AN RFID BASED SMART WARNING SYSTEM AT SIGNALIZED INTERSECTION

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ABSTRACT

The visibility of traffic signals to drivers at intersections (green, yellow, and red) is often blinded by tree leaves, sunshine and many other obstacles, which may cause serious vehicle-to-vehicle and vehicle-to-pedestrian crashes. This research is to develop a smart warning system so that the drivers can be informed about the change of traffic signals through an RFID based in-vehicle smart warning system, which will reduce the crashes caused by sun glare effects on traffic lights. This research has great impacts on both safety and air quality at intersections. The RFID based smart earlier earning system can be embedded into the current GPS system, and can definitely be incorporated into the future advanced in-vehicle co-pilot system to enhance the powers of Intelligent Transportation System (ITS) and the eco-traffic signal control system. With the implementation of this earlier warning system, it is envision that crash rates at signalized intersections will be greatly reduced and the surrounding environment be improved.

Keywords: Intelligent Transportation System, traffic signal, traffic safety, RFID

INTRODUCTION

Background of Research

Crash Factors at Intersections

According to a United States (U.S.) Federal Highway (FHWA) report, the recognition error was the most important reason (55.7%) for accidents at intersections (Choi, 2010). Figure 1 illustrates the reasons for intersection-related crashes from 2005 – 2007 in the U.S.

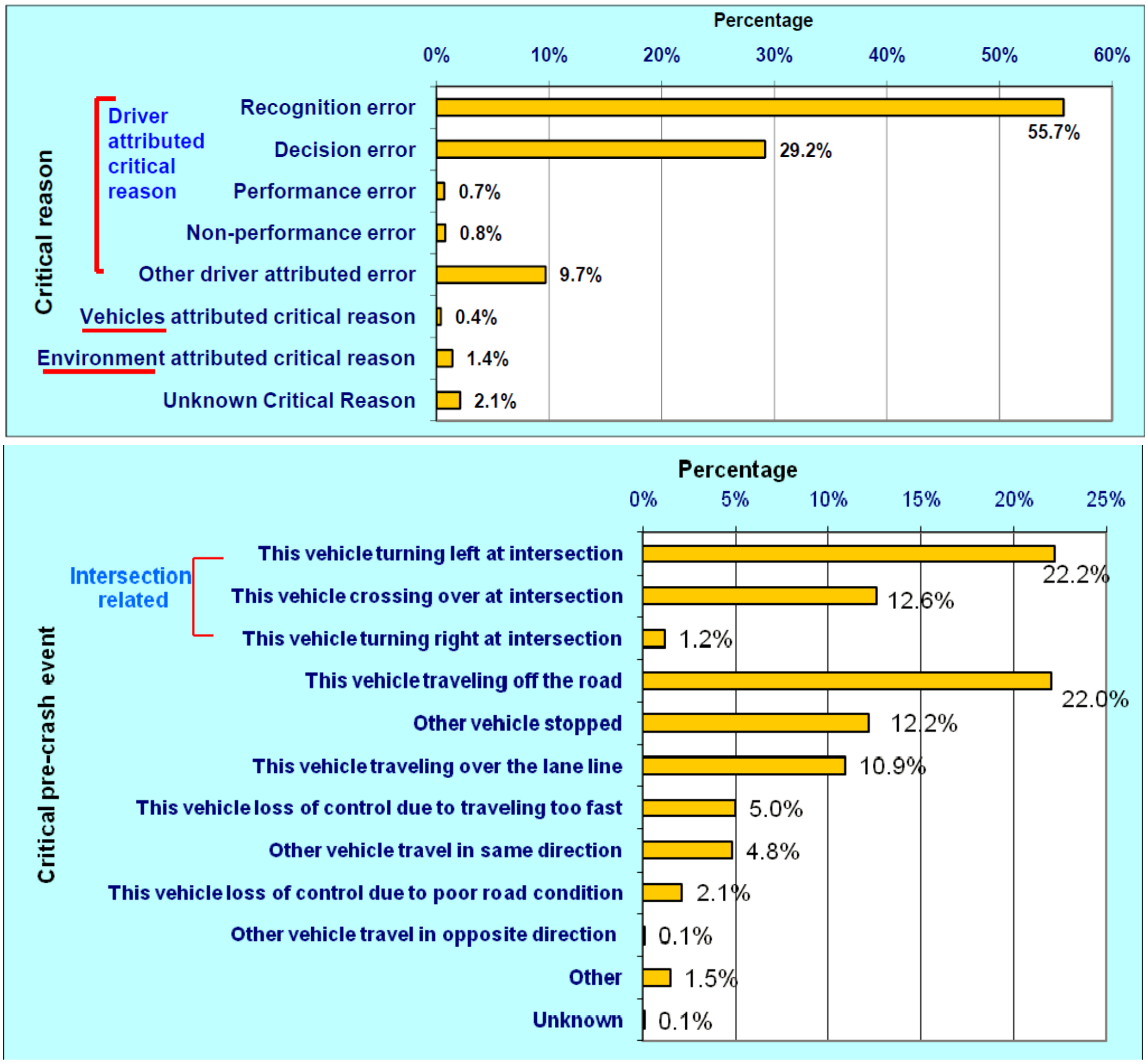


Figure 1 – Distribution of critical reasons for intersection-related crashes (Data Source: Choi, 2010)

Accidents Related to Blinding of Traffic Lights

Choi's report (2010) indicates that, most accidents happened at intersections are related to unclear traffic signals. Many traffic accidents have happened because of temporary blinding of traffic lights. Here is several traffic accidents related to the sunset blinding of traffic lights in different cities:

> On February 17th, 2012, a man named Mitchell Kowalewicz was blinded by sunset lights, ran through red light and killed one man in the City of Amtramck. He couldn't see the red light because of the strong sunset lights. Several people were interviewed in that area and the witness said driving west bound has been very difficult because of the sunset lights. A blinding sun can be very dangerous (Sercombe, 2012).

In the first eight months of 2010, around 22 traffic accidents were related to the blinding sun in Abu Dhabi. Abu Dhabi Traffic Department analysed their data and found many accidents were due to the sun's glare. The motorists urged the government to consider the effects of sun's glare when they analyze traffic accidents. The picture below shows a typical scene of an intersection with sun lights effect (Salama, 2010).

Figure 2 – Sun Glare Effects on Signal Lights (Source: Salama, 2010)

Research in This Field

In order to enhance the safety in intersection area, many studies have been conducted using advanced and intelligent transportation system (ITS) technologies. For example, Wu et al. (2010) developed an advanced driving alert system (ADAS), which contains Stationary ADAS (based on roadside infrastructure such as Changeable Message Signs - CMS) and In-Vehicle ADAS (driven by advanced communication technology such as VII). They also did simulator test to evaluate this system in which traffic signal status (TSS) information was used for energy and emission reductions. Real-time traffic signal status (TSS) information can alert drivers to slow down at some distances from an intersection and prevent unnecessary cruising or accelerating and provide safety co-benefits by reducing the likelihood of red light running (Wu, etc., 2010).

Schultz and Talbot (2009) developed an Advance Warning Signals (AWS) that provide advance warning of an approaching intersection or an impending signal change at such an intersection is an AWS. The AWS systems have helped to maintain higher operating speeds and may also have improved capacity when vehicles do not need to stop. Meanwhile, speeds have been reduced in the time just before the onset of the yellow interval (Schultz and Talbot, 2009).

Singh, et al. (2012) proposed an Intelligent Traffic Lights using Radio Frequency Identification (RFID). The proposed system provides quality of service to emergency vehicles and improves the accuracy of Automatic Traffic Light Violation Detection system as well as helps to trace out the stolen vehicles using RFID (Singh, etc., 2012). The RFID in this system is used to recognize the emergency vehicles.

The above types of advanced driving alert systems, even though will definitely enhance the safety and efficiency, are still in the stage of lab testing. The detailed impacts to driving behaviours and environments, as well as the tools for short range communications between vehicles and infrastructures are still in developing. Therefore, there are many rooms in this area on hardware/software designs, and the impacts on driving behaviours.

Research Objective

In this paper, RFID is used as a tool to implement a short range Infrastructure to Vehicle (I2V) communication, which aims to enhance the safety in intersection areas. The research objectives are to develop this RFID based Smart Warning System (SWS) at signalized intersections to reduce the impacts of sunset glares in intersection area, and to examine its impacts to driving behaviours on safety and efficiency.

RFID BASED SMART WARNING SYSTEM AT SIGNALIZED INTERSECTIONS

Components of RFID System

The RFID technology has been utilized in many areas such as logistics, inventory management, vehicle tracking, agriculture, etc. (Qiao et al, 2009; Qiao et al., 2012a; Qiao et al., 2012b). A typical RFID system has several components including tag, reader and processing computers. Figure 3 is an illustration of the different components of a RFID system.

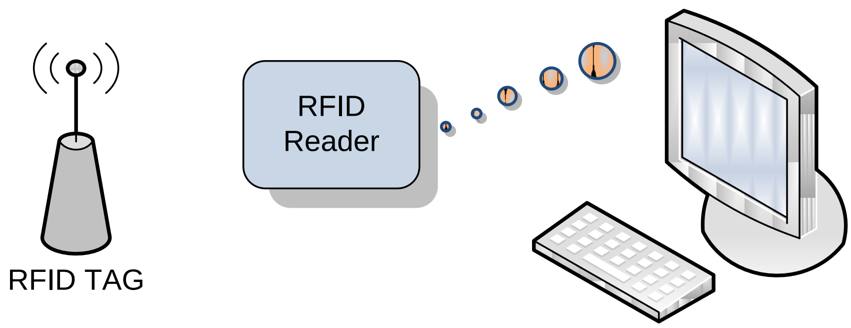


Figure 3 – Components of RFID System (Source: Qiao, et al., 2009)

Qiao et al. proposed a RFID based smart guide signing system, and have conducted on road on the working range of RFID tags in front of a stop sign. 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 (Qiao, etc. 2012b). The impacts of such system at signalized intersections are also unknown.

Kotchasarn reported an RFID-based in-vehicle alert system to alert vehicle drivers about road sights at an optimum distance before encountering them. It enables transmission of important data to vehicles within an effective non-line-of-sight (NLOS) distance. Paul et al. tested an RFID enabled system that will deliver 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 (Kotchasarn, 2009).

RFID Application on Safety Improvement of Signal Lights

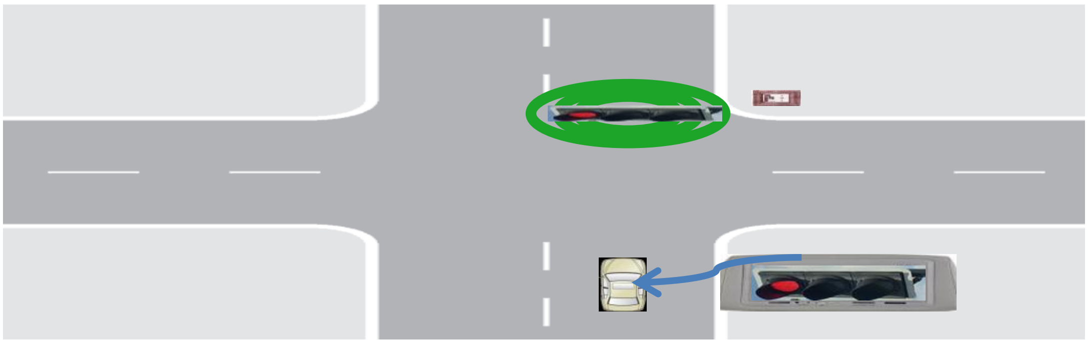
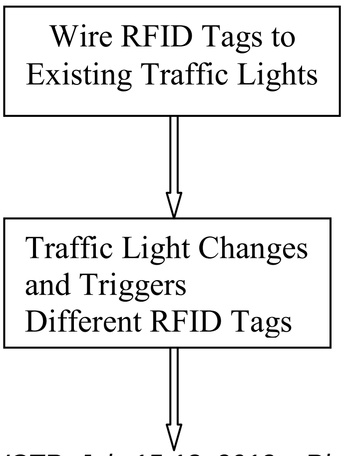


Figure 4 – Illustration of the RFID based Smart Warning System (SWS) at signalized intersections

As Figure 4 shows, the RFID tags can be attached to traffic lights and these tags can send signals to RFID readers. If we can wire the RFID tags to the traffic light, different RFID can represent different colors of traffic light. On board RFID readers can receive the signals and provide road assistance to the drivers. Portable mini computers can be installed on vehicles and analyze the data received from RFID system and display on LCD screens of vehicles.

System Design

Figure 5 illustrates the system design of the RFID based Smart Warning System (SWS) at signalized intersections. This system has several important components including: RFID emitter, RFID receiver, GPS receiver, computer processing software and database.



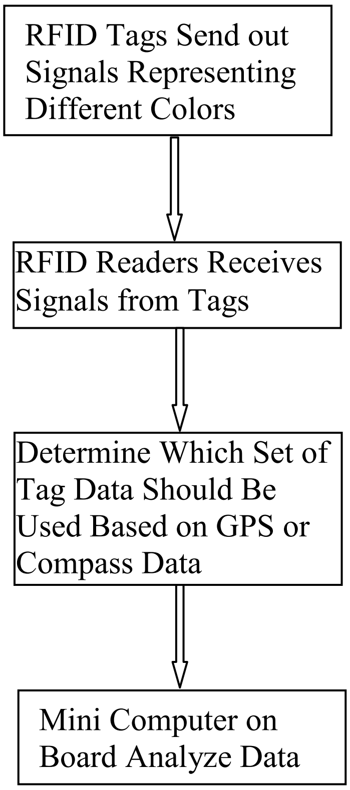
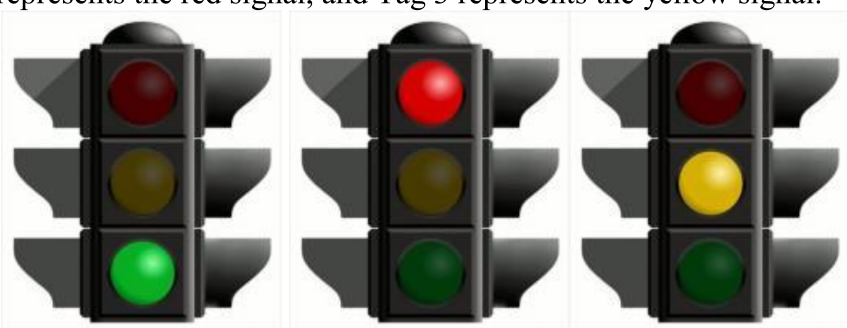


Figure 5 – System design of the RFID based Smart Warning System (SWS) at signalized intersections

In Figure 5, the RFID tag is wired to existing traffic lights, which can be detected by the receiver (the readers) installed inside the vehicles. In the meantime, the GPS unit reports the geographical locations of the vehicles. The on board computer checks if the tag signal(s) are approaching based on the tag and GPS information received. If the tag ID is a valid one, based on the tag inventory database search, proper voice prompts and visual warning message will be provided to drivers.

If having enough tags, tags can be coded with different IDs. Each tag can represent different signals. The on vehicle GPS/Compass system can tell the driving direction of vehicles. For example, on the west bound, if there is no protected left turn phase, then can use three tags to represent the signals for west bound traffic. As shown in Figure 6, Tag 1 represents the green signal; Tag 2 represents the red signal, and Tag 3 represents the yellow signal.



(a) Tag1 (b) Tag2 (c) Tag3

Figure 6 – E-Tag system for a typical traffic signal system

An onboard compass/GPS system can easily tell the direction of the car is travelling. Therefore the onboard computer system can easily tell which sets of tags are applied to the drivers. In a regular intersection, usually the test will have four sets of tags. The onboard compass/GPS system is needed to tell which set of tags should be used. Generally speaking, GPS system is better than compass system because GPS is a better reliability. Once the RFID reader receives the tag information, the minicomputer in vehicles can process the information and display the corresponding signals in LCD screen. Figure 7 is the interface of this system.

Figure 7 – Interface of the on-board Smart Warning System (SWS)

Software Design

The Visual Basic (VB) programming tool is used to develop the RFID based Smart Warning System (SWS) at signalized intersections. The Microsoft Communications Control, Microsoft Data Access Object, Microsoft MapPoint and Microsoft Winsock Control are major components of the software system (Table 1).

TABLE 1: The List of Used Software Components

Component	**Function**
Microsoft Communications Control	Communicate with GPS unit
Microsoft Data Access Object	Communicate with database
Microsoft Map Point	Navigate and display map view
Microsoft Winsock Control	Communicate with RFID receiver and tags

The SWS is developed in Visual Basic 6.0 environment, so it is a Microsoft Windows desktop application. SWS integrates all kinds of information together and this capability can provide drivers full support to their decision making process, thus it can ensure drivers drive safely in regular roads and work zone segments. The RFID device used is an Ethernet based RFID system, while the Microsoft Winsock Control is used to communicate with RFID receiver. The RFID receiver can upload information to on-board processing computer every second. As soon as this system detects the signal from the tags, this system begins to give visual display and voice prompts to the drivers.

RFID System Testing

The RFID sets from Tagsense were used for test, while the reader was installed with the vehicle (Figure 8), then a short range communication between vehicle and infrastructure(s) can be set up.

Figure 8 – The RFID receiver is inside a vehicle, however the antenna of which can be placed anywhere inside or outside the vehicle, depending on the connection availability

Qiao et al. (2012b) have conducted road tests using the RFID based warning system at stop signs. They have found that RFID can support E-Stop sign system and it provides guidance to the drivers once they reach a stop sign with poor visibility.

PILOT TEST OF RFID BASED SMART WARNING SYSTEM

The pilot test of this system was conducted by selecting 10 test subjects. The major purpose of this test is to evaluate this system and find whether this system is useful and practical based on the feedback from test drivers. The secondary purpose is to evaluate the impact of SWS on safety and emission. The last purpose is to evaluate the various human factors. To ensure the drivers can drive safely and comfortably, we have to evaluate different settings in this system such as the frequency of warnings, the stress levels and the work load, etc. After evaluate these factors, we can optimize the design to improve the safety of operating this system.

Test Design

As showed in Figure 9, a test route was selected along the westbound of Blodgett Street in Houston, TX, USA. The traffic signals at the intersection of Blodgett & Tierwester are where SWS should provide warnings. The tests covered the fall season of 2012 (from September to October).

In this test, the drivers need to drive the designated route for 20 runs under normal situation (no any in-vehicle warning of traffic signals) when facing sunsets. This way almost all signal phases (red, green, and yellow) are included. The test time was set from 5pm to 7pm, when sun glares were always affect drivers' visions to traffic lights.

After the 20 normal runs, the drivers were asked to drive another 20 runs following the same routes. The only difference is that the SWS is quipped in the vehicle to report drivers on the real time signal phases. The messages included "Right Ahead", "Green Ahead", and "Yellow Ahead". After the road test, the drivers were asked to fill a post survey form to indicate their actual feelings about the warning message from SWS.

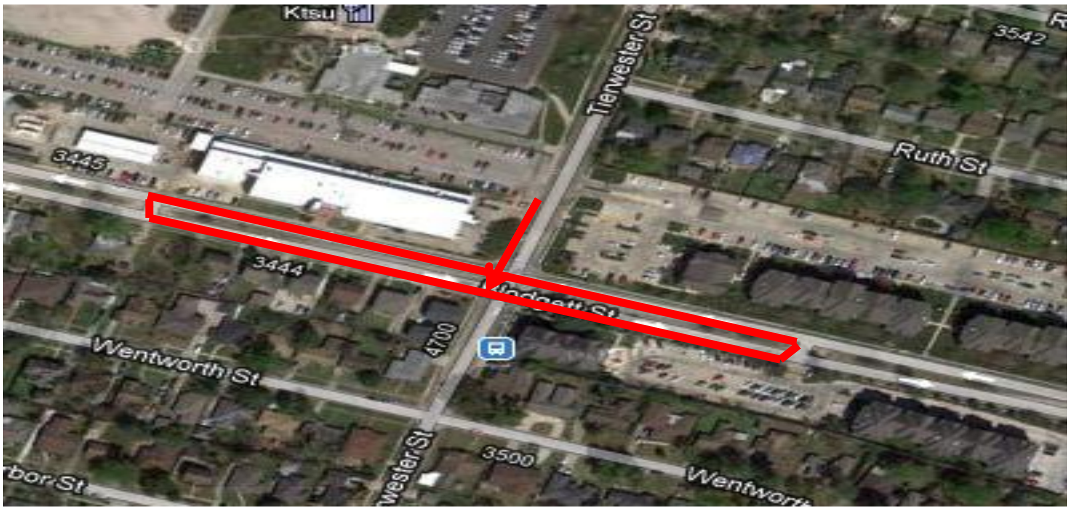


Figure 9 – The Test Route for SWS, where the red arrow indicate the target intersection that the SWS provided warning message for. In this test field, the westbound vehicles (from right to left) were normally facing sunset glares during 5pm and 7pm in sunny days in the fall season.

Participants

A total of 10 subjects with valid driver licenses were recruited to test drivers' feelings of SWS. Subjects were selected to represent Houston's demographics (gender, age, and educational level) based on the 2010 census data listed in Table 2. Table 2 also lists the age and education distributions of recruited drivers. For example, the gender distribution from census data suggests half male and half female to be recruited for tests.

Table 2 Gender, Age and Education Distribution Based on 2010 Census Data in Houston

Subject	Gender		Age				Education	
	Male	Female	under 5	5-18	18- 64	65 +	High school+ Associate degree	Bachelor's degree or higher
Houston statistics	49.8%	50.2%	8.1%	26.9%	57%	9%	74%	28.2%
Adjusted Distribution			------	------	86%	14%	---	----
Subjects in test	5	5	-------	------	9	1	7	3

High school+ Associate degree	6	1
Higher education	3	

ANALYZING RESULTS OF PILOT TEST

After conducted the pilot road tests, the impacts of SWS are analysed in afterwards, including the drivers' feeling from post survey form, and the impacts on drivers' trajectories, acceleration/deceleration rates, and safety.

Drivers Feeling from Post Survey Form

According to the post survey of pilot test, 80% of the subjects believe that this system is **useful or extremely useful**. 90% of the test participants agree that SWS can enhance safety when they crossed the intersection. 100% of the test participants agree that SWS can make them more aware of the traffic signal at intersection.

100% of the test participants believe this system does not make drivers stressful. 80% of the participants feel very comfortable and relaxed when the system provides warnings before stop lines. 100% of the test participants agree that this system supplied clear warnings and guidance. This possibly implies that SWS does not too much add extra work load to drivers.

As for the types of warning message, 100% of the subjects prefer voice prompts warning. 80% participants suggest that the SWS be integrated into the GPS unit. 100% of them claim that they will purchase this system if it is available in market.

Impacts on Drivers' Trajectories and Safety when Traffic Light is Green

Figure 10 illustrates the situation when vehicles arrive at intersection when the traffic light was green. Due to sun glare, some drivers were very sure about the phase of traffic light. To ensure safe driving performances, these drivers might chose to decelerate and even stop at stop line even though the light could be green and they had the right-of-way to pass the intersection. Figure 10 illustrates the conceptual trajectories of vehicle under such situation. The blue lines in Figure 10 represent vehicles stopping during green, which not only introduced unnecessary delay (one of the vehicles even missed the green phase and had to waiting for next green), but also induced safety concerns as the following vehicle might not be award of such sudden stops that would cause real-end collisions. Besides, the extra idling and unnecessary deceleration will definitely cause extra vehicle emissions and fuel consumption.

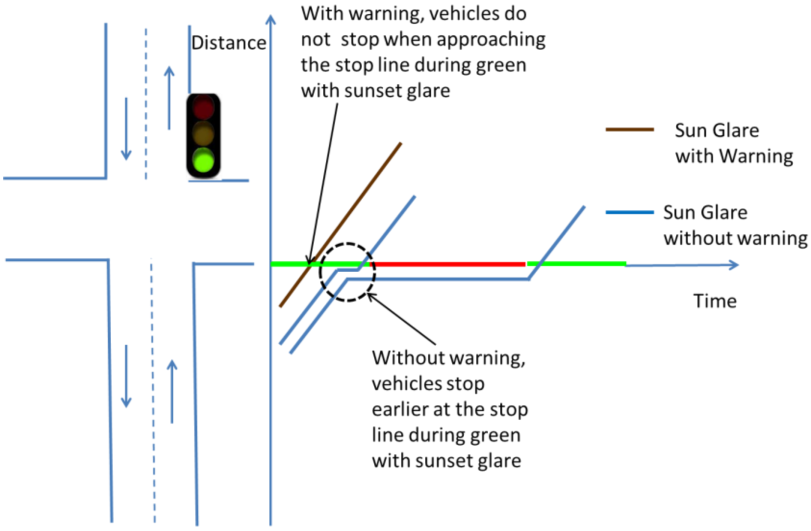


Figure 10 – Conceptual trajectories of vehicles when encountered sun glare during green signal

Figure 11 was plotted using real data from pilot test. In this time-space diagram, one typical trajectory with SWS and one typical trajectory without SWS for each of the 10 subjects were selected for comparison purpose. The 10 dashed lines in Figure 11 show trajectories of vehicles that were equipped with SWS, while the 10 solid lines show the trajectories of vehicles without SWS. It is obvious in Figure 11 that almost all solid lines slowed down with smaller slops (meaning slower speeds) when approaching intersections due to sun glare. However with the SWS equipped, the dashed lines all smoothly and even more aggresively passed the intersection. In the pilot tests, there was no vehicle stopped for an additional red phase, which is illustrated in the conceptual trajectory in Figure10.

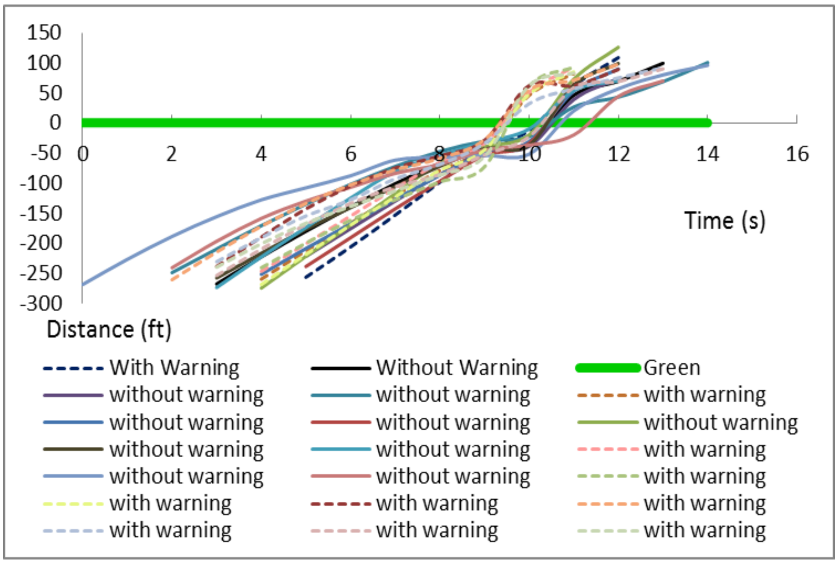


Figure 11 – Vehicle trajectory with and without SWS during green signal

Impacts on Drivers' Trajectories and Safety when Traffic Light is Red

Figure 12 illustrates the conceptual trajectories of vehicles arriving intersection when the traffic light is red and there is sun glare. In this case, the drivers would either sharply slowed down, or even run red light, simply because they are not sure what color the traffic light is displaying, and they may not be stopped properly. This will cause serious safety concerns and extra vehicle emissions due to sharp decelerations.

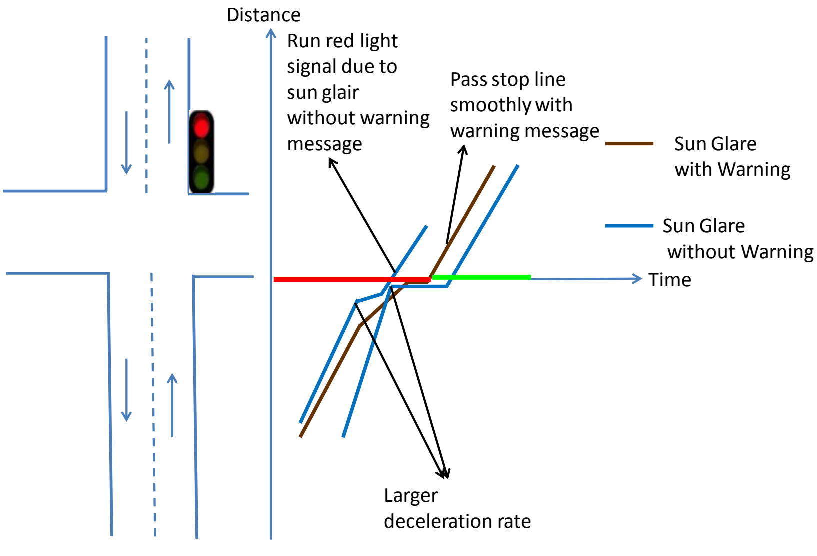


Figure 12 – Conceptual trajectories of vehicles when encountered sun glare during red signal

Figure 13 show the trajectories in time-space diagram from pilot test data. Similarly in this time-space diagram, one typical trajectory with SWS and one typical trajectory without SWS for each of the 10 subjects were selected for comparison. The 10 dashed lines in Figure 13 represent the normal cases with no SWS, while the 10 dashed lines represent the cases with SWS.

It is obvious in Figure 13 that the approaching speed with no SWS is higher than those with SWS, while the deceleration rates without SWS is much higher that with SWS. From the test data (10 pairs of typical trajectories from 10 subjects) in Figure 13, the average deceleration with no SWS is **8.60 mi/hr/sec**, and the average deceleration with SWS is reduced to **3.89 mi/hr/sec.** The average speed with no SWS is **25.16 mi/hr**, while the average speed with SWS is **17.84 mi/hr**. The smaller approaching speeds during red phase yield out smaller deceleration rates with less safety concerns, less vehicle emissions, and less fuel consumption. On special case in the test was that, one subject even run red light due to sun glare. This happened when no SWS is equipped. The subject claimed that he/she could not figure out which colour the light displayed and so he/she did not stop at stop line. This is really a bad experience during the test.

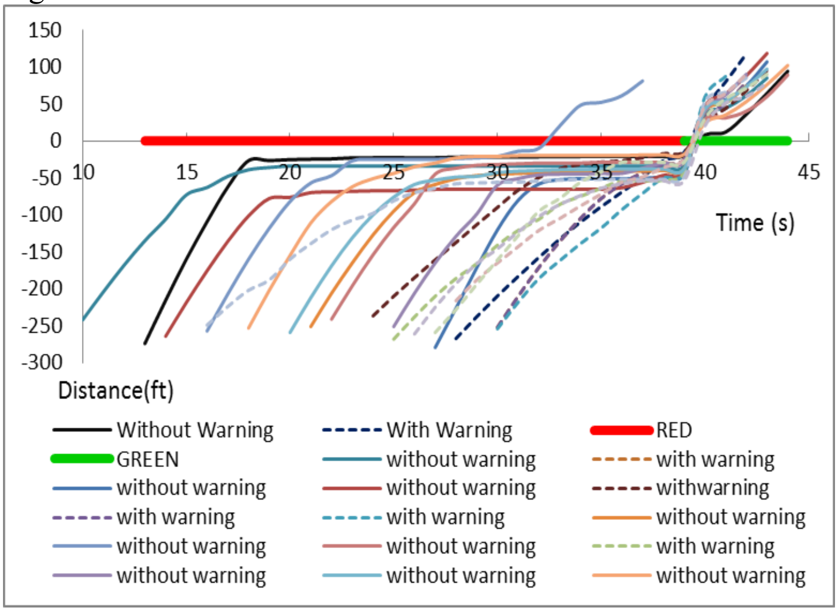


Figure 13 – Vehicle trajectory with and without SWS during red signal

Impacts on Vehicle Approaching Speeds

Figure 14 illustrates the distributions of approaching speeds for all test runs with and without SWS. There are 200 speeds with SWS (10 persons x 20 runs each = 200 speeds), and 200 speeds without SWS. The mean of all 200 speeds without SWS was 21.524 mi/hr, while mean of all speeds with SWS was reduced to 15.869 mi/hr. This implies that with the advice of signal warning message, vehicle approaching speeds tended to be reduced, which was conceptually safer.

Another statistical phenomenon is that the standard deviation of approaching speeds with SWS was reduced from 10.804 mi/hr to 5.701 mi/hr. This means that without warning message, vehicle approaching speeds had relatively bigger variations: some drove more quickly, some slower. When provided with warning messages, the variation of approaching speeds become smaller: most of the vehicles drove in similar and lower speeds when approaching the intersections. This would enhance the safety at the relevant signalized intersection, especially when there were sun glares affecting drivers to receive traffic control signals.

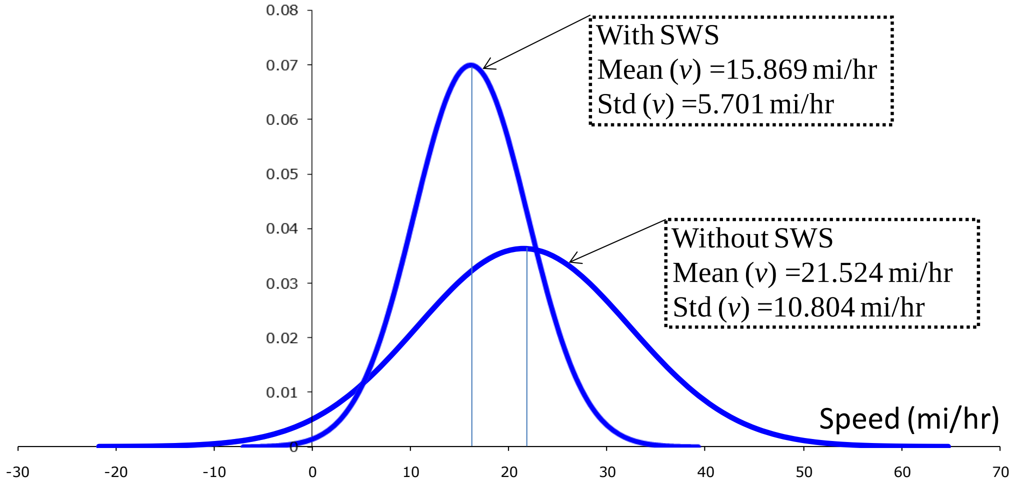


Figure 14 – Distribution of speed with and without SWS

Impacts on Vehicle Acceleration Rates

Figure 15 illustrates the distributions of acceleration rates for all test runs when vehicles approached intersection and decelerated with and without SWS. The mean value of acceleration rates reduced from -3.699 mi/hr/sec (without SWS) to -1.943 mi/hr/sec (with SWS). Besides, the standard deviation with SWS (0.983 mi/hr/sec) was also smaller than that without SWS (1.821 mi/hr/sec). This tells that very high absolute values of acceleration rates could be reduced if SWS was provided.

Normally the acceleration rates that are closer to zero are highly related to lower vehicle emissions and less fuel consumption. The data and charts showing in Figure 15 implies that the signal warning message provided by SWS can positively impact both safety and air quality at signalized intersections.

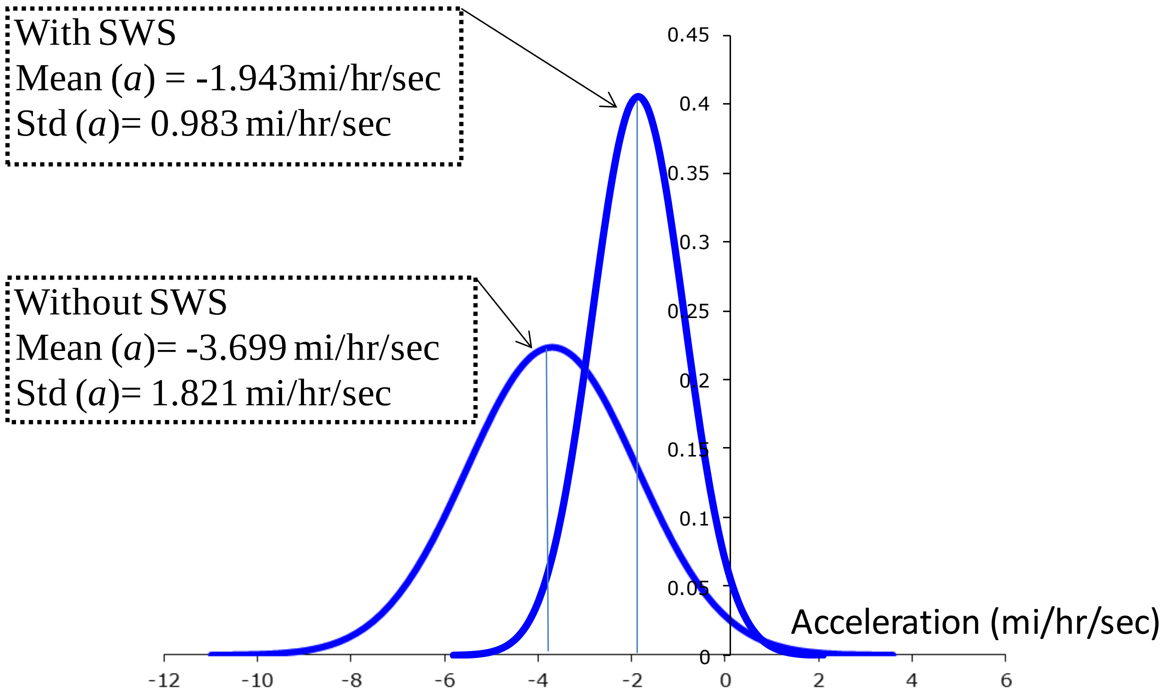


Figure 15 – Distribution of acceleration rates with and without SWS

CONCLUSIONS

In this paper, the RFID technology based SWS program was developed to reduce the unnecessary safety concerns and air quality impacts. A VB program was developed including several different software components. The system can provide drivers with real time voice prompts and visual message regarding traffic signal information at signalized intersections. Twenty subjects were selected for the pilot test based, which were carefully selected based on the 2010 census demographical data in Houston, Texas, USA. Statistical analysis to the test results shows that the developed SWS can effectively reduce vehicles' chance of running red lights and avoid unnecessary waiting time in front of green lights. Deceleration rates while approaching intersections during red phase were reduced if SWS message is provided. The next step of studies is to further investigate the impacts of SWS to driving behaviours and vehicle emissions through larger scale tests.

ACKNOWLEDGEMENT

This paper is prepared in partial supports by the U.S. National Tier 1 University Transportation Center (UTC) TranLIVE, the U.S. National Science Foundation (NSF) CREST #1137732, and Texas Southern University Seed Grant.

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