An Emergency Real-Time Route Avoidance System for DSRC-Enabled Vehicles in Vehicular Ad-Hoc Networks

A Thesis

presented to

School of Applied Computing, Faculty of Applied Science and Technology

of

Sheridan College, Institute of Technology and Advanced Learning

by

Devon A. Fazekas

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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.

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Acronyms

|  |  |
| --- | --- |
| ERV | Emergency Response Vehicle |
| ER | Emergency Responder |
| DOT | Department of Transportation |
| LOS | Line-of-Sight |
| NLOS | Non-Line-of-Sight |
| DSRC | Dedicated Short-Range Communication |
| ITS | Intelligent Transportation System (ITS) |
| VANET | Vehicular Ad-Hoc Network |
| CV | Connected Vehicle |
| RV | Regular Vehicle |
| WAVE | Wireless Access in Vehicular Environments |
| OBU | Onboard Unit |
| RSU | Roadside Unit |
| WSM | WAVE Short Message |
| V2V | Vehicle-to-Vehicle |
| V2I | Vehicle-to-Infrastructure |
| V2P | Vehicle-to-Pedestrian |
| V2X | Vehicle-to-Everything |
| GUI | Graphical User Interface |

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# Chapter 1

## 1.1 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 [26]. Given the time-sensitive nature of emergencies, ERs need to quickly and safely reach their destination [31]. 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 [7, 26, 31].

As traffic volumes continue to rise, both the arrival times to emergencies and the risk that ERs become involved in accidents also increase [21]. 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 [26]. The relevant causative factors attributing to these crashes include complicated urban intersections [26, 28], high traffic volumes [21, 26], lack of recognition by other drivers [6, 21, 26], and human error [6, 7].

In the United States, there were more than 37,600 LEO injuries between 2004 and 2006 [26], 17,000 firefighter injuries in 2015 [26], and 1,500 EMS technician injuries in 2009 [26], all related to preventable crash-related incidents. Additionally, each year there are approximately 100 LEO fatalities [26, 29, 30], 45 EMS technician fatalities [26, 30], and 15 firefighter fatalities [26, 30] as the result of these accidents. Furthermore, there are 60 civilian fatalities each year due to ER-related accidents [26]. These accidents incur many lawsuits that cost the cities millions of dollars every year due to injuries, property damage, and life loss [26].

## 1.2 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 drivers should respond to nearby ERs.

Unfortunately, the traditional methods used by ERs have been proven ineffective at attaining attention and negotiating traffic. By the time civilian drivers recognize the signals, they have difficulty identifying the source's direction and thus do not know how to react correctly.

Continuing with the reliance on human perception warning signals results in additional traffic chaos and accidents. Developing a more sophisticated and assistive system to be used by ERs and civilian drivers during emergencies could help the Ministry of Transportation reduce traffic volume and improve road safety while ultimately reducing arrival times.

## 1.3 Purpose of the Study

The study will be limited to DSRC-enabled vehicles operated by both first responders and civilians. For our system to consume traffic data, RSUs need to be installed throughout an urban area, such as traffic lights. For the system to avoid route collisions, both drivers need to enter their destinations and follow the routes provided by some mobile applications. This study aims to explore the relationship of reduced traffic volumes to reduced annual accidents involving ERs within urban areas.

## 1.4 Theoretical Framework

Many studies have been done on developing VANET-based routing systems for ERs [8, 12, 15 21]. A common goal among these studies was to examine how using a centralized server and RSUs could reduce arrival times for ERs. It was shown that these servers could be effectively used to help ERs avoid congested roads, such as by controlling traffic lights or by settling for alternative but ultimately longer routes. Additionally, studies have been done on VANET-based emergency warning systems for civilian drivers [7, 10, 13] to provide ample time to yield for nearby ERs safely. While this approach might increase road safety during emergencies, it does not help reduce arrival time for ERs. Research has shown that even minor increases in traffic volume can significantly increase the heavy visual, mental, and cognitive workloads for ERs [7, 26, 27, 28]. Therefore, we want to reduce traffic volume as much as possible.

In this research, we are going to connect these two approaches. Past research has not focused on preemptively assisting civilian drivers in avoiding roads that ERs actively use. This route avoidance system will decrease the traffic volume along the roads soon to be occupied by ERs. By guiding CVs away from emergency reserved routes, we should reduce traffic volume by 5% for ERs to move along the roadway when responding to emergencies.

In this research, we aim to provide vehicle manufacturers with our route avoidance system that they can utilize with their DSRC-enabled motor vehicles, which improves their vehicle safety ratings by helping navigate drivers away from dangerous routes. By doing this, we should reduce traffic volume along emergency routes by upwards of 5%, given the current penetration rates of DSRC-enabled vehicles on the market.

## 1.5 Research Question

This study will explore the use of real-time route avoidance for CVs in VANET for emergency route reservations. This paper will explore the CV routing times, ER arrival times, and traffic flow along emergency reserved routes. The populations that this study will explore are CV owners and ERs in urban areas. This study aims to answer the research question: Does guiding CVs away from emergency reserved routes reduce traffic volume and increase arrival times for ERs?

## 1.6 Significance of the Study

By leveraging CVs' communicative features in VANET, ERs will overcome human perception limitations and more effectively warn civilian drivers with concise instruction on how to avoid increased traffic congestion during emergencies. This reduced traffic volume will help ERs reduce arrival times and the risk of accidents while responding to emergencies.

## 1.7 Overview of Methodology

Our experiment will be performed with human participants after developing a GPS-enabled navigation mobile app 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 civilian driver. Each driver type has a dedicated version of the app. Both driver types will generate a route between an origin and destination point of their choosing. While driving, if the CV driver is on or approaches a road along the ERs' route, the CV driver will be warned and suggested a detour. If the detour is declined and the difference in distance between the ER and CV drivers is below a threshold, an emergency message will be sent to the CV driver instructing them to yield immediately until the ER has passed the minimum distance is met. Data will be collected on how CV drivers will react to and avoid an approaching ER driver, how quickly the CV driver adjusts to detours and the distance between ERs and CVs.

## 1.8 Definition of Terms

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

## 1.9 Organization of the Thesis

In this chapter, we introduced our topic, 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.

# 2 Literature Review

## 2.1 Introduction

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 [1], making road traffic accidents the third leading cause of death in the United States [2]. Among these reports, 90% result from human error (i.e., the improper reaction to impending danger) [3]. 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 [4] 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 [5].

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:

* 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 array of blindspots and many threats live outside the line-of-sight (LOS), usually obstructed by other vehicles, buildings, trees, and poor weather conditions [6];
* 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;
* 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 [7].

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) [8][9][10].

## 2.2 Intelligent Transport Systems

VANET is considered the most trusted and intelligent transport system [11]. 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 [11]

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 [12]. The message contains their speed, acceleration, location, and heading [11][10].

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 [8][11][10].

Throughout the last decade, many countries have been investing in standardizing traffic management communication infrastructure to increase the demand for CVs [8]. 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 [13][14]. 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 [16][22][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 [25], and cooperative lane changing [19].

### 2.2.1 NLOS Vehicle Sensing

In 2018, there were more than 12 million reported car-related accidents in the United States [24], with more than 36,000 involving fatalities [24]. 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 [25].

One study by [7] 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 [7]. 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 [7]. 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 [7][8]. 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 [23]. 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 [19] and 10% of traffic congestion [19]. Among these reported accidents, 75% of them were caused by human error [19]. 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 [19]. 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 [14]. 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 [13] 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

### 2.3.2 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 [7].

The study, [15], 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, [8], 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 [12] 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. They perform

### 2.3.3 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 [20]. 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 [21]. 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 [7]. 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 [17][18], fleet management [16], and parking management [16].

# 

# 3 Methodology

## 3.1 Introduction

[TODO: write methodology]

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# 4 Findings (Analysis and Evaluation)

## 4.1 Introduction

[TODO: write findings]

# 

# 5. Discussion

## 5.1 Introduction

[TODO: write discussion]

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# 6 Conclusion

## 6.1 Summary

[TODO: write conclusion]

## 6.2 Conclusions

[TODO: write conclusion]

## 6.3 Limitations

[TODO: write conclusion]

## 6.4 Future Work

[TODO: write conclusion]

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# Appendix A

[TODO: write appendix]