Developing a Short Range Vehicle to Infrastructure Communication System to Enhance the Safety at STOP Sign Intersections

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16. Abstract
Stop sign controlled unsignalized intersections raise a public safe concern. Even though various strategies, such as engineering, education, and policy, have been applied in practice, there are a number of fatal crashes occurred at unsignalized intersections nationwide. The visibility of a STOP sign is essential for the fatal crashes. Besides, drivers may neglect the STOP signs simply because they are tired, talking over the phone, listening to the music or radio, under negative emotions, etc. In other words, drivers' awareness of safety at STOP signs intersection is not sufficient. In this thesis, a short-range Vehicle to Infrastructure (V2I) wireless communication was developed, which is a Radio Frequency Identification (RFID) based Drivers Smart Assistance System (DSAS) proposed to address the visibility of traffic control sign, such as the STOP sign, and improve drivers' awareness of safe driving. The system hardware are all low-cost devices, while the current version of the system software is compiled in the computer program Visual Basic (VB). The RFID tags are placed on roadside, while the receivers and other devices such as GPS are equipped into the vehicles. Twenty subjects were recruited for an on-road driving test with the DSAS in a residential area in Houston. The impacts of the DSAS on drivers' driving performance were defined and measured based on the observed drivers' driving behaviors, in terms of speed profile, acceleration, and braking distance for a STOP sign. Moreover, the impacts of the DSAS on vehicle emissions were explored as well. The statistical results from the tests show that the warning message from the DSAS can enhance drivers' visibility of the STOP sign, so that they are able to decelerate earlier to approach the upcoming unsignalized intersection with a stable speed. Further, the DSAS messages do not raise extra vehicle emissions. Instead, a slight reduction in emission rates was found on the through movement. For even general observation, more road test with more participants and different test routes were recommended.

17. Key Words
RFID, Drivers Smart Assistance System, STOP sign, Fatal Crash, Vehicle Emissions, Driving Performance.

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ABSTRACT

Stop sign controlled unsignalized intersections raise a public safe concern. Even though various strategies, such as engineering, education, and policy, have been applied in practice, there are a number of fatal crashes occurred at unsignalized intersections nationwide. Stop signs are usually used to control conflicting traffic movements at intersections. In the United States (U. S.), the stop sign is not intended to serve as a traffic-calming device. The installation of a STOP sign is dedicated to improve safety and/or assign right-of-way for a certain direction. The STOP sign may be erected on all intersecting roads, resulting in three- and four-way stops, in order to enhance driver's visibility of traffic situations at the conflicting area. However, there are still one-third of all intersection crashes and more than 40% of fatal crashes recorded at the STOP sign-controlled intersections in U.S. The visibility of a STOP sign is essential for the fatal crashes (Li et al., 2015a). Besides, drivers may neglect the STOP signs simply because they are tired, talking over the phone, listening to the music or radio, with negative emotion, etc. In other words, drivers' awareness of safety at STOP signs intersection is not sufficient.

In this research, a short-range Vehicle to Infrastructure (V2I) wireless communication was developed, which is a Radio Frequency Identification (RFID) based Drivers Smart Assistance System (DSAS). The DSAS was proposed to address the visibility of the STOP sign and improve drivers' awareness of safe driving. The system hardware are all low-cost devices, while the current version of the system software is compiled in the computer program Visual Basic (VB). The RFID tags are placed on roadside, while the receivers and other devices such as GPS are equipped into the vehicles. Once a tag coded as a stop sign is

detected by the in-vehicle reader, the warning signal(s) will be broadcasted to drivers in the form of verbal and/or image message.

Twenty subjects were recruited for an on-road driving test with the DSAS in a residential area in Houston. The impacts of the DSAS on drivers' driving performance were defined and measured based on the observed drivers' driving behaviors, in terms of speed profile, acceleration, and braking distance for a STOP sign. Moreover, the impacts of the DSAS on vehicle emissions were explored as well.

The statistical results from the tests show that the warning message from the DSAS can enhance drivers' visibility of the STOP sign, so that they are able to decelerate earlier to approach the upcoming unsignalized intersection with a stable speed. Further, the DSAS messages do not raise extra vehicle emissions. Instead, a slight reduction in emission rates was found on the through movement. For even general observation, more road test with more participants and different test routes were recommended.

EXECUTIVE SUMMARY

This research is proposed to develop a short-range Vehicle to Infrastructure (V2I) wireless communication system, which is a Radio Frequency Identification (RFID) based Drivers' Smart Assistant System (DSAS) to warn drivers of the possible traffic control signs in a different way from the conventional traffic communication system, such as static traffic signs and traffic signals on the road. The DSAS provides drivers with timely and effective warning messages in a form of image and/or audio on traffic control signs, such as a STOP sign, and other relevant traffic information, which may induce the change in drivers' driving behaviors for safety purpose. The warning message is triggered by the short-range wireless communication between the roadside devices and approaching vehicles.

An on-road pilot test was conducted to examine the operation of such a warning system and evaluate its impacts on operation, drivers' driving behaviors, safety and air quality. The DSAS is comprised of three components: one or more high frequency active RFID tags, a RFID reader, and an in-vehicle signal system with an on-board display or an in-vehicle audio system. A RFID tag is mounted on or nearby a traffic device like a STOP sign, and a reader is equipped within an approaching vehicle. The mounted RFID tag transmits a set of unique identification number that is detected by the in-vehicle signal system, which is consisted of a message receiver and a signal processor. The RFID used in the driving test was an active 2.4 GHz tag with adjustable transmit power. The recognition distance of the RFID tag-reader pair was 500 ft above, which was tested by Qiao et al. (2012a). When a vehicle is approaching the RFID tag within a certain read range, the in-vehicle signal system recognizes

such unique identification number and conveys the represented message “STOP” (in this study), to drivers through the on-board display or an audio warning message.

The effectiveness of the developed DSAS was tested by an on-road driving pilot test in a residential area in Houston, Texas, United States (U.S.). Within a specific design test route in this residential area, drivers may encounter STOP signs intersections. The timing of providing drivers with an audio/image warning message is determined by the speed limit associated with stopping sight distance. A total of 20 persons (10 females and 10 males) with a valid driver license were recruited for the pilot test, based on Houston’s demographical data from 2010 Census.

Each driver was requested to drive through the test route twice without and with the DSAS. The DSAS message in this study was an alarm of deep beep and lasts about 1 second. A comparable study was conducted to obtain an insight into the impacts of the DSAS on drivers’ behaviors, in terms of driving speed, acceleration rates, and braking distance. The feasibility of the DSAS application is evaluated by a survey of drivers’ feedbacks as well. Further, vehicle emissions were estimated using Environmental Protection Agency (EPA) released MOtor Vehicle Emission Simulator (MOVES) model in the comparable study.

Results show that the DSAS alarm was able to significantly induce drivers’ approaching speed, minimize the fluctuation in acceleration/deceleration rates, and enhance drivers’ awareness of the STOP sign indicated by decelerating earlier. All test drivers believed that the DSAS did not cause any confusion or stressful to them, and agreed that the DSAS is able to provide clear warnings and guidance, and is worth to be equipped with their vehicles. Further, the DSAS alarm did not raise extra vehicle emissions. Instead, a slight reduction in emission rates was found on through movement. For even general observation, more road test with more participants and different test routes were recommended.

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Stop signs are usually used to control conflicting traffic movements at intersections, when is not satisfied with the warrants for the installation of a traffic signal or roundabout (MUTCD, 2003). In the United States, the stop sign is not intended to serve as a traffic-calming device (MUTCD, 2014). The installation of a stop sign is dedicated to improve safety and/or assign right-of-way for a certain direction. Stop signs may be erected on all intersecting roads, resulting in three- and four-way stops.

More than 40 percent of fatal crashes occur at stop sign-controlled intersections in the United States (IIHS, 2000). Retting et al. (2003) analyzed police reports of 1,788 crashes at two-way stop sign-controlled intersections during 1996-2000 in four United States cities, and found that stop sign violations accounted for about 70% of all crashes. Rear-end crashes accounted for about 12% of all crashes. One of the major reasons caused the crashes is insufficient visibility of the STOP sign, which results in the failure of taking an on-time stop action (FHWA, 2009).

The visibility of a STOP sign could be somehow physically interfered by tree leaves, heavy-duty trucks, buses or other obstacles (Qiao et al., 2012a). Further, drivers may neglect the STOP signs simply because they are tired, talking over the phone, listening to the music or radio, with negative emotion, etc. In other words, drivers' awareness of safety at STOP signs intersection is not sufficient.

To enhance drivers' compliance with the STOP sign and awareness of intersections, previous research suggested some simple and low-cost treatment, such as increasing the visibility of STOP signs and / or adding pavement markings, (Ripley, 2005). Transportation Research Board of National Academies (TRBNA, 2003) reported a series of strategies to improve the safety at un-signalized intersections like STOP sign, such as geometric design modifications, use alternative traffic control devices, targeted enforcement efforts, public education program, and so on.

Further, since the late of last centenary, varies applications of novel technologies (e.g. communication, detection, control, signal processing, artificial intelligence, system engineering, computer engineering) in transportation have brought in revolutionary changes in traditional transportation systems. For example, Li et al. (2013) proposed a wireless communication system called Pedestrians-to-Vehicle (P2V) to enhance the safety in a conflicting area. Based on the P2V, Li and Qiao (2014a) developed V2I system for the signalized intersection under sun glare effect to improve drivers' visibility of signal change. Rahman et al. (2015) developed smartphone application to provide drivers with warning messages for the forward collision area in a work zone. Munni et al. (2015) also designed a smartphone application for the advanced warning messages at signalized intersection under foggy weather condition. Therefore, it is convinced that proper applications of intelligent transportation system (ITS) technologies would potentially assist drivers' awareness of traffic signs at intersections, thereby enhancing the safety. What's more, Li et al. (2015b) found that except of the safety enhancement, a wireless communication system can also make obvious contribution to the reduction in vehicle emission rates in a work zone and signalized intersections. The reduction in vehicle emission is achieved by switching the distribution of operating mode identifications (OpMode IDs) from higher emission rates to lower emission rates (Li et al., 2016). Each OpMode ID represents different Vehicle Specific Power's (VSP) and driving speed, which means changing vehicle's activities is able to lower vehicle emissions. Besides, V2I systems have been considered as a strategy to reduce vehicle emissions by improving drivers' smooth driving behaviors (Qiao et al., 2014; Li et al., 2014 b).

1.2 Objectives of Research

The goal of this research is to develop a short-range Vehicle to Infrastructure (V2I) wireless communication system to warn drivers of the possible conventional traffic control signs and other relevant information at a conflicting area, such as a STOP sign intersection, for safety purpose. The V2I is Radio Frequency Identification (RFID) based Drivers' Smart Assistant System (DSAS), which is able to provide drivers with image as well as audio warnings from pre-equipped roadside devices. A pilot test is conducted to examine the operation of such warning system and evaluate its impacts on operation, safety and vehicle emissions.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a comprehensive literature review is conducted to understand the general strategies addressed the safety at an unsignalized intersection and the potential application of the wireless communication technology as a technical solution for the safety issue. More specifically, this literature review will focus on 1) issues at stop sign controlled unsignalized intersections, 2) short-range Vehicle to Infrastructure (V2I) wireless communication system.

2.1 Issues at STOP Sign Controlled Unsignalized Intersections

2.1.1 Special Hazards at Unsignalized Intersections

Unsignalized intersections are usually equipped along low- to moderate-volume roads in rural and suburban areas. Unsignalized intersections represent special hazards since vehicles stopping or slowing to turn create speed differentials between vehicles traveling in the same direction (Neuman et al., 2003).

In 2010, there were 32,885 people death in motor vehicle traffic crashes in the United States, which is the lowest number since 1949. Of this number 6,758 peoples were killed in motor vehicle traffic crashes at an intersection (US DOT, 2012a). Intersections account for a small portion of the total highway system, yet intersection related crashes constitute over 30 percent in rural and suburban areas (Kuciemba and Cirillo, 1992; US DOT 2012b).

As is shown in Figure 1, approximately 90% of intersection fatalities occur at unsignalized intersections in rural area, and approximately 60% occur at unsignalized intersections in urban area (US DOT 2012b).

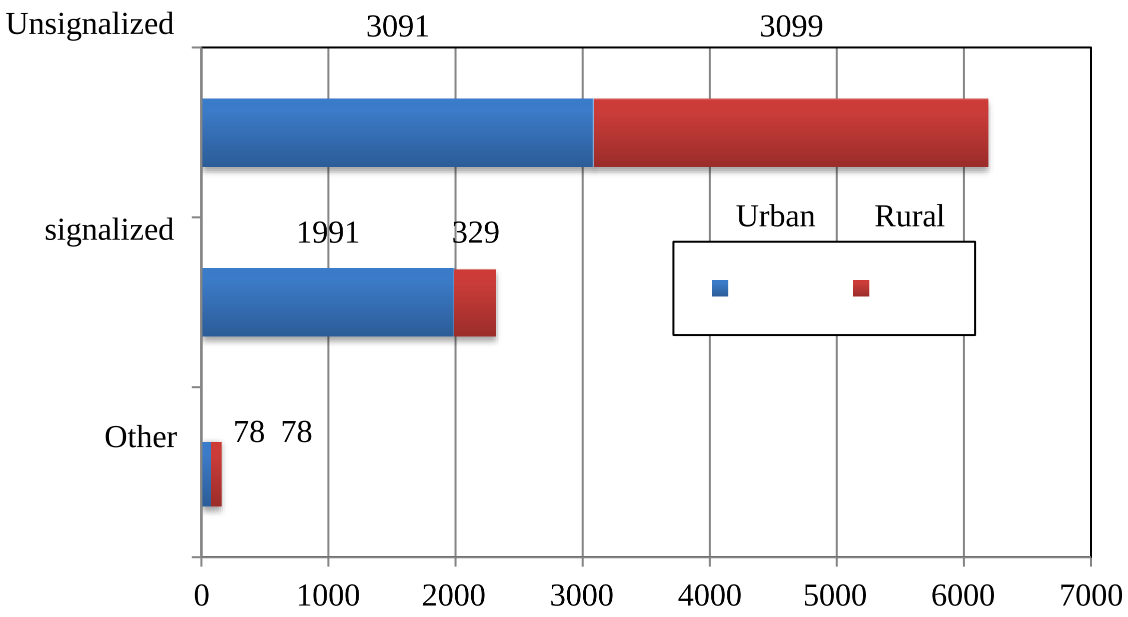


Figure 1 Intersection Fatalities in year 2007, USA (Source: US DOT 2012b)

Freeman et al. (2008) analyzed eighteen urban unsignalized intersections in the State of Florida and found that the most frequent crash types are:

- Rear end – principally occur during the recurring traffic congestion in the morning- and afternoon- peak periods and in urban environments.
- Left turn – high traffic demand resulting in queues from downstream signalized intersections blocking the median opening resulting in a pattern of left turn crashes.

- Angle crashes – high mainline volumes not generating enough gaps to safely accommodate the side street demand and not providing proper intersection sight distance.

At unsignalized intersections, where the installation of a traffic signal or roundabout is not warranted, a STOP sign is usually placed to request drivers to stop before proceeding, so as to control conflicting traffic movements. A STOP sign is dedicated to enhance the safety and/or assign right-of –way for a certain direction, which design and warrants is specifically described in Chapter 2B of the Manual on Uniform Traffic Control devices (MUTCD) (MUTCD, 2014).

By Retting et al. (2003), STOP sign violations accounted for about 70% of all crashes at STOP sign-controlled intersections during 1996-2000 in four U.S. cities. Typically, these crashes were angular collisions. Among crashes not involving STOP violations, rear- end crashes were most common, accounting for about 12% of all crashes. STOP sign violation crashes were classified into several subtypes - driver stopped, driver did not stop, snow/wet/ice, and other/unknown. In two-thirds of STOP sign violation cases, drivers were not aware of the STOP sign. In these cases, inability or failure to see approaching traffic often was cited as the cause of the crash. Drivers younger than 18 as well as drivers 65 and older were disproportionately found to be at fault in crashes at STOP signs. A Minnesota DOT study (Harder et al., 2003) also identified that 56% of right-angle crashes were caused by an inability to judge adequate gaps, and about 25% of the right-angle crashes were associated with a failure to stop on the minor roadway.

2.1.2 General Strategies to Improve Safety at Unsignalized Intersections

Since unsignalized intersections have a lot number of possible geometric and environmental configurations, no one treatment will be able to resolve all possible safety problems and in fact safety issues could potentially arise at intersections that match all of the related design standards (Freeman et al., 2008). Section V of the NCHRP report 500 describes a series of objectives and strategies to improve the safety at unsignalized intersections considering geometric design modifications, changes to traffic control devices, targeted enforcement efforts, and public education (Neuman et al., 2003). The following is a list of objectives.

Objective 17.1 A Improve management of access near unsignalized intersections

Objective 17.1 B Reduce the frequency and severity of intersection conflicts through geometric design improvements

Objective 17.1 C Improve sight distance at unsignalized intersections

Objective 17.1 D Improve availability of gaps in traffic and assist drivers in judging gap sizes at unsignalized intersections

Objective 17.1 E Improve driver awareness of intersections as viewed from the intersection approach

Objective 17.1 F Choose appropriate intersection traffic control to minimize crash frequency and severity

Objective 17.1 G Improve driver compliance with traffic control devices and traffic laws at intersections

Objective 17.1 H Reduce operating speeds on specific intersection approaches

Objective 17.1 I Guide motorists more effectively through complex intersections

The NCHRP report 500 (Neuman et al., 2003) proposes a lot of corresponding strategies to address above objectives. To create a truly comprehensive approach to the highway safety problems associated with this emphasis area, five additional strategies are recommended to be included as candidates in any program planning process: (a) public information and education programs; (b) enforcement of traffic laws; (c) strategies to improve emergency medical and trauma system services; (d) strategies directed at improving the safety management system; and (e) strategies that are detailed in other emphasis area guides.

2.1.3 Practical Issues at STOP Sign Controlled Unsignalized Intersections

One of the purposes of intersection control, including the STOP sign at unsignalized intersection, is to make sure that the stopping distance is sufficient for drivers to anticipate and avoid collisions. The American Association of State Highway and Transportation Officials (AASHTO, 2004) measure such a distance as the so-called Stopping Sight Distance (SSD). Another term of intersection Sight Distance (ISD) is measured along the major road beginning at a point that coincides with the location of the minor road vehicle.

Table 1 lists the stopping sight distance and design intersection sight distance with corresponding driving speed.

To enhance traffic operations, sight distance that exceed the recommended SSD are desirable. Note that design intersection sight distance criteria for stop-controlled intersections are longer than stopping sight distance to ensure the intersection operates smoothly.

Table 1 Stopping Sight Distance and Design Intersection Sight Distance

Speed (MPH)	Stopping Sight Distance (ft)	Design Intersection Sight Distance (ft)
25	155	280
30	**200**	**335**
35	250	390
40	305	445
45	360	500
50	425	555
55	495	610
60	570	665

Source: (AASHTO, 2004)

Poor visibility at street intersections would induce collisions that are normally accompanied with the loss of property and even human lives. There are serious crashes that occur because motorists cannot see oncoming traffic, or cannot see the traffic signs / signals when entering an intersection. However, a stop-controlled intersection could somehow be blocked by trees, big trucks or buses, glare, or other obstacles

Further, drivers neglect the STOP and other signs simply because they are tired, talking over the phone, listening to the music or radio, with negative emotion, etc. In other words, the drivers' awareness of STOP signs at unsignalized intersection is not sufficient if only rely on the physical static STOP signs and pavement markings.

Since the late of last centenary, various applications of novel technologies (e.g. communication, detection, control, signal processing, artificial intelligence, system engineering, computer engineering) in transportation have brought in revolutionary changes of traditional transportation systems. Under such situations, it is envisioned that proper applications of intelligent transportation system (ITS) technologies would potentially assist drivers' awareness of traffic signs at intersections and thus enhance the safety.

2.2 Short-range Wireless Communication System for V2I Communication

Vehicle-to-Infrastructure (V2I) communications realize the wireless exchange of critical safety information between vehicle and infrastructure so as to avoid or at least mitigate the vehicle to vehicle, or vehicle to person collisions, which has brought in tremendous attentions from public and private sectors. For example, the United States

Department of Transportation (USDOT) has launched a national program to enhance vehicle transportation through the applications of communication technologies known as IntelliDriveSM (succeeding the USDOT's VII - Vehicle-Infrastructure Integration, program). This system considers safety, mobility, and environmental improvements through a combination of vehicle-to-vehicle and vehicle-to-infrastructure communications. On the other hand, the fast developing wireless communication technologies provide many up-to-date innovative technologies that have the potential to improve the communications between vehicles and infrastructures. This research intends to review the available devices/systems that can be used for such applications. Possible candidates for dedicated short-range communication (DSRC) include Bluetooth, WIFI, Radio Frequency Identification (RFID), ZigBee, XBee and smartphone. The physical features, typical applications, advantages and disadvantages of these systems are tabulated and compared. Potential benefits of these devices are categorized into four subjects: (1) safety, (2) efficiency (3) enforcement, and (4) environment. Implementation plans and recommendations on how to use these DSRC devices to improve V2I communication are proposed.

2.2.1 Bluetooth

Bluetooth was invented by the Swedish company Ericsson, and was named after Harald Bluetooth, a legendary Nordic king of the late 1900s that all Swedes are taught about in grade school. Bluetooth is a technology that allows electronic devices to communicate without wires. It was designed for low power consumptions and is based on low-cost transceiver microchips. Bluetooth communicates using radio waves with frequencies between 2.402 GHz and 2.480 GHz which is within the 2.4GHz ISM frequency band, a frequency band that has been set aside for industrial, scientific and medical devices by international agreement. The Bluetooth specification was conceived in 1994 and is now managed by the Bluetooth Special Interest Group (SIG) (Chen, 2011, PP 158-166)

The first version of Bluetooth provided 1 Mbps speed, which is certainly enough for some applications, although the 3 Mbps provided by the second version are beneficial when more devices are connected and when the data requirements are higher, such as when connecting a printer or smartphone being used as a wide area network modem. Bluetooth is divided into three classes, class 1, class 2 and class 3, which range located from 100M, 10M and 5M. In order to avoid interference, Bluetooth uses spread-spectrum frequency hopping technology which makes it unlikely that two devices will transmit the same frequency and therefore minimizes the risk of interference.

Recently wireless positioning can be categorized as outdoor and indoor technologies. Outdoor positioning mainly uses satellites technology such as the well-known GPS (Global Positioning System) system to navigating (Razi and Kenichi 2011). However, a satellite based positioning system needs the tracking device to receive line-of-sight signals. If the satellite is deployed indoor, buildings may block signals, which will affect the accuracy.

Some popular methods of indoor wireless positioning system used different wireless communication protocols will be introduced as following

This first method is called as “Angle of arrival (AOA)” which is a geographic positioning method, also called the triangulation method. This system includes receiver and sender. The receiver uses a directional antenna or antenna array to measure the signal, which is received from a sender. Two such AOA measurements will be able to locate the target’s location (shown in Figure 2). For example, the received arrival orientation of signal determines the location of mobile devices shows in Figure 2.

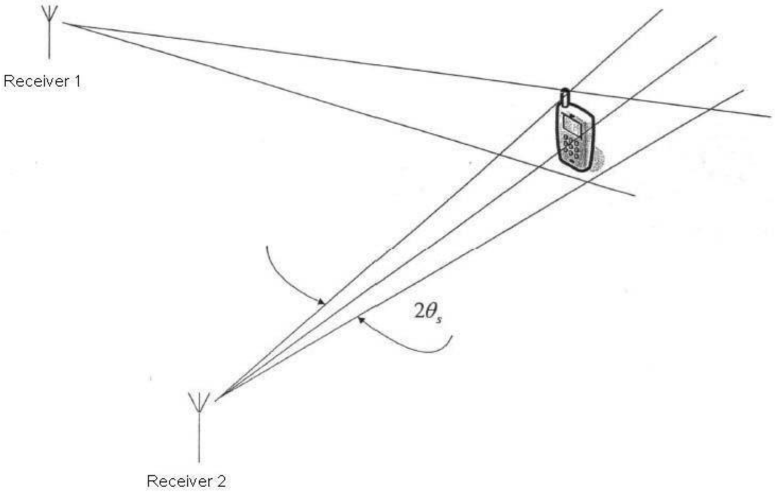


Figure 2 AOA geographic positioning technology

The major problem of this system is the accuracy of position, which is depended on the sender relative to the receiver’s position. Another situation is that if the sender is precisely in a straight line between the two receivers, the AOA measurement cannot detect the target’s location. Thus, usually more than two receivers, at least three of them, will ensure more accurate position. In indoor environment, because buildings and other adjacent objects will block the signal path, AOA technology is not applicable to indoor positioning system. Additionally, since AOA needs expensive antenna array at receivers to strong signal arrival orientation, therefore, it is not a good way for low-cost indoor applications at all. The second method is called as distance based triangulation, which is illustrated in Figure 3.

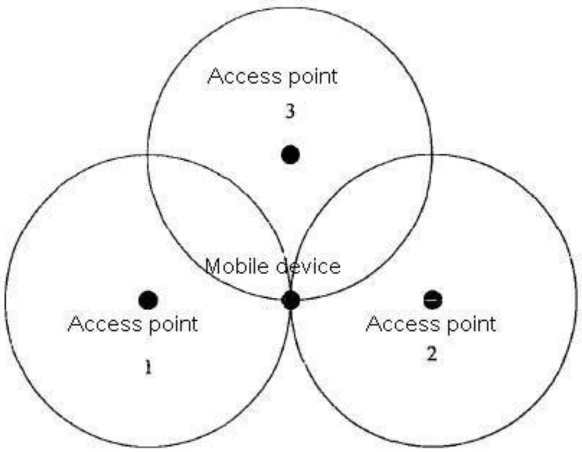


Figure 3 Magnetization as a function of applied field.

As Figure 3 shows, the distance between sender (Mobile device) and the receiver can be estimated by Received Signal Strength (RSS), time of arrival (TOA), received signal phases and other techniques. In order to estimate the accuracy location of mobile device in two-dimensional space, we at least need three measurements. If the estimated distance value between receiver and mobile device is d, mobile device can be positioned to a circle and the receiver as the centered, d as the radius of the circle. The second measure reduces the ambiguity of positioning, and the mobile device positioned in two crossing circular arc. The third measure locks the position of mobile device (Wang et al., 2011).

2.2.2 Wi-Fi

Another technology we used for short-range communication is Wi-Fi. Even though Wi-Fi does not really fit in the classification of short-range wireless system, since its application only as a general purpose wireless LAN and it always relies on a base station, Wi-Fi is very important as the standard against other unlicensed wireless communications. Short-range wireless systems have carved out niches beneath Wi-Fi, compensating for a lower bandwidth with significantly lower power consumption and smaller form factors, and also with niches above Wi-Fi's providing higher speed for specific applications. The IEEE 802.11 family is the king of the wireless LAN, and it does not seem like to reduce in rank from its current position as the protocol best suited to the moderate fast interconnection of a huge number of computers and shared devices, such as internet routers, printers and cloud servicer. Wi-Fi positioning systems (WPS) were established that rely on wireless access points for location coordinates. For the proper functioning of a wireless architecture, IEEE project 802 defined a standard which assigns a Media Access Control (MAC) address to local area network devices. In a WPS, the MAC address for a Wi-Fi access point becomes an index for a geo-location reference point. The Service Set Identifier (SSID) is an additional identifier for Wi-Fi access points. Collecting and locating Wi-Fi access points for a WPS database is the major method using Wi-Fi to locate (Ann and Cameron, 2011).

2.2.3 Radio frequency identification (RFID)

RFID is also a form short-range wireless communication device, but it is more oriented towards the identification of a nearby object (including animals and people) via its negative tag. Factors such as attenuation, cross paths of signals and interference from other RFID tags, RFID readers and RF devices, may affect the communication between the tag and RFID readers. Though there is some overlap at the higher level of RFID devices, the technology generally assumes that an RFID tag will be brought within a few centimeters of a reader in order to scan its specific and unique ID and possibly to obtain a small amount of additional information. By contrast, the general definition of short-range wireless devices assumes that devices communicate from a static location or anywhere within a certain radius of other short-range wireless devices and can communicate whenever the device decides that it needs to. Although RFID could be called "Ultra Short Range", it is really the nature of the application that is different (Lee et al., 2012). The extreme shortness of range is just a reflection of the need to bring an object near to a reader before communications can occur. RFID is most applicable when an object can easily be brought to a particular location to be scanned, such as an automated checkout counter at a supermarket, or a gate through which trucks enter and exit a port with tagged containers. A Radio Frequency Identification–Based Real-Time Locating System (RFID-RTLS) was proposed. The development of an RFID-based- RTLS has three aspects essential to a robust and accurate RTLS: localization methods, wireless networking technologies, and an Assistant Tag (AT) (Ham and Hargrove 2011). The localization method minimizes localization errors and retains high accuracy in localization against obstacles, whereas the wireless networking technology deals with data on a real-time basis and has a strong signal-transfer capability that could minimize information loss during signal transfer. In addition, the AT is a virtual reader that aims to maintain signal availability when many obstacles that hamper signal transfer are present. This section will discuss details about these three aspects and will be followed with a discussion on how the system has been developed (Ting et al., 2011 pp 9-15).

Several available localization methods include received signal strength indication (RSSI), time difference of arrival (TDOA), angle of arrival (AOA), time of flight (TOF), and TOA(lee, 2012). A full discussion of these localization methods is beyond the scope of this research, although the TOA method has been adopted in this research and so will be discussed further. The TOA method estimates the distance between reader and tag using

RF signaling speed and turnaround time of signaling between the two. Then this information is used to calculate the tag's location using a trilateration technique. The benefits of the TOA method are that its accuracy is not much affected by distance and that it is less influenced by a multipath effect. Also, the TOA method performs well in an NLOS environment and outdoors. As a result, it can have high accuracy in tracking object positions and has a large coverage area without being much affected by obstacles (Samsung,
2004, PP 33-39).

2.2.4 GPS based relative positioning methods

The positioning problem of interest herein is the estimation of 2-D inter-vehicle vectors to determine along and across track vehicle separations. The scope of the study was limited to the two-dimensional positioning performance analysis although the system used was capable of generating a three-dimensional solution, GPS being intrinsically a 3D system. The positioning performance criteria of relevance in the present context are availability, accuracy and reliability. The focus was to determine if and how GPS can achieve these requirements. GPS can be used in two modes, namely single point and relative. These are described in more detail later. In addition, two measurements are used for positioning, namely code (or pseudo-ranges) and carrier phase. The former are obtained through delay lock loops and are accurate to the sub-meter level but are affected significantly by signal reflection, also called multipath. The latter are obtained through phase lock loops and are accurate to a few mm and are minimally affected by multipath; however, they are ambiguous and carrier phase ambiguity resolution is a complex process that can successfully be achieved only under certain conditions (Williams et al., 2012).

In single point mode, a single receiver is used to provide positions. The accuracy of these positions is governed by numerous factors, namely satellite availability and geometry, receiver and antenna specifications, satellite errors, atmospheric effects and the multipath environment. Under ideal conditions whereby line-of-sight signals are available down to a few degrees above the horizon, single point accuracy is better than 5 m. With the use of the Wide Area Augmentation System (WAAS), which provides additional signals and corrections to GPS satellites from geostationary satellites covering North America, accuracy can reach 1–2 m with the appropriate receiver. These instantaneous position solutions are based on the use of code measurements.

V2V applications require relative positioning between two vehicles. There are three methods for determining the relative positions between two vehicles as shown in Figure 4. The single point positions between the two vehicles are exchanged and the relative positions are calculated as the differences between the positions. This method is referred to as the difference in position (DPOS). The typical position accuracies for DPOS depend primarily on the magnitude of the atmospheric errors and multipath errors, however the largest impact on position accuracy is the number of uncommon satellites used in each of the solutions (Maitipe and Ibrahim 2011). The typical position accuracies are 1–3 m.

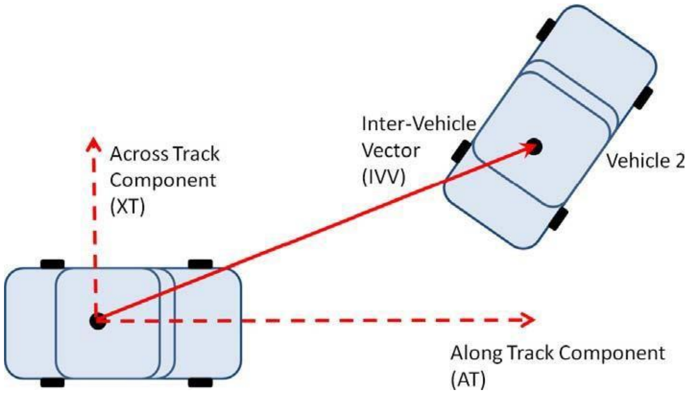


Figure 4 Inter-Vehicle Vector (IVV) defined as that from Vehicle 1 (the trailing vehicle) to Vehicle 2. The AT and XT components of the IVV were defined using the heading of Vehicle 1 which was obtained from that vehicle integrated GPS/INS system (Williams et al., 2012).

In the second method, the code measurements are exchanged between the receivers. The code measurements are differenced and then used to calculate the relative position. This method is called Differential GPS (DGPS). This has the significant advantage over the DPOS method of ensuring that only common satellites are used in the computation of the position solution. When common satellites are used in the DPOS method it performs similarly to DGPS. DGPS was not considered in this research because the performance was expected to be similar to DPOS with similar limitations as RTK, which has significantly better performance. When uncommon satellites are used then the DPOS method performs significantly worse than if only common satellites are used. This is because significant measurement errors for a given satellite will impact both receivers similarly and bias the solutions in the same way. Although this provides a biased absolute position error, the relative position error is unaffected. When an uncommon satellite is used the errors of this satellite will bias the position of one receiver and not the other. This causes an error in both the absolute and relative positions.

The third method is similar to DGPS except it uses the carrier phase measurements in addition to the code measurements. This method is called RTK. The carrier phase measurements are much more precise than the code measurements and therefore provide a much more accurate relative position. The disadvantage of this method is that both code and carrier phase measurements must be exchanged between the vehicles. This is significantly much more data than the position states required for the DPOS method. Time must also be given for determining the carrier phase ambiguities, which can be difficult if the vehicles are separated by more than a few tens of kilometers. Typical position errors are 0.2–1 m when the carrier phase ambiguities cannot be determined and as low as 0.01 m when the carrier phase ambiguities are known (Petty and Mahoney, 2007).

The second and third methods require the OTA sharing of additional GPS data using RTCM format messages (RTCMv3). These messages contain actual GPS carrier and code measurements. The size (bytes) of the additional message used in the test implementation is given by 8 + 7.25Ns, where Ns is the number of satellites observed by the vehicle GPS receiver (Maitipe et al. 2011 PP 67-73).

2.2.5 Zigbee

ZigBee is a short-range wireless technology from IEEE 802.15.4 family. ZigBee is low power and low cost as compared to other short-range wireless technologies of its class. Below is ZigBee comparison with other short-range wireless technologies.

ZigBee is low power and very inexpensive as compared to other short-range wireless technologies. ZigBee devices can work for years without worrying about replacing batteries, which makes it an excellent choice to be used in mountainous areas where power is a major concern.

Below are the major reasons why ZigBee is considered for such system;

- ZigBee is Low cost
- Data rate is enough to transfer information between Car and the Hurdle.
- ZigBee is not much affected by the signals of other short-range wireless technologies.

2.2.6 Comparison of Short-range Wireless Communication Systems

ZigBee (IEEE 802.15.4) and Bluetooth (IEEE 802.15.1) are designed for wireless personal area networks (WPANs) with smaller coverage area and lower power consumption. ZigBee operates at the frequency spectrum of 902 to 928 MHz and 2.4 GHz, whereas Bluetooth operates at 2.4 GHz. The transmission range of ZigBee is 100 m, while that of Bluetooth is only 10 m. On the other hand, the data rate of ZigBee is only 20 to 250 kbps, while that of Bluetooth is 1 Mbps. Because of their low data rates and transmission range, these protocols are not considered for vehicle networks.

2.3 Inspiration from Reviewed Literatures

From literature review, it is concluded that, conventional ways are not able to so efficiently enhance the driving performance of vehicles approaching a STOP sign controlled unsignalized intersection. One of the feasible ways is to develop a suitable short-range wireless communication between in-vehicle devices and roadside devices with a certain identification preset as for STOP signs. In this way, the drivers' performance could be greatly improved.

CHAPTER 3

DESIGN OF THE STUDY

3.1 Design Concept

The developed smart warning system in this research uses the low-cost RFID devices that are able to set up a short-range communication between in-vehicle devices and roadside devices with a certain identification preset as for STOP signs. Once the in-vehicle devices detected the occurrence of the signal representing the STOP sign, a warning signal is sent to the drivers via either the in-vehicle display device or audio warnings.

A Global Positioning System (GPS) could be accompanied with such detection and warning system. GPS can not only help the RFID devices to identify which STOP sign signal applies to the driver, but also assist in providing warning information through image and/or verbal prompts.

3.2 Functions and Components of RFID

RFID is a set of wireless devices that stores and retrieves data remotely. The technology allows sensitive information to be read and written to tags and for numerous tags to be scanned simultaneously from a distance. In a typical RFID system, individual objects are equipped with a small, inexpensive tag that contains a transponder with a digital memory chip and a unique electronic product code. The RFID reader, which is an antenna packaged with a transceiver and decoder, emits a signal activating the tag so it can read and write data to the tag. The reader decodes the data in the tag's integrated circuit, and that data is then passed to a host computer's database for processing. Figure 5 illustrate the components of an RFID system.

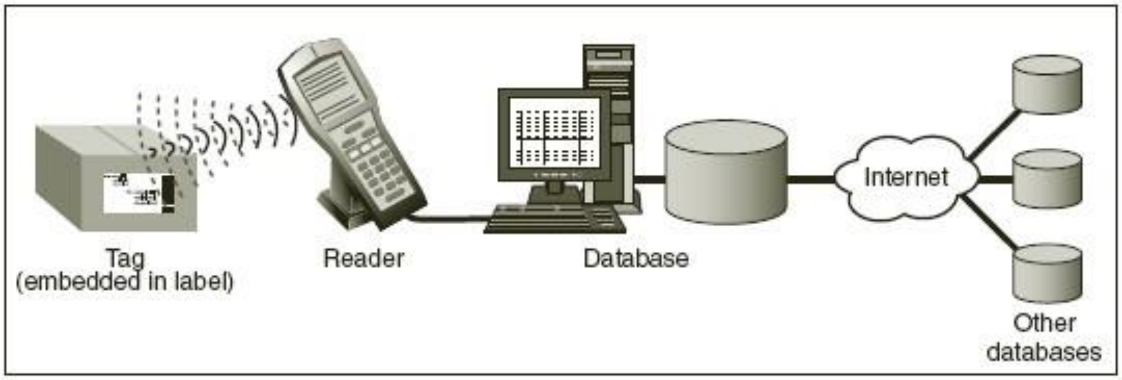


Figure 5 Components of an RFID System (Source: US GAO, 2005)

There are three types of tags in use today: (1) Active tags - store large amounts of information using a power source within the tag; (2) Passive tags - no separated external power source but rather obtain operating power from the tag reader; and (3) Semi-passive tags - use an internal power source to monitor environmental conditions, and require radio frequency energy transferred from the reader to power ta tag's response.

RFID has introduced new technology to various fields including transportation engineering. The flexibility and portability of RFID technology and devices increase the need for movement. A U.S. Government Accountability Office (GAO) report published in May 2005 states that "… *Without effective security controls, data on the tag can be read by any compliant reader; data transmitted through the air can be intercepted and read by unauthorized devices; and data stored in the databases can be accessed by unauthorized users*." (US GAO, 2005)

Kotchasarn reported an RFID-based in-vehicle alert system to alert vehicle drivers about road signs at an optimum distance before encountering them. These road signs are generally scattered, inconspicuous and appear too late for corrective action, also this device will aid in averting accidents and traffic jams, and in implementing traffic law and order (Kotchasarn, 2009). It enables transmission of important data to the vehicles within an effective non-line-of-sight (NLOS) distance.

Paul et al. (2011) tested an RFID enabled system that delivered prior alerts for all nuances of road oddities on an on-board LCD display with voice capability. A low frequency reader (135 KHz) was used with a read range of 10 cm and the RFID readers were equipped on the underside of the model vehicle. This research however did not conduct any on-road test using real vehicles.

3.3 Using RFID to Communicate between Vehicles and STOP signs

Qiao et al. proposed a RFID based smart guide signing system (Qiao et al., 2012a) as is illustrated in Figure 6, and have conducted on-road on the range of RFID tags (Qiao et al., 2012b), together with a pilot test for the impact of RFID-based e-STOP sign on vehicle emissions.

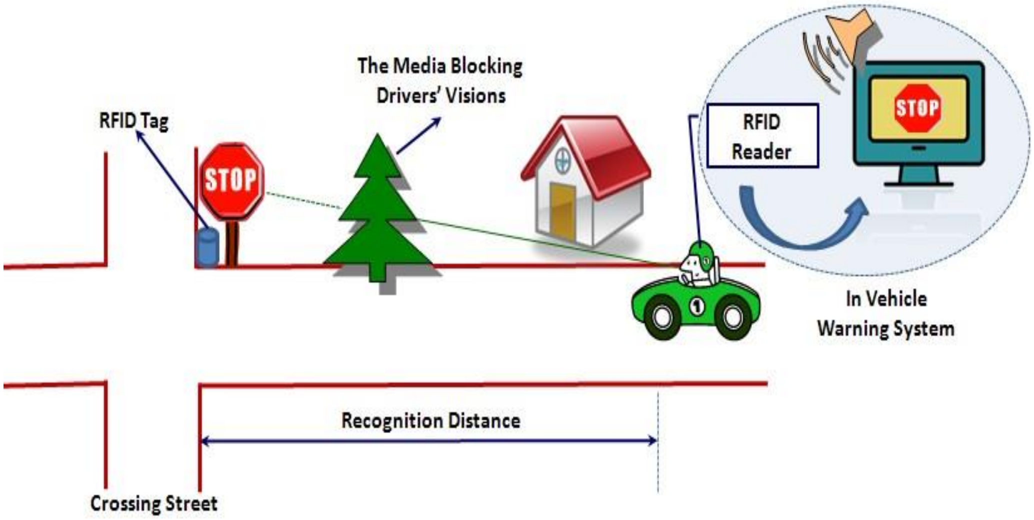
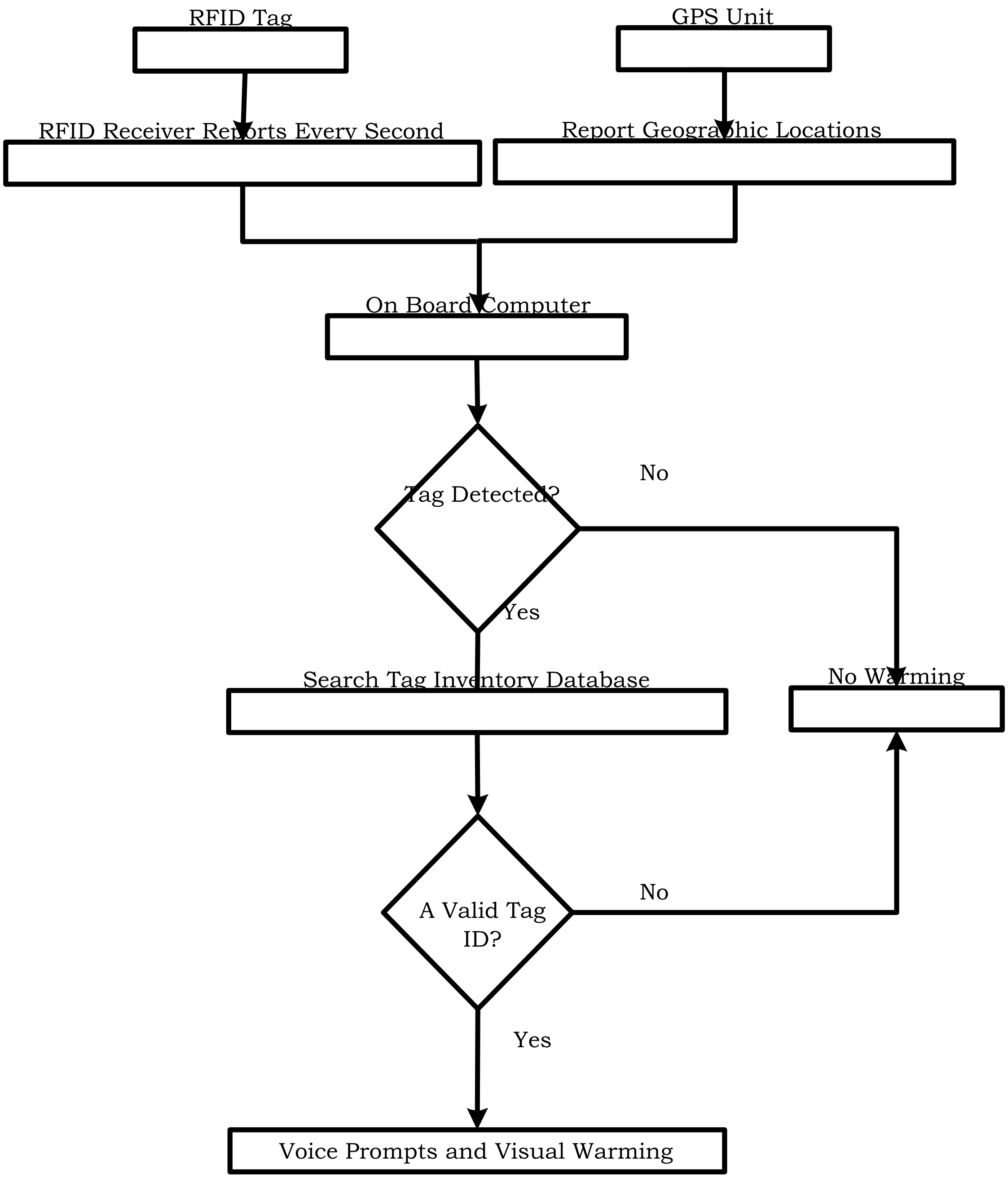


Figure 6 The Illustration of a RFID Based Smart Signing System (Source: Qiao et al., 2012a)

The active RFID tags are mounted on the roadside, while the readers were placed within vehicles. Each RFID receiver transmits one set of unique identification number that can be detected by the receiver(s) inside the vehicle that are located upstream of traffic flow from a certain distance away. The data can be further recognized by the in-vehicle signal-processing component, which can convey the represented message (here: STOP) to drivers through on-board display system or in-vehicle audio system. In (Qiao et al., 2012a; Qiao et al., 2012b; Qiao et al., 2012c) however, there were no detailed reports and analyses on how the vehicle trajectories, speeds and accelerations would be affected by using this system, and thus what are the relevant impacts on safety and air quality.

3.4 Pilot Test of Drivers Smart Assistance System

In this research, a Driver Smart Assistance System (DSAS) was developed including the RFID tags and readers, a GPS device, and a laptop computer. The tag that represented a STOP sign was placed on roadside nearby a real STOP sign, while the rest (RFID readers, GPS, and the laptop) were carried onto test vehicles. The system block diagram is in Figure 7 (a). A computer program compiled in Visual Basic (VB) was developed with a Graphical User Interface (GUI) as is illustrated in Figure 7 (b). The GPS device helps to identify vehicle’s actual longitude and latitude.



(a) The system block diagram of the developed RFID based DSAS

TAGS DETECTED

21:36:17

(b) The display of warning message of the DSAS

Figure 7 The Developed Driver Smart Assistance System (DSAS) providing STOP sign message

The RFID readers could sense the tag that was placed nearby the real STOP sign if the test vehicle is within the working range of RFID tag-reader pair. Through proper decoding to the detected RFID code, the DSAS would translate such code into an image of STOP sign and display such image on interface of the program. In the meantime, a verbal warning to the driver “STOP SIGN AHEAD!” also prompted so that the driver could be aware of the STOP sign placed ahead.

The awareness distance (i.e. the distance between the location when the warning message was conveyed to drivers and the stop line of the unsignalized intersection) should meet with the requirements in relevant guidelines such as the MUTCD and AASHTO guidebooks. In the pilot test in this research when the vehicles were driving along the local streets with a speed limit of 30 mph, the awareness distance for DSAS was set as 350 ft, which satisfies both the Stopping Sight Distance (200ft) and the Design Intersection Sight Distance (335ft) under such speed limit in Table 1.Also vehicles equipped with RFID readers traveling on the main road will not receive any signal from on-side street intersections.

3.5 Test Design

The pilot real road tests were conducted in a residential area nearby Downtown Houston and the two pilot test routes are illustrated in Figure 8. All test vehicle departed from point A and terminated at point B in the two test routes.

(a) Test Route 1

(b) Test Route 2

Figure 8 Road Test Locations

Test Route 1

In Figure 8 (a) for route 1, the vehicle departed from point A traveling along Cleburne Street, where no STOP sign was displayed in the downstream intersection (Cleburne Street and Delano Street, which is marked with a RED circle in Figure 8a). Vehicles should make four continuous right turns at Delano Street, Isabella Street, Ennis Street and Cleburne Street. After returning back to Cleburne Street, the vehicles should make three continuous left turns when meeting Delano Street, Eagle Street, and Ennis Street. An RFID-equipped STOP sign was installed in RED circle intersections.

The drivers were asked to drive along the above mentioned route for two rounds. For the first round, the vehicles would not stop at the intersection Cleburne Street and Delano Street. It is simulated that the STOP sign at this particular intersection (Cleburne Street and Delano Street) was completely blocked by an unknown obstacle.

For the second round, the drivers were prompted with an image and verbal warning message (“STOP sign ahead”) 350 ft ahead of the intersection Street and Delano Street (the red circle in Figure 5(a)). If the warning message could really warn drivers about the STOP sign information, this situation should yield out the effects of the DSAS.

Test route 2

In Figure 8 (b), test route 2 covers a bigger area than that for test route 1, but in the same location. Route 1 actually located in the right bottom part of route 2. The drivers were asked to drive along the plotted paths from point A to point B, meeting four right turns and three left turns. Three RFID tags were installed at the intersection of Live Oak street and Wheeler Street, Barbee street and Eagle street, Live Oak street and Cleburne street.

Again, the drivers were asked to drive route 2 for two rounds. For the first round, there is no in-vehicle warning to drivers, while for the second round, the DSAS would be in effect by providing suitable warnings before the vehicles entered the STOP signs controlled unsignalized intersections.

3.6 Test Subjects

A total of 20 subjects with valid driver licenses were recruited to conduct road tests. The selection of the 20 subjects followed Houston's demographical data from 2010 U.S. Census (2010). Table 2 lists how the gender, age, and educational level of the subjects fitted for the Houston 2010 Census data.

Table 2 Gender, Age and Education Distribution of the Subjects for On Road Test

Subject	**Gender (%)**		**Age (%)**			**Education Background (%)**	
	Male	Female	15-24	25- 64	65 +	High school and Associate Degree	Bachelor's degree or higher

Houston 2010 Census data	49.9	50.1	19.3	69.4	11.4	73.4	27.6
Adjusted Distribution	50.0	50.0	20.0	70.0	11.0	70.0	30.0
Test Drivers	**10**	**10**	**4**	**14**	**2**	**13**	**7**
Total	**20**		**20**			**20**	

3.7 Testing Procedure

All road tests were arranged between 10am to 12pm, or 3pm to 5pm. Also drivers were recruited based on what is indicated in Table 2. No advanced notice on the test routes was provided to each driver before road test.

In Figure 8 (a) for route 1, the distance between start point A and the first intersection (Cleburne Street and Delano Street) is 620 ft. After making right turns, there are another 280 ft to drive before reaching the next intersection. The moving of a vehicle within this entire range (620ft+280ft=900ft) is considered as the entire test of this particular intersection.

Each driver was instructed to drive two rounds along route 1: first without RFID, second with RFID. To collect test drivers' normal reaction, rather than surprising response to the DSAS system, test drivers were informed that the RFID would be activated right before the second round.

Since there is actually no STOP sign (also no traffic light) at the intersection Cleburne Street and Delano Street, all vehicles never stopped before any further manipulations (e.g. left turn or right turn) were in actions.

In Figure 8 (b) for test route 2, the drivers were instructed to drive two rounds as well. In the first round, there was no any warning message prompted. In the second round however, the DSAS was in act and provide necessary message “STOP SIGN AHEAD” to warn drivers so that they could decelerate earlier and finally stopped in front of the stop line of the downstream intersection.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Defining Performance Measures

The influences of the DSAS on driving performance were thus measured within the distance that DSAS can provide messages, in terms of the approaching speed profiles, the acceleration rates, and the braking distance to a STOP sign.

The vehicles' geo-location information was recorded for each second together with the needed speed, acceleration rates, and braking information. These time domains based second-by-second information were converted into the space domain based meter-by- meter information through a proper interpolation procedure. By such, the approaching speed profile can be measured as the mean driving speeds of all drivers at each meter along the road approaching the STOP sign intersection.

Similarly, the drivers' mean acceleration rates and braking distance were analyzed also in this way as well. Drivers' statistically significant differences in their driving performance with and without the aid of the DSAS were assessed by t-tests. The confident level of 0.05 is defined for statistical significance.

4.2 Comparison of Speed Profiles

The DSAS messages may influence drivers' driving speed to approach the upcoming STOP sign intersection. The change in drivers' speed at two critical points was measured. The first point was the location where they received the DSAS message, approximately 350 ft toward the intersection; another one was the location where they might prepare for turning movement, about 50 ft toward the intersection. Drivers' mean speeds passing by the two points are illustrated in Figure 9.

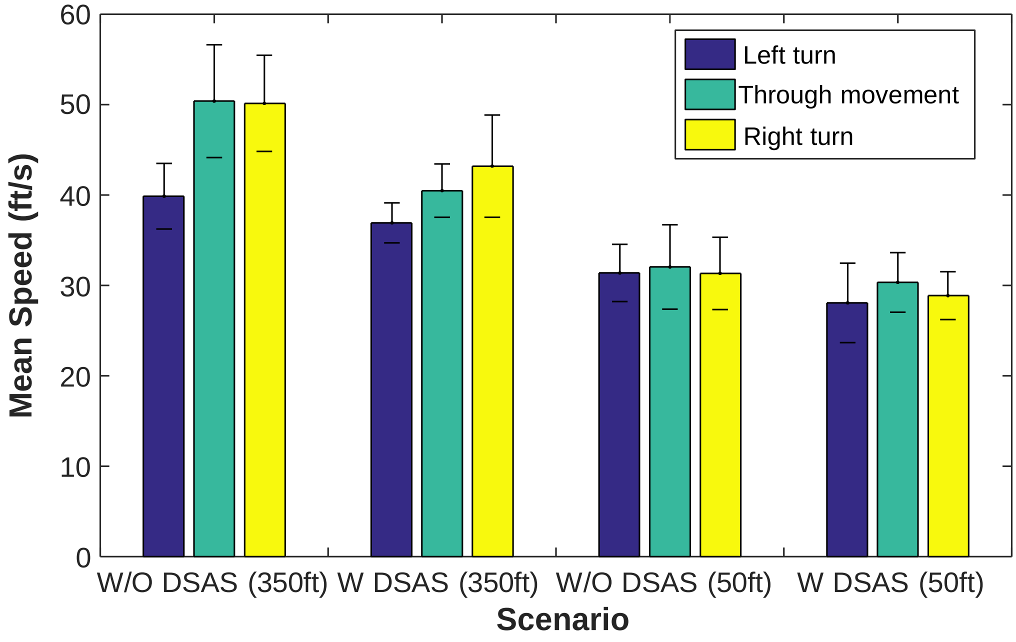


Figure 9 Mean approaching speeds at 350 ft and 50 ft toward the upcoming intersection in the two scenarios with and without the DSAS messages

At first glance, with the DSAS message, drivers' mean speeds (the bars under W DSAS 350 ft and 50 ft) were visibly lower than without the message at the two critical points. The difference at the distance of 350 ft was more obvious than that of 50 ft. The DSAS messages induced lower mean speeds by about 3-10 ft/s. More specifically, without the DSAS messages (W/O DSAS 350 ft), the speeds were 39.8±3.6 ft/s, 50.4±6.2 ft/s and 50.1±5.3 ft/s for left turn, through movement, and right turn, respectively. When the DSAS message was triggered (W DSAS 350 ft), the speeds decreased to 36.9±2.2 ft/s, 40.5±2.9 ft/s, and 43.2±5.6 ft/s, respectively.

At the distance of 50 ft, the difference in the mean speed caused by the DSAS message became little, between 2-3 ft/s. Specifically, without the DSAS message (W/O DSAS), mean speeds at the two critical points were 31.4±3.2 ft/s, 32.0±4.7 ft/s and 31.3±4.0 ft/s for left turn, through movement, and right turn, respectively. When the trigger of the DSAS message was on (W DSAS), the speeds declined to 28.0±4.4 ft/s, 30.3±3.3 ft/s, and 28.9±2.6 ft/s for left turn, through movement and right turn, respectively.

The statistically significant difference in the approaching speed profile caused by the DSAS message was examined by t-test. Table 3 illustrates the t-test results for the approaching speed profile of 350 ft and 50 ft toward the STOP sign.

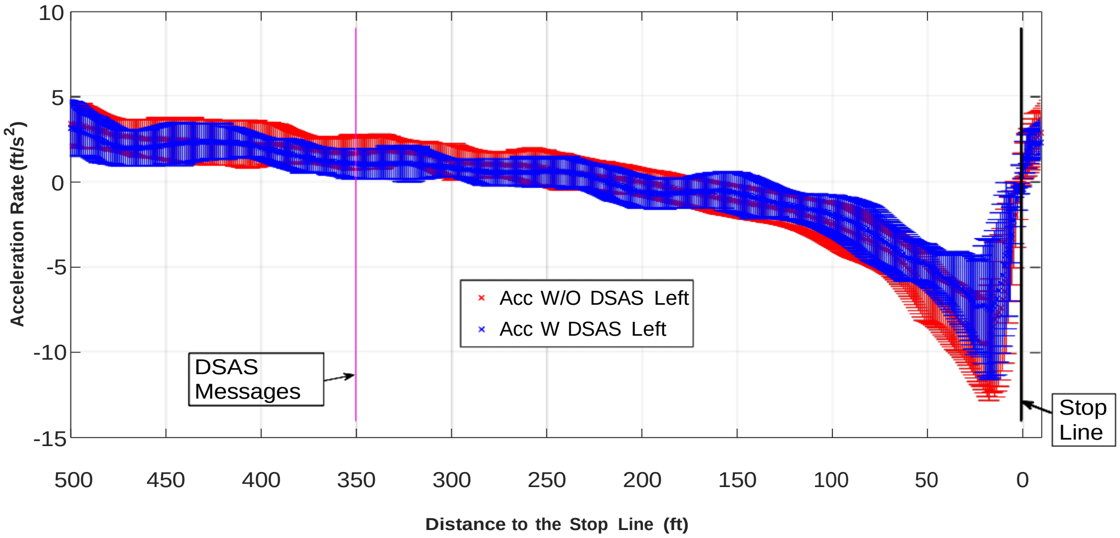
Table 3 t-test Results for the Speed Profile in the Scenarios with and without DSAS Messages within 350ft and 50 ft Towards Intersections

Distance	**Turning Movement**	***t***	***P*-two tail**	**Significant**
350 ft	**Left Turn**	70.91	2.5E-209	Yes
	Through	38.23	8.3E-127	Yes
	Right Turn	47.80	3.1E-155	Yes
50 ft	**Left Turn**	11.32	2.09E-15	Yes
	Through	2.55	1.385E-2	Yes
	Right Turn	11.01	5.64E-15	Yes

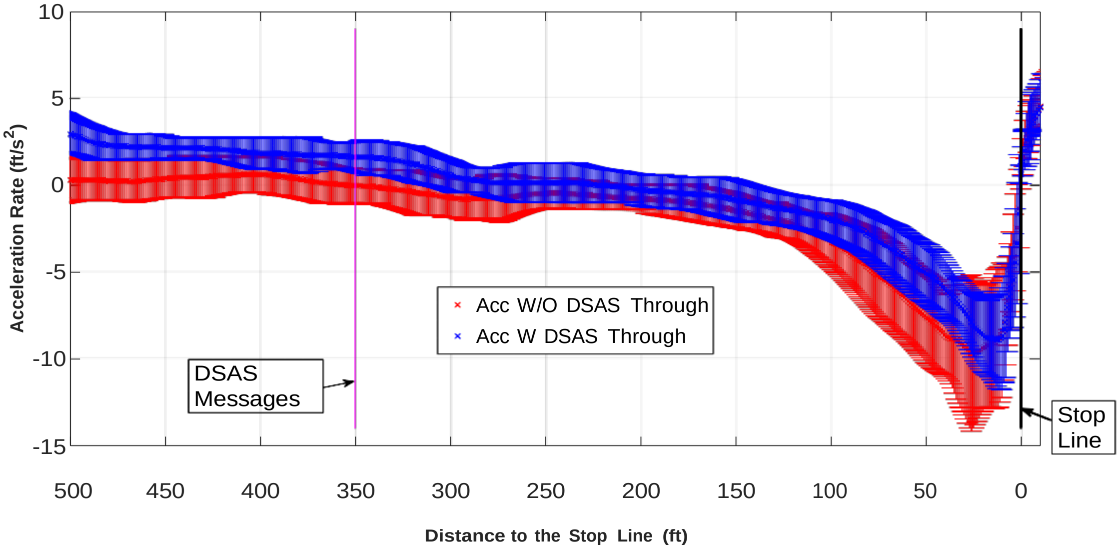
Table 3 shows that there are significant differences in the approaching speed profile between the scenario with and without the DSAS message for all turning movement. In other words, the DSAS message influenced drivers' entire approaching speeds positively, not only the moment that they received the warning.

4.2 Comparison of Acceleration Rates

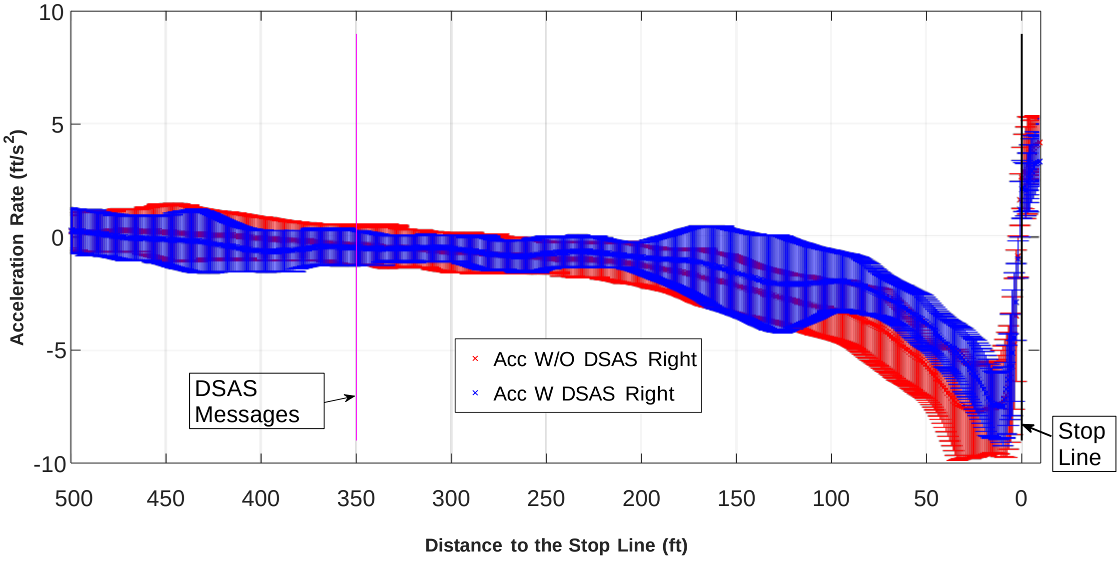
To further gain an insight into the impacts of DSAS messages on vehicle operations, the profiles of accelerations for all turning movement are plotted in Figure 10. The red crosses are the acceleration rates profile from the scenario without DSAS message, while the blue cross from the scenario with the DSAS message. The light pink and light blue shadow areas indicate their standard deviations.



(a) Left turn



(b) Through movement



(c) Right turn

Figure 10 The Acceleration Profile with and without the DSAS Messages.

General speaking, beyond the distance of 350 ft to an intersection, the red and blue cross are similar and close to each other for left and right turn. For through movement, the accelerate rates in the scenario with the DSAS (blue crosses) are apparently higher than with the DSAS (red crosses). Bear in mind that the mean driving speed in this scenario is obviously lower, as shown in Figure 10 (b). It seems that test drivers were trying to keep low driving speed by an accelerate-then-braking maneuver, with which action drivers can gain sufficient time to respond to any surprising traffic situations ahead for safety purpose.

Within the distance of 350 ft toward an intersection, the red crosses gradually changed to locate below the blue ones for the three turning movements. This implies that the DSAS messages induced drivers to decelerate earlier and harder. It is noticing that, there is a greater variation (the red shadow area) in Figure 10(c) on right turn between the distance of 200 ft and 100 ft. Drivers' hesitation whether accelerating or decelerating to approach the intersection may be responsible for the greater variation. For the same situation, drivers' hesitation does not present in the scenario with the DSAS. In other words, with the aid of the DSAS, drivers are confident in their driving maneuver.

Furthermore, Table 4 shows that the mean standard deviations in the scenario with the DSAS messages were smaller than the scenario without the DSAS in the approach profile between 350 and 51 ft as well as between 50 and 0 ft toward the stop line. The statistical difference in the standard deviations were further assessed by t-test and shown in Table 5.

Table 4 Mean Standard Deviations of Acceleration Rates with and without DSAS Messages.

Turning Movement	**350-51 ft distance**		**50-0 ft distance**	
	W/O DSAS	**W DSAS**	**W/O DSAS**	**W DSAS**
Left turn	0.976	0.965	2.432	2.386
Through	1.215	1.063	3.202	2.056
Right turn	1.049	1.045	2.056	1.454

Table 5 The t-test Results for Acceleration Rates and Standard Deviations with and without DSAS Messages

Turning Movement	**Measured Profile**	**Acceleration rates**			**Standard Deviation**		
		t	***P*-two tail**	**Significant**	***t***	***P*-two tail**	**Significant**
Left Turn	350-51 ft	-6.01	4.68E-09	Yes	1.77	7.70E-02	No
	50-0 ft	-9.89	2.94E-13	Yes	-1.57	0.12	No
Through	350-51 ft	-20.02	6.19E-60	Yes	6.24	8.21E-10	Yes
	50-0 ft	-2.60	1.24E-2	Yes	3.48	7.30E-04	Yes

Right Turn	350-51 ft	-15.06	7.87E-40	Yes	0.84	0.40	No
	50-0 ft	-17.43	1.19E-22	Yes	4.96	2.93E-06	Yes

Table 5 shows that there were statistically significant differences in acceleration rates for all turning movements in the travel profile between 350 ft and 51 ft and between 50 ft and 0 ft, whereas the difference in the standard deviations were not all significant.

More specifically, significant difference in standard deviations were only observed on the through movement for the two measured profiles (350-51ft: p-value=8.21E-10; 50-0ft: 7.30 E-04) and the right turn for the travel profile between 50 and 0 ft to the stop line (p-value= 2.93E-06). No significant difference was found for the left turn (350-51ft: p-value= 7.70E-02; 50-0ft: 0.12) and the right turn for the travel profile between 350 and 51 ft (p-value=0.40). In other words, the DSAS messages can help drivers to accelerate smoothly, which is reflected by the smaller fluctuations, particularly on the through movement and the right turn approaching to a stop line. The impacts of the DSAS messages on the left turn were insignificant. Therefore, the DSAS messages were able to induce drivers to drive smoothly with significant less acceleration.

4.4 Comparison of Braking Distances

The braking distance in this research is defined as from the location where the DSAS messages were (or supposed to be) provided to the location when drivers started to decelerate within the message effective zone (i.e. within 350ft towards intersections). The braking distances for all turning movement in the scenarios with and without DSAS messages are listed in Table 6.

Table 6 Average Locations when Vehicles Start to Decelerate after Receiving the DSAS Messages (unit: ft)

Scenario	**With DSAS**			**Without DSAS**			**Change in Braking Distance**
Turning Movement	**Average Location to Decelerate**	**Standard Deviation**	**Braking Distance**	**Average Location to Decelerate**	**Standard Deviation**	**Braking Distance**	
Left Turn	274	28.35	76	238	26.76	112	36
Through	271	24.06	79	232	31.87	118	39
Right Turn	258	21.82	92	237	32.42	113	21

In Table 6, across the three turning movement, the average locations to decelerate in the scenario with the DSAS messages are apparently farther to a STOP sign controlled intersection. With the DSAS message, drivers started earlier to decelerate for the upcoming intersection, which is consistent with the finding from the acceleration performance mentioned above. The difference between the two scenarios were 36 ft, 39 ft, and 21 ft for left turn, through movement, and right turn, respectively.

4.5 Drivers' Feedbacks from Survey

Right after completing the driving test, a survey form was distributed to all test drivers to inquire their opinions and preferences to the DSAS. In total, there are 19 questions in the survey, which are mainly related to whether the DSAS could improve their driving behavior, whether the DSAS was useful, and whether they would use the DSAS, if it was available? About 95% (19 out of 20 in total) of the test participants thought the DSAS message was extremely useful. Most of them (18 out of 20) believed that audio warning message is better than visual warning for safety concern. All (20 out 20) participants believed that the DSAS did not cause any confusion or stressful to them. About 85% (17 out of 20) of participants preferred to follow the instruction from the DSAS messages, while operating vehicle, in order to be aware of the traffic situation better and gain time to respond to the situation earlier. All of the participants agreed that the DSAS provides clear warnings and guidance and is worth to place it in vehicle.

4.6 Impacts on Vehicle Emissions

Based on binning standard of the EPA's new emission estimation model MOtor Vehicle Emission Simulator (MOVES) in Table IV (US EPA, 2002), the VSP distribution and the associated emission rates in the operating mode 30 bins were calculated. The information of the test vehicle is listed below.

- Modal: Nissan Altima
- Year: 1999
- Mileage: 80,000 mile

The emission rates used for emission estimation in this research was derived based on the properties of this vehicle, where the emission database were prepared though the various on-road test to this vehicle using the Portable Emission Measurement System

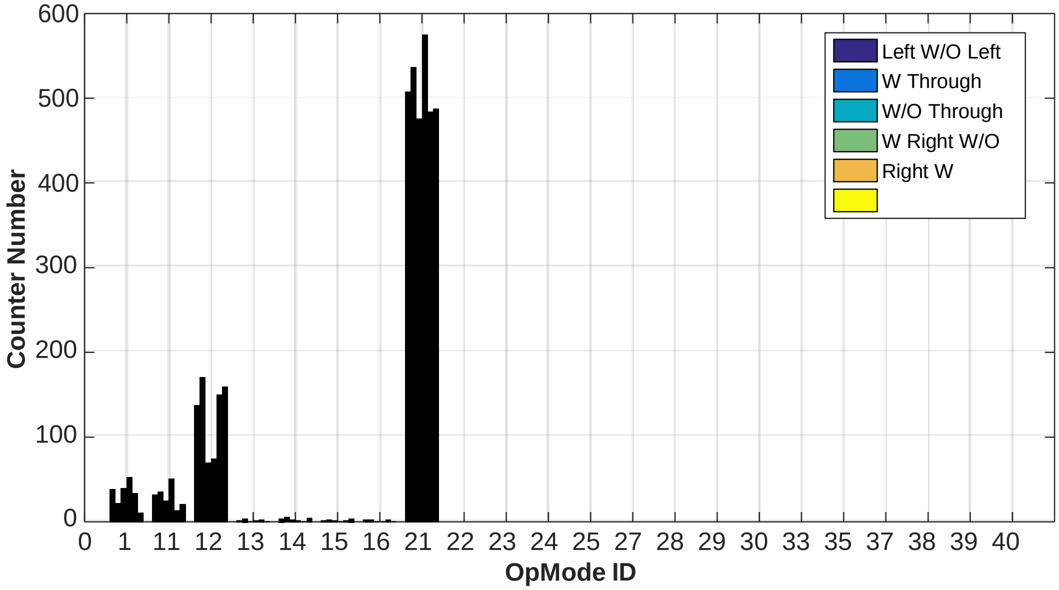
(PEMS). The OpMode ID and the emission rates used for emission calculation are listed in Table 7 (Tao et al., 2011).

Table 7 Operating Mode ID and Emission Rates (Source: Tao et al., 2011).

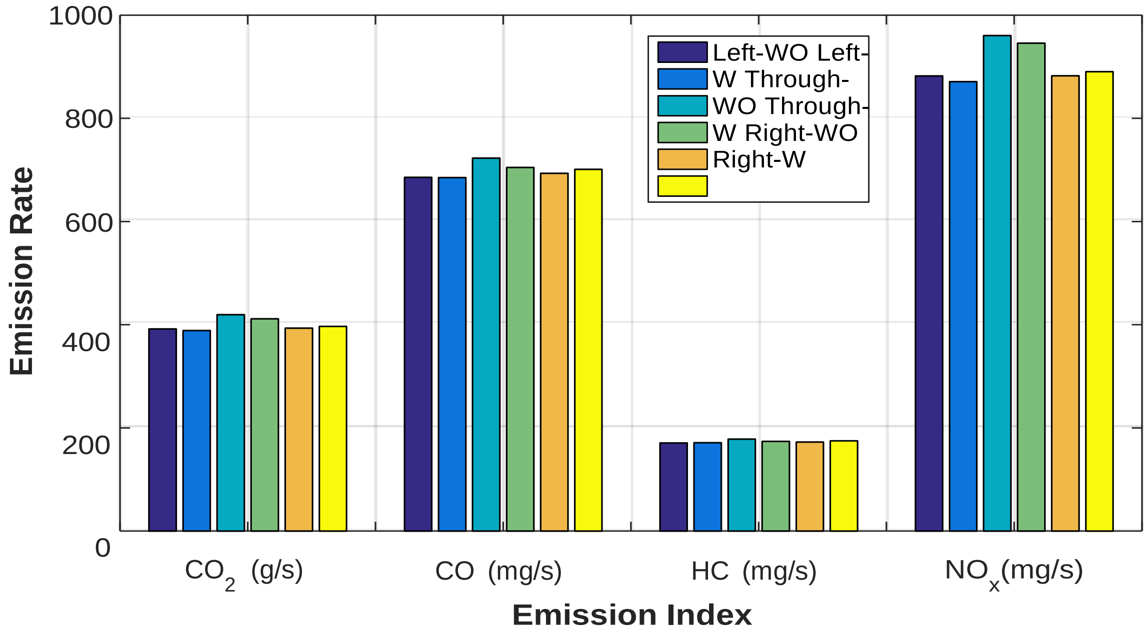
opModeID	Operating Mode Name	Frequency (%)	CO_2 (g/s)	CO (mg/s)	HC (mg/s)	NO_x (mg/s)
0	Braking: Acceleration<-2 mph/s, or<-1 mph/s for 3 consecutive seconds	9.7152	0.919917	1.487536	0.367345	1.044941
1	Idling: -1<=Speed<1	38.2848	0.819847	0.393507	0.267676	2.141207
11	Low Speed Coasting: VSP<0; 1<=Speed<25	3.808	1.175464	3.233798	0.987479	1.155647
12	Cruise/Acceleration: 0<=VSP<3; 1<=Speed<25	7.1744	1.790468	5.660321	1.243497	2.076512
13	Cruise/Acceleration: 3<=VSP<6; 1<=Speed<25	5.056	3.014824	7.76362	1.605278	2.92462
14	Cruise/Acceleration: 6<=VSP<9; 1<=Speed<25	4.6848	4.094227	6.934645	1.560997	4.633115
15	Cruise/Acceleration: 9<=VSP<12; 1<=Speed<25	1.8368	4.832245	8.338537	2.021707	6.973868
16	Cruise/Acceleration: 12<=VSP; 1<=Speed<25	0.576	5.076952	8.624111	2.088111	11.948889
21	Moderate Speed Coasting: VSP<0; 25<=Speed<50	3.2064	1.270065	4.522635	0.866627	0.763174

22	Cruise/Acceleration: 0<=VSP<3; 25<=Speed<50	3.904	1.853479	4.782885	1.256803	0.975984
23	Cruise/Acceleration: 3<=VSP<6; 25<=Speed<50	2.9376	2.885862	13.042658	2.352288	1.900087
24	Cruise/Acceleration: 6<=VSP<9; 25<=Speed<50	2.4704	3.369477	7.837228	1.980389	2.870155
25	Cruise/Acceleration: 9<=VSP<12; 25<=Speed<50	1.8624	4.141253	17.379759	3.429588	5.018007
27	Cruise/Acceleration: 12<=VSP<18; 25<=Speed<50	1.4144	4.980276	11.994299	2.628869	8.560814
28	Cruise/Acceleration: 18<=VSP<24; 25<=Speed<50	0.1856	6.124917	17.021034	4.126897	15.96069
29	Cruise/Acceleration: 24<=VSP<30; 25<=Speed<50	0.0256	5.3957	80.1975	19.0225	10.715
30	Cruise/Acceleration: 30<=VSP; 25<=Speed<50	0.0192	3.700133	3.153333	0.896667	5.52
33	Cruise/Acceleration: VSP<6; 50<=Speed	2.5408	3.435962	4.941839	1.08801	2.731965
35	Cruise/Acceleration: 6<=VSP<12; 50<=Speed	5.4656	4.529078	5.790972	1.450433	3.744169
37	Cruise/Acceleration: 12<=VSP<18; 50<=Speed	2.7648	5.077762	6.476736	1.678218	5.565324
38	Cruise/Acceleration: 18<=VSP<24; 50<=Speed	1.5616	5.439107	5.927131	1.693074	6.435246
39	Cruise/Acceleration: 24<=VSP<30; 50<=Speed	0.3136	5.965447	7.944694	1.97102	8.029796
40	Cruise/Acceleration: 30<=VSP; 50<=Speed	0.192	5.097057	6.474	1.709333	8.066

Figure 11(a) illustrates the distribution of the OpMode IDs, while Figure 11(b) shows the emission rates of the four environmental indexes, including CO_2, CO, HC, and NO_x.



(a) Distribution of OpMode IDs



(b) Emission Rates

Figure 11 Estimated Vehicle Emissions during the Tests

In Figure 11 (a), the OpMode ID mainly distributed in the ID of 1, 11, 12, and 21 in the two scenarios (W/O and WO DSAS), which indicate the status of idling, coasting at low speed (<25 mph), cruise/acceleration, coasting at moderate speed (25-50 mph), respectively. In particular, the ID of 21 occupied the most, followed by the ID of 12. It seems that the DSAS rarely induced the switching of OpMode ID distribution, which could be resulted from the change in drivers’ travel pattern.

In terms of emission index, CO_2 emission occupied the most, followed by the emission of NOx and CO. HC is emitted the least. Regarding the impacts of the DSAS message on the emission rates, there was little difference observed for left turn and right turn. For through movement, the emission rates in the scenario with the message were slightly lower than without the message for the four emission indexes.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The RFID based Drivers Smart Assistance System (DSAS) was developed, which is dedicated to enhance the safety at a conflicting area, such as a STOP sign intersection. In this research, the impacts of the DSAS on drivers' driving behaviors and vehicle emissions were measured and studied, while approaching a STOP sign intersection. Twenty subjects were recruited for testing the effectiveness and feasibility of the DSAS within a small residential area in Houston, in terms of speed profile, acceleration, and braking distance for an upcoming STOP sign.

Results show that the DSAS message was able to significantly reduce drivers' approaching speed, minimize the fluctuation in acceleration/deceleration rates, and enhance drivers' awareness of the upcoming STOP sign that is indicated by decelerating earlier. All test drivers preferred to follow the DSAS messages on the road for safety concern. Further, the DSAS messages do not raise extra vehicle emissions. Instead, a slight reduction in emission rates was found on the through movement. For even general observation, more road test with more participants and different test routes were recommended.

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