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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 [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 the following:

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 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];
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 to 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].

2.1 General Literature Review of VANET, WAVE, and DSRC

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 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].

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