation, "minutes")
        er_arrivalInMinutes = CalculateArrivalTime(step, er.currentSpeed, er.currentLocation, "minutes", SAFETY_THRESHOLD)
        absArrivalDifferenceInMinutes = |ar_arrival - cv_arrival|
        if absArrivalDifferenceInMinutes <= 2.0 then
            stepsToAvoid.append({step, absArrivalDifferenceInMinutes})
        end if
    end for
    cv.route = Detour(cv.route, stepsToAvoid)
    return cv
end function
```

Figure 3-6: Pseudocode for path collision detection between the routes of an ER and CV.

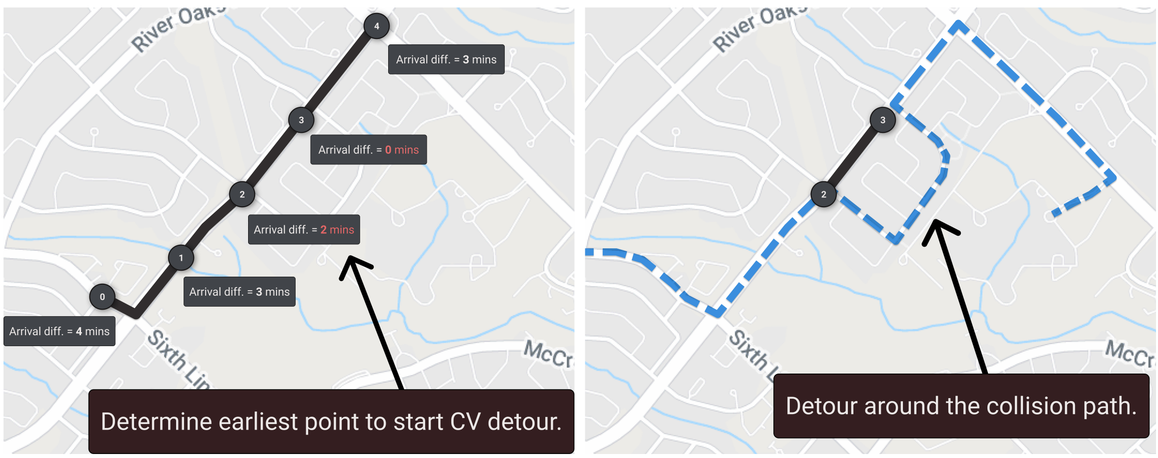

Figure 3-7: Illustration of the path collision detection algorithm between the routes of an ER and CV.

of intermediate steps between an origin and destination and a polyline that connects them. From the PolyUtil library, the ‘locationIndexOnEdgeOrPath‘ function takes a polyline and a single location and checks if the point lies on the line. We leverage this function to identify if and where the routes overlap for ERs and CVs and generate a polyline between all collision steps.

Knowing the overlapping regions between the two routes is not enough to determine whether a collision would happen. The pseudocode in Figure ?? elaborates on the process of predicting the exact locations and times that collisions could happen based on the speed and current locations of both vehicles. The algorithm compares the arrival times for both vehicles within the array of possible collision locations and decides that a detour is necessary if the absolute difference between their times is less than two minutes.

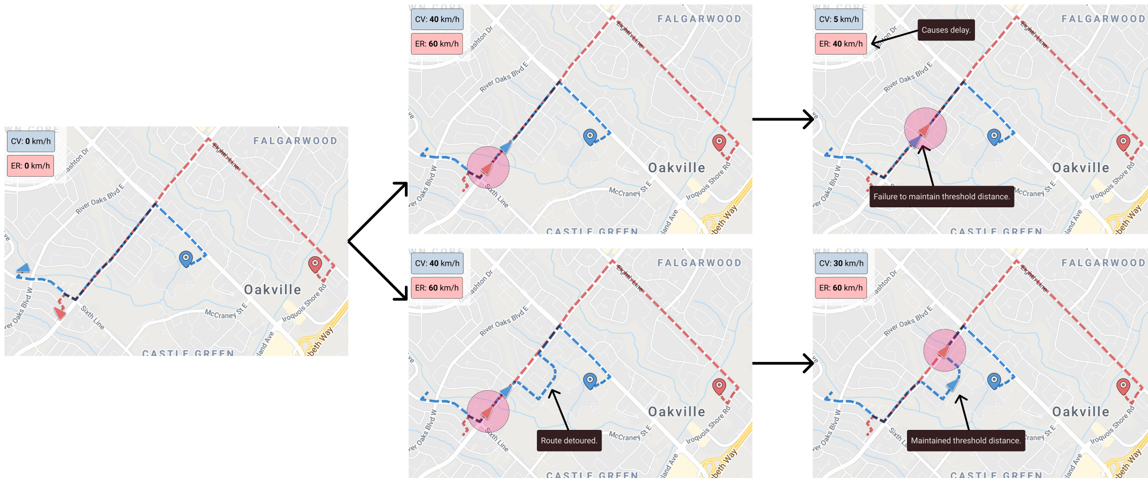

Figure 3-8: How the CV reacts to an approaching ER when their distance falls below the safety threshold.

3.6 Comprehensive Experiment Framework

Before the experiment begins, the examiner randomly shuffles the six possible scenarios' order to follow. From there, we allow the participants to get familiar with reading instructions from a phone while driving and using our application to guide them to their respective starting locations. When both the participants (CV and ER) have arrived at their starting places and confirmed that they are ready to begin the experiment, the application will initiate a countdown timer. When the timer ends, the application displays their new destination and the route they must follow.

The CV driver must follow proper protocol when being approached by an active ER, such as slowing down, moving over, and halting until the ER is 150 meters away [9, 10]. The application emits a siren-like noise while the CV driver is within this range. So the driver may continue to drive when the noise has faded.

There are three scenarios with two variations each (i.e., with or without the Route Avoidance algorithm), summing to six scenarios in total. As the participant drives towards their destination along the route provided, our system will track and record their progress.

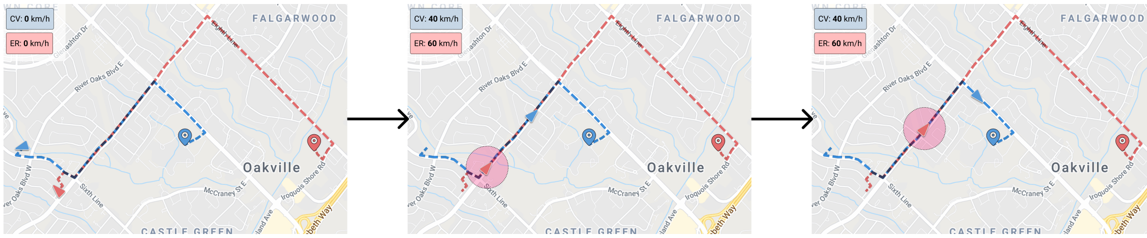

Figure 3-9: How the CV reacts to an approaching ER when their distance never falls below the safety threshold.

In scenario one, shown in Figure 3-8, we give the CV driver a start delay of zero seconds (i.e., no delay) while the ER driver has a start delay of two minutes. The difference in delay allows the CV to drive without any active ER for a short period. After this period, the vehicles' distance should be small enough that the ER can catch up and overtake the CV before their routes diverge. In the version without the Route Avoidance algorithm, the CV relies only on a siren-like warning emitted from the application as the ER inevitably approaches and overtakes the CV. In the version with the algorithm, the system could periodically change the CV's route to avoid having the two vehicles break the safety threshold.

In scenario two, shown in Figure 3-9, we give the CV driver a zero-minute start delay and the ER driver a five-minute start delay. This delay difference distances the two vehicles such that they will never overlap during their commute. We do not expect any difference between the versions with or without the algorithm as no detour would occur.

For scenario three, depicted in Figure 3-10, we give the CV a five-minute start delay and the ER a zero-minute start delay. Additionally, the ER's destination now resides on the default route for the CV, representing the event that a CV approaches an accident scene. The CV has to slow down in the version without the algorithm as it passes the parked ER. In the second version, the CV is detoured around the road using the algorithm, ensuring the safety threshold is maintained.

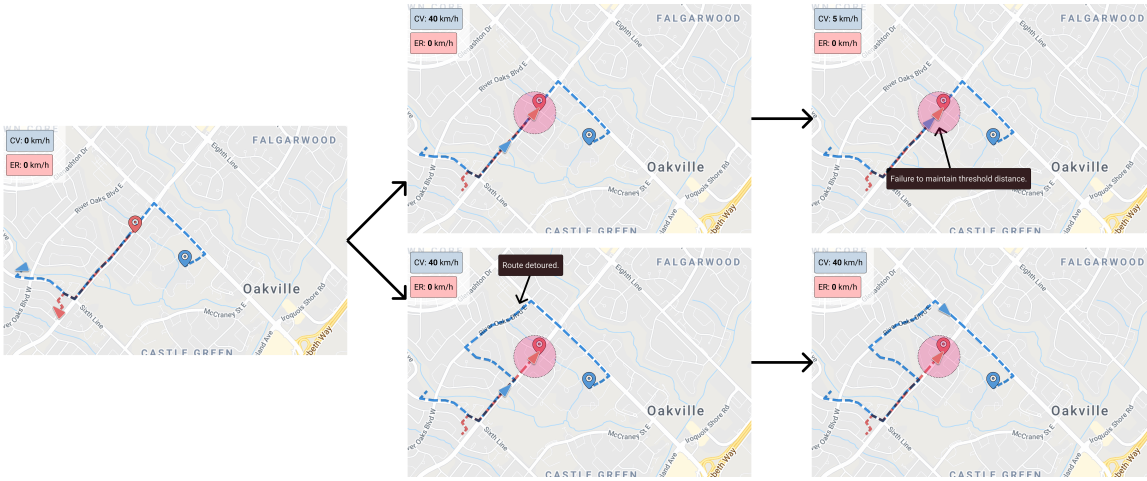

Figure 3-10: How the CV reacts to an upcoming ER when their distance falls below the safety threshold.

3.7 Data Analysis Methods

The following quantitative analysis types will be performed: 1) evaluating the minimum and average distance between the CV and ER across the various scenarios; 2) determining the accuracy of our algorithm's collision predictions.

3.8 Research Validation

The Ministry of Transportation of Canada made it law to keep at least 150-meters (aka. legal threshold) from any active ER [9, 10]. One of the leading factors contributing to ER crashes is the failure to maintain this distance. Although ERs use warning signals to gain CVs' attention, they are proven inadequate as providing enough context, confusing drivers and leaving them to decide for themselves how best to react [11]. By applying our Route Avoidance system, we can extract the minimum and average distances between CVs and ERs and compare these values against the legal threshold. If our value is around the same or less than the legal threshold, our system fails to provide any safety benefit. Oppositely, if our value is greater than the legal threshold, it demonstrates that our system provides some safety benefits. The degree of benefit depends on the contrast between the two values.

3.9 Assumptions & Limitations of the Study

In the real world, ERs use the "code three running" option when responding to calls [1, 2], enabling them to exceed speed limits and use warning signals like a siren. The ability to exceed speed limits means they can overtake any law-abiding driver on the road. To mimic their range of speed within our experiments without breaking the law, we chose to constrain our participants' maximum speeds to 70% of the speed limit of any given road. We reserve the remaining 30% for our ER drivers. As for mimicking the sirens used by actual ERs, based on Section 75(6), it is illegal in Ontario to mount any horn that may be mistaken for an emergency siren under the Highway Traffic Act [9, 10]. Alternatively, we chose to have the mobile application emit a sound within the vehicle whose volume increases the closer the CV is to the active ER. This noise will inform the driver of a nearby active ER without providing context to its exact current location and heading. We aim to cause increased tension and confusion for the driver, mimicking the effects caused by sirens [11].

3.10 Summary

In this chapter, we described the design and rationale of the experiments' setup, defined the system architecture design and data collection processes, explained the various experiment scenarios, explaining how the results will be used to validate our research, and highlighted any assumptions and limitations.

Chapter 4

Findings (Analysis and Evaluation)

4.1 Statistical Analysis to Test the Classifiers

...

4.2 Summary of Main Findings

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Chapter 5

Discussion

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5.1 Significant Factors in Designing Good Models

...

5.2 Implications for Practice

...

5.3 Limitations

...

Chapter 6

Conclusion

6.1 Summary

...

6.2 Future Work

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Appendix A

Tables

Table A.1: Acronyms

ER	Emergency Responders
CV	Civilian Vehicles
DOT	Department of Transportation
LOS	Line-of-Sight
NLOS	None-Line-of-Sight
GUI	Graphical User Interface