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CONNECTED VEHICLE V2I COMMUNICATION APPLICATION TO ENHANCE DRIVER AWARENESS AT SIGNALIZED INTERSECTIONS

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ABSTRACT

This study introduces a Vehicle-To-Infrastructure (V2I) architecture to enhance driver awareness at signalized intersections. The main objectives are to (i) provide a proof-of-concept field experiment on the use of V2I communication architecture at a signalized intersection and (ii) evaluate the impact of V2I communication on improving driver performance while crossing the intersection. The proposed V2I communication application will relay an advisory auditory message to the driver regarding the status of the traffic signal. It is expected that driver behaviour is going to change as a result of the in-vehicle audible message. Consequently, the proposed application will collect additional driver performance indicators which include information on average speed, maximum speed, and the acceleration\deceleration profiles. To understand the impact of the advisory message on changing driver behaviour, a comparison was performed between the indicators with and without the in-vehicle message. Driver behavior was investigated under two scenarios, namely; as the driver heads towards a green signal and as the driver heads towards a red signal. For both scenarios, the results show that the average speed of the driver have changed significantly after turning “on” the in-vehicle messages. In addition, the maximum speed distribution shifted towards a lower value indicating decreases in maximum speeds. Moreover, the difference between the acceleration\deceleration profiles near the intersection when driving with and without the message, while heading towards a red signal, was found to be significant. These preliminary results show that the proposed V2I communication application can have promising impacts on improving driver awareness at signalized intersections.

Keywords: Connected Vehicles, Vehicle-To-Infrastructure, Communication, Driver Behavior, In-Vehicle Message

1. INTRODUCTION

Connected vehicle (CV) technologies are innovations with the potential to reshape the current transportation sector. These new technologies have the ability to significantly improve traffic safety and mobility while reducing environmental impacts on our roads (Olia et al. 2014,Lee and Park 2012, Paikari et al. 2014). Research has shown that CV technologies, including both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, are expected to reduce 83% of all unimpaired crashes (Harding et al. 2014). In addition, CV technologies are expected to target almost all crash types (i.e., rear-end collisions, lane-changing collisions, etc.) (Najm et al. 2010). This new type of technology has also been found to provide substantially better results when combined with automated vehicles and autonomous emergency braking systems in terms of their ability to mitigate different crash types (Najm et al. 2010, Doecke and Anderson 2014).

As intersections are considered to be one of the most problematic spots in a traffic network, several CV-V2I applications (e.g. running red light warning, stop sign violation warning, stop sign gap assist, railroad crossing violation warning, etc.) have been developed and tested to address the safety concerns at these hotspot locations. However, most of these experiments were undertaken in a simulation environment (Olia et al. 2014, Lee et al. 2012, Paikari et al. 2014, Doecke and Anderson 2014, Basma et al. 2011, Zha et al. 2015). The results provide overwhelmingly positive evidence supporting the application of CV-V2I to improve intersection safety, especially when they are signalized. When approaching a signalized intersection at a certain speed and distance, the driver could be guided to drive at an advisory speed in order to minimize fuel consumption or to reduce his stopping time at the intersection. In addition, this advisory speed may assist the driver in avoiding unnecessary evasive maneuvering (i.e., acceleration or deceleration) to reach the intersection during the green phase or to stop at the red signal. The Green Light Optimal Speed Advisory (GLOSA) application can provide drivers with advisory speeds through an in-vehicle message. The GLOSA has been tested in simulation environments and the results showed that the GLOSA can reduce fuel consumption and improve traffic efficiency (Krajzewicz et al. 2012, Katsaros et al. 2011).

In this study, the in-vehicle message will be sent to the driver based on a GLOSA application through a proposed V2I communication architecture. Consequently, the first objective of this study is to provide a proof-of-concept of the V2I communication architecture to be used at a signalized intersection using a field experiment. While approaching the signalized intersection, an in-vehicle message will be relayed to the driver that is expected to change the driver’s behaviour, and consequently his action and decision process should change accordingly. Hence, the second objective of this paper is to analyze and evaluate the preliminary impact of this in-vehicle advisory message on driver behaviour. The change in driver behaviour will be assessed using several performance indicators (e.g. driver’s speed and acceleration/deceleration profiles).

2. LITERATURE REVIEW

2.1 CV-V2I Applications

As mentioned previously, CV-V2I technologies have several applications that aim at improving traffic safety and mobility at signalized and unsignalized intersections. Some of these applications were proposed in the Cooperative Intersection Collision Avoidance Systems (CICAS) initiative, which was a project supported by the U.S. Department of Transportation (USDOT). The CICAS-V project, which was limited to stop sign and traffic signal violation, aimed to develop a warning system that alerts the driver of an expected violation of a stop sign or traffic signal to avoid potential collisions at the intersections. However, this project stopped before executing a full-scale field operational test, but the project was still able to achieve a few important goals. For example, the system is now ready for a full-scale field operation after a pseudo-naturalistic test, and an effective warning algorithm has been developed and tested (Maile et al. 2008).

An additional example of a safety application included warning drivers about the dilemma zone. Zha et al. (2015) used V2I communication to evaluate a dilemma zone protection framework to improve safety at signalized intersections. This framework combined actuated signal control and a cost-benefit approach, which weighs the cost of the dilemma zone protection and the delay due to conflicting movements. In order to evaluate this framework, a microsimulation model was developed in VISSIM assuming different market penetration rates. The results showed that the best performance was at 100% penetration rate. Since the evaluation was based on a microsimulation model, this study did not evaluate the real driver reaction to the warning. Another V2I application focused on mitigating red light running (RLR) violations. An algorithm was developed to predict RLR in a CV environment and extend the all-red time based on the V2I communication (Chen et al. 2013). A huge amount of real-life data using radar sensors was collected to simulate the data collected by the CV technology. This study showed that the CV-V2I technology will improve the correct prediction rate of RLR by 2%-3% higher than the fixed sensor based approach. In addition, the false alarming (i.e. when non-RLR vehicles is considered as a RLR vehicle) will decrease from 10-15 times per 1000 vehicles with fixed sensor based approach to 2-3times per 1000 vehicles with CV-V2I approach.

In conclusion, warning the driver about an expected violation or crash using V2I communication has been tested in several previous studies. The warning systems and the algorithms were tested either in the real life (Maile et al. 2008, Park et al. 2013) or in simulation environments (Zha et al. 2015, Chen et al. 2013). In this study, besides providing a proof-of-concept for the whole V2I communication architecture including the proposed algorithm, the preliminary driver behavior change will be evaluated in an urban signalized intersection.

2.2 Driver Behavior and CV-V2I Warning Messages

Investigating the primary cause of road crashes showed that approximately 95% of crashes are caused due to some kind of driver error (Sayed et al. 1995). The CV-V2I advanced warning capabilities will attempt to reduce these errors by warning the driver about potential violations or expected collisions. Hence, these messages will have a significant impact on driver behavior. Farah et al. (2012) analyzed some physiological measurements and drivers' acceptance of a cooperative V2I system. In addition, the impact of the warning messages on driver behavior was investigated in terms of driving speed, lane-changing frequency, following gaps, and acceleration noise (i.e. the fluctuation in the acceleration profile due to the change in road and traffic conditions and the driver behavior) Herman et al. (1959), in a real-life situation. The messages provided in this study were non-audible messages to warn the driver about the speed limit, an accident ahead, traffic congestions, road construction, hazardous conditions due to adverse weather, and lane status. However, the messages sent to the drivers during the test were simulated messages, as the test site did not have any critical events that would activate the system. While using this system, drivers were found to be less stressed, and the average speed reduced and the following gap increased. These results reflected a positive impact on driver behavior, especially for the drivers who are 45 years old and above. Moreover, the system reduced acceleration and deceleration differences among drivers and unified their behavior (Farah and Koutsopoulos 2014).

Yan et al. (2015) used simulator-based techniques to analyze the change in driver behavior due to an in-vehicle warning message. Since the main concern in this study was the occurrence of right-angle collisions at signalized intersections, a message was sent to the driver only if a RLR vehicle was coming from either the right or the left side. The driver reaction towards these messages was measured in terms of the brake reaction time, alarm-to-brake-onset time, and the deceleration. The results showed that the proper warning message timing will make the deceleration smoother. Consequently, the system will improve driver performance, and hence can significantly reduce RLR collisions. Moreover, Zhao et al. (2014) evaluated the human-related factors through testing an eco-driving application in a traffic network simulator. However, the focus was mainly on the reduction in fuel consumption and emissions. The results showed that the application could reduce drivers' hard accelerations/decelerations and maximum speed, and hence, the application would have a positive safety impact. In a real-life controlled track, Ruscio et al. (2015) tested and analyzed the impact of a collision warning system on the braking reaction time steps with different levels of driver expectancy (i.e. information expectation, previous experience, warning reliability, hazard prediction) by monitoring the driver's facial expressions. However, the acceleration/deceleration and speed profiles were not investigated; it was found that a reliable warning accelerates the decision-making process and that the absence of the warning during a hazardous situation will affect driver response negatively.

In summary, the impact of the messages on the driver behaviour due to V2I communication at signalized intersections was not clearly evaluated in real life at signalized intersections with clear performance indicators. A number of studies tested algorithms to avoid certain collision types using high-resolution data to simulate CV data. Other studies tested these algorithms in simulation models like VISSIM or in driver simulators with the aid of volunteer drivers. On the other hand, real-life tests were executed on a freeway or in controlled tracks to investigate the driver behavior change due to service messages. In this paper, an algorithm embedded in a mobile application, which was developed based on CV-V2I communication, is proposed to relay an audible warning message while approaching a signalized intersection. This warning message is based on the signal timing data, vehicle speed, and the distance to the intersection. In addition, the change in driver behaviour due to the warning will be assessed. This preliminary evaluation has been executed at a signalized intersection, as a case study, near the University of Alberta North Campus, Alberta, Canada.

3. METHODOLOGY

In order to prove the V2I communication architecture concept, this study had three sub-objectives: i) prepare and test the communication between the V2I architecture components, ii) develop and test an algorithm that will relay a variable audible advisory message for certain scenarios, and iii) collect several performance measures with and without the advisory message. The following subsections will discuss each objective and will also include a description of the study.

3.1 V2I Architecture and Communication

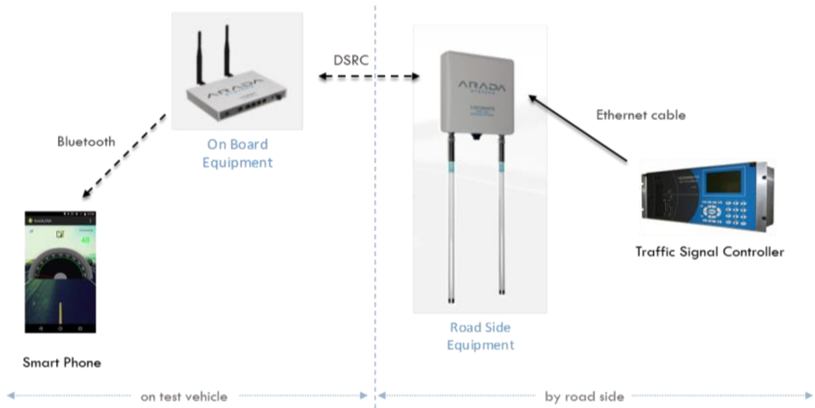

Figure 1: The components and the connection of the testbed.

As shown in Figure 1, the V2I system used in this study consisted of the following components:

- Traffic Signal Controller: a signal controller is the data source of the signal phase and timing (SPaT) information. The SPaT information collected from the signal controller can be used to obtain the current traffic light status and the remaining time of the current status for the test vehicle, therefore enabling the optimization of safety performance.
- Roadside Unit (RSU): the RSU collects the SPaT information from the controller, and encapsulates and encodes it in to a standard SPaT message defined by the standard SAE J2735 (SAE International 2009). The SPaT message, specifically designed for infrastructure-to-vehicle (I2V) communication, is then broadcast on a dedicated short-range communication (DSRC) channel, a channel in the 5.9GHz band specified for automotive use (Kenney 2011). The broadcast can be received by all on-board equipment within communication range.
- On-Board Equipment (OBE): the OBE receives the broadcast of the SPaT message. After decoding the message, the OBE obtains the traffic light status and the timing information for the lane of concern (the lane in which the test vehicle is driving). The obtained information is then sent out via Bluetooth.
- Smartphone: the smartphone is the data sink of this testbed. It receives the SPaT information from the OBE via Bluetooth. This information is processed through the algorithm with the vehicle speed and distance to the intersection. This distance is calculated based on the vehicle coordinates, which are updated each time step using the GPS navigation in the smartphone, and the intersection coordinates which are stored in the application.

3.2 Algorithm Development

This subsection discusses the development of a prototype algorithm, which is the core of the smartphone application; based on the algorithm, the message will be relayed to the driver automatically. This algorithm is developed mainly as a part of the proposed V2I system architecture and to serve the main objectives of this study. The coverage of the RSU is about 200 meters, so the OBE starts to receive data around 200 meters from the intersection. The OBE receives the SPaT from the RSU and sends it to the smartphone via Bluetooth. The smartphone will record the distance between the vehicle and the intersection, which is calculated as mentioned before, as well as the speed. Knowing the SPaT, the distance to the intersection, and the speed, the algorithm will calculate whether the vehicle will be able to cross the intersection or has to stop before the intersection.

As shown in Figure 2, the algorithm deals mainly with two major scenarios as an exploratory stage to provide a proof-of-concept of the proposed architecture. The first scenario is when the driver is heading towards a green signal and is advised to keep his current speed or increase his speed (maxed at a certain threshold) in order to clear the intersection during the green signal. On the other hand, the driver will be advised to prepare to stop when there is insufficient green time to pass through the intersection as the signal is expected to turn red. Similarly, the second scenario is when the driver is heading towards a red signal time, and the driver is advised to keep his current speed or to slow down to a certain speed in order to pass through the intersection without stopping. On the other hand, the driver is advised to start preparing to come to a complete stop due to the length of the remaining red time since the signal is not expected to turn green.

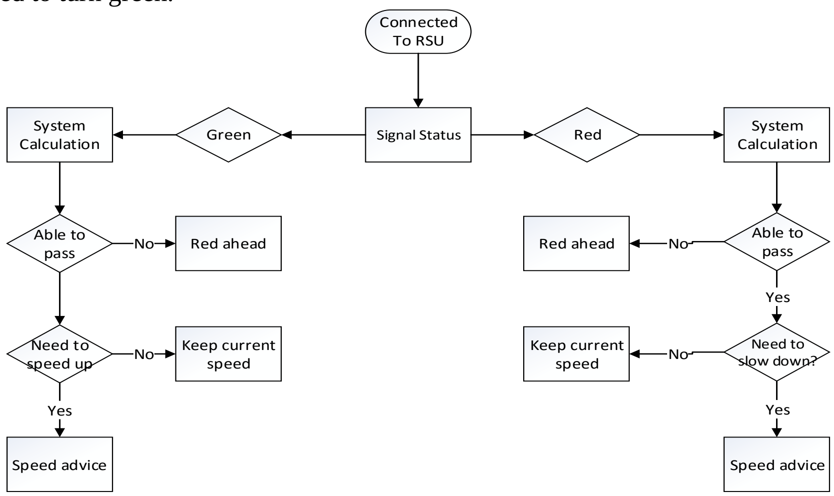

Figure 2: Framework of GLOSA strategies

The following notations are used throughout the following paragraphs to describe the algorithm and how it works:
t_{green} = the remaining green time;
L_{green} = the distance between the vehicle and intersection when the signal is green;
v_0= the current vehicle speed;
a_{ar} = the vehicle general average acceleration rate at the current speed;
v_{max} = the speed limit on the segment (50 km/hr);
t_{red} = the remaining red time;
L_{red} = the distance between the vehicle and intersection when the signal is red;
a_{dr} = the deceleration rate at the current speed; and
v_{min} = the minimum speed limit, which will be assumed as half the speed limit.

The following scenarios will use acceleration and deceleration models that are found in the literature. At current speed, the vehicle average acceleration rate and deceleration rate will be calculated as in Eq. 1 (Mehar et al. 2013) and Eq. 2 (Maurya and Bokare 2012) respectively.

[1] $a_{ar} = 1.70e^{-0.04v_0}$

[2] $a_{dr} = -0.005{v_0}^2 + 0.154v_0 + 0.493$

3.2.1 Scenario 1: Heading towards a Green Signal

This scenario occurs when the vehicle is approaching the intersection and the signal is green. The vehicle may be in one of the following cases:

- If $\frac{L_{green}}{v_0} < t_{green}$, the vehicle can pass through the intersection without stopping. In this case the application will advise the driver to keep the current speed.

- If $\frac{L_{green} - \frac{(v_{max}^2 - v_0^2)}{2 * a_{ar}}}{v_{max}} + \frac{v_{max} - v_0}{a_{ar}} \leq t_{green} < \frac{L_{green}}{v_0}$, the vehicle cannot pass through the intersection safely with its current speed; however, if the driver speeds up to a certain safe speed, the vehicle will pass through the intersection without having to stop
- If $\frac{L_{green} - \frac{(v_{max}^2 - v_0^2)}{2 * a_{ar}}}{v_{max}} + \frac{v_{max} - v_0}{a_{ar}} > t_{green}$, the vehicle cannot pass through the intersection even if the driver speeds up. Consequently, the application will advise the driver to prepare to stop.

In this scenario, the vehicle needs to speed up or keep the current speed in order to clear the intersection during the green phase.

<u>3.2.2 Scenario 2: Heading towards a Red Signal</u>

In this scenario, the vehicle is approaching the intersection and the signal is red. The vehicle may be in one of the following cases:

- If $\frac{L_{red}}{v_0} > t_{red}$, the vehicle can pass through the intersection without stopping, so the application will advise the driver to maintain the current speed.
- If $\frac{L_{red}}{v_0} < t_{red} < \frac{L_{red} - \frac{(v_0^2 - v_{min}^2)}{2 * a_{dr}}}{v_{min}} + \frac{v_0 - v_{min}}{a_{dr}}$, the vehicle cannot pass through the intersection with its current speed; however, if the driver slows down, the vehicle will pass the intersection without having to stop. In that case, the application will advise the driver to slow down and drive under a certain speed.
- If $\frac{L_{red} - \frac{(v_0^2 - v_{min}^2)}{2 * a_{dr}}}{v_{min}} + \frac{v_0 - v_{min}}{a_{dr}} \leq t_{red}$, the vehicle is unable to clear the intersection and will need to slow down and come to a complete stop since the signal will be red upon arrival at the intersection.

In this scenario, the vehicle needs to slow down or maintain the current speed in order to reach the intersection after the signal turns green.

3.3 Performance Indicators

One of the main objectives of this paper is to evaluate the change in driver behaviour due to an advisory message sent to the driver using V2I communication. Consequently, several performance indicators are selected for this evaluation based on the data availability. In this paper, the speed profile, maximum speed, and acceleration/deceleration profiles with and without the advisory message are compared based on real-life runs. Many performance measures have been used in previous studies in order to investigate changes in driver behavior at signalized intersections. Speed and acceleration are the most common measures used for this purpose. For instance, average speed, acceleration noise, lane-changing behavior, and the car following gap were used to assess the impact of the V2I system on driver behavior on freeways. However, acceleration and lane-changing behavior did not differ significantly before and after the use of the system; the average speed reduction and the car following gap increased significantly (Farah et al. 2012). Moreover, relative speed distribution and acceleration have been used to evaluate the change in drivers' car following behavior due to the deployment of the V2I system (Farah and Koutsopoulos 2014). In a simulator experiment, the speed at the yellow onset, the deceleration rate (from the speed at the yellow onset to 5 mph), and the red entry time (i.e. the time elapsed from the red onset to the time when the vehicle reaches the stop line) were used in a logistic regression analysis to investigate the capability of a RLR warning message to reduce the RLR violations (Yan et al. 2015). Therefore, changes in speed and acceleration were chosen as the two main performance indicators in this study.

3.4 Case Study Area

The test site, which is used as a case study, is a signalized intersection located near the University of Alberta North campus, AB, Canada. The major road is 87 Ave. NW, which consists of two entering lanes; one is a dedicated left-turn lane, and the other is an exit lane for both the east and the west approaches. The minor road, which is 111 St.

NW, consists of one entering and one exit lane for the south approach and two entering lanes and one exit lane for the north approach. The study area is bounded by two intersections on the main road. The first is a signalized intersection 200 meters to the east, and the second is a pushbutton pedestrian crossing 190 meters to the west. There are no bus stops in proximity to this intersection. The traffic signal heads, which are horizontally-arranged signal face, are visible to the driver without any obstructions from both directions. This signal has two phases, one for the east-west movements, including left turns, and one for the north-south movements including left turns. Separating the left-turn movement in a dedicated lane will facilitate the test of the application, as the scope of this test will be on the through movement on the main road. However, the main road has a long green time, which limits the testing of all possible vehicle arrival scenarios at the intersection, as will be discussed later. For pedestrians crossing, this intersection has only blinking hand as a warning for the pedestrians without any countdown. This pedestrian display will not help the driver when exactly the green phase will end.

The study was conducted on several days in order to achieve all objectives. First, the communication between the components of the V2I communication system was tested and the controller was successfully synchronized with the real signal plan. Second, the algorithm and the smartphone application were tested several times on separate days and debugged successfully. In addition, the smartphone application was prepared to collect the data for this study. Finally, the data were collected on different days, four hours in total, with the same weather conditions. In order to provide a clear proof of concept of the V2I communication architecture, the context of this study focused only on the case where a single vehicle is approaching the intersection and is not impeded by any slow-moving vehicles ahead. Thus, the test was carried out during off-peak times to ensure the free flow movement of traffic. Speed, acceleration, and the distance to the intersection were collected every time step (i.e., one second). This set of data was collected continuously during the study period and then filtered to separate the data into runs. All the data was collected for the same driver in order to facilitate the comparison between his behaviour with and without the message. The driver was asked to drive through the intersection in both directions (i.e., east and west) with total period of two hours without the message and two hours with the message in different days.

4. RESULTS AND DISCUSSION

After filtering the data, a total of 30 runs were produced without the message (i.e., normal driving mode) which are divided into 19 runs for scenario 1, when the driver is going through the intersection during a green light, and 11 runs for scenario 2, when the driver is slowing down or stopping when approaching the intersection during a red light. In addition, a total of 28 runs with the message, divided into 18 runs for scenario 1 and 10 runs for scenario 2, were produced. A single run is defined as when the vehicle crosses the signalized intersection once on the vehicle's route. The reason for having only two analyses scenarios is that the driver was asked to drive through the intersection continuously during the study period, so the same scenarios were repeated and it was difficult to target all the vehicle arrival scenarios. On the other hand, many runs were produced from the study period for each scenario, as mentioned before, which will make the results more robust. In addition, the same driver performing the whole test will serve the make it possible to compare his behaviour during the test.

In the first scenario, a vehicle is approaching the intersection at the start of or midway through the green time. When the message is turned on, the driver will hear the following command "keep current speed" only once. As previously discussed in the algorithm description section, the driver should have enough time to cross the intersection during the green light while maintaining his current speed. This should provide the driver with enough information to modify his behavior as he approaches the intersection. It is assumed that when the message is not playing, the driver will either maintain his speed or increase it slightly to pass through the intersection during the green phase, since he does not know when the signal will turn to yellow. In the second scenario, the vehicle is approaching the intersection during the yellow phase or at the start of the red light. When the message is turned on, the driver will hear the following command "signal will turn red" only once; consequently, the driver should reduce his speed and prepare to stop. The driver is considered stationary when the speed is less than 5 km/h. Again, without the message, it is expected that the driver will continue to drive normally and will only start to reduce his speed before the intersection when he sees the signal turn red. The smartphone application was programmed to collect time, distance to the intersection, speed, acceleration, and signal status (i.e. green, yellow, or red) and remaining time for each. Based on the collected data, the average speed and acceleration\deceleration profiles for each scenario were developed for both cases (i.e., with and without the advisory message). The results are shown in the following subsections.

4.1 Speed Profiles

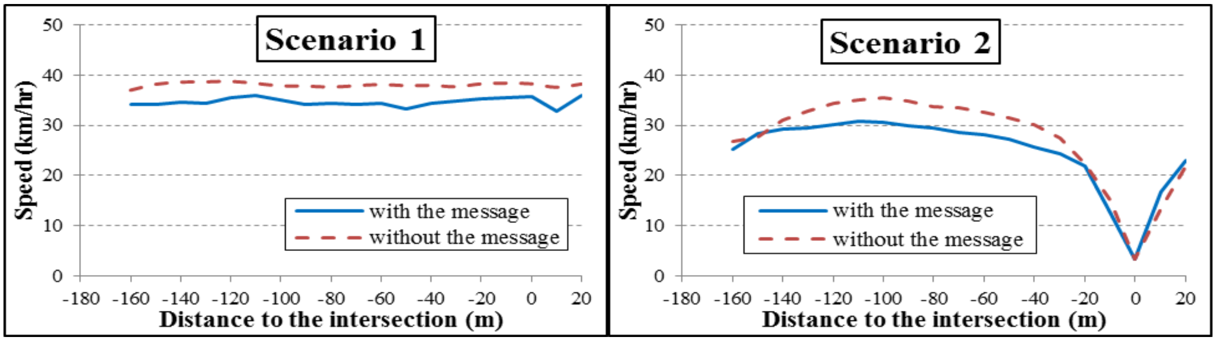

Figure 3: The speed profiles for both scenarios with and without the advisory message.

The average speed profiles were created for each scenario in the two cases (i.e., with and without the message) as shown in Figure 4. It is worth mentioning that the message is relayed to the driver once the smartphone receives the data from the OBE and after the OBE is connected to the RSU. In other words, the driver will start hearing the message around 190 meters from the intersection. As mentioned previously, because the study area is bounded by two intersections 200 meters to the east and 190 meters to the west, the profiles start from 160 meters from the intersection to avoid the effect of these adjacent intersections. Figure 4 shows that the driver speed when the messages are being played is less than the speed without the message. According to the Wilcoxon Signed Rank Test, the difference between the speeds with and without the message is significant at the 95% confidence level for both scenarios and the *p*-value is 0.00013 and 0.00148 for scenario 1 and 2, respectively. These results show that the message has a significant impact on the driver's choice of speed as he is approaching the study intersection.

4.2 Maximum Speed

The maximum speed not only reflects the impact of the message on driver behaviour, but it can also be indicative of the severity of an expected collision. When the maximum speed is reduced, it is expected that a collision, if it occurs, will be less severe. The maximum speed between two conflicting vehicles is typically used as a surrogate safety measure (Gettman and Head 2003). The maximum speed is calculated for each single run and the maximum speed percentage frequency is plotted for each scenario for both cases as shown in Figure 5. The figure shows that the maximum speed percentage frequency, for scenario 1, has been reduced and distributed in a wide range instead of the being concentrated from 40 to 42 km/h. For scenario 2, the peak of the maximum speed distribution is not only reduced but also shifts to lower values.

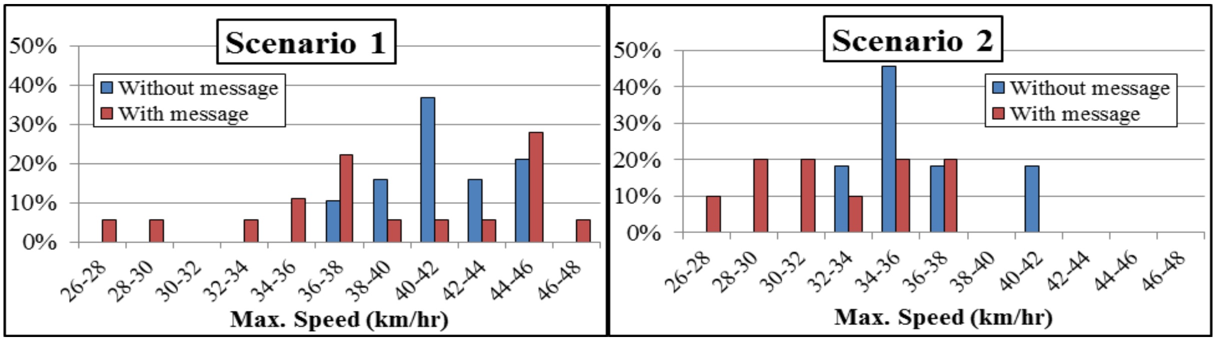

Figure 4: The maximum speed percentage frequency for the runs of each scenario with and without the message.

4.3 Acceleration\Deceleration Profiles

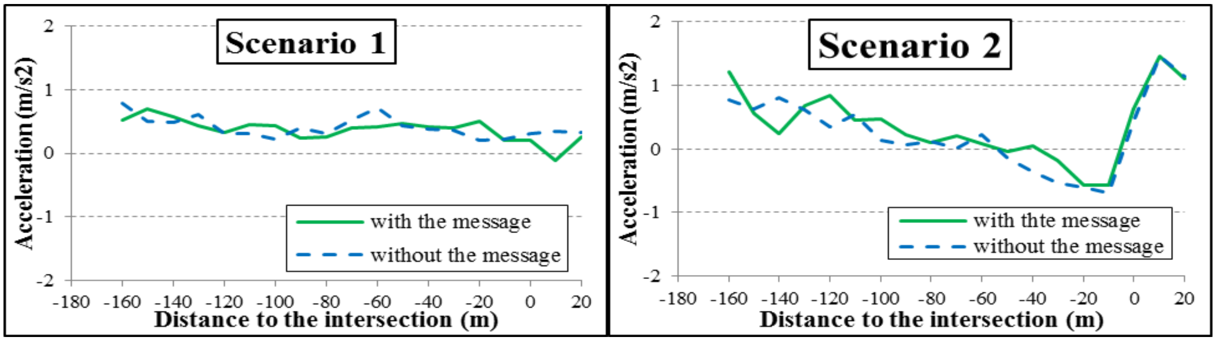

Figure 5: The acceleration\deceleration profiles for both scenarios with and without the advisory message.

The acceleration\decelerations profiles were generated for both scenarios with and without the message. As shown in Figure 6, the differences between the acceleration\deceleration profiles for the first scenario are not significant, which is reinforced by the Wilcoxon Signed Rank Test. The results for this scenario show that there is no significant difference at the 95% confidence level, as the *p*-value is 0.52. This may be due to the fact that, approaching the intersection during the green phase, as in scenario 1, the driver is cautious and prefers to maintain that same speed as shown in Figure 4. On the other hand, the Wilcoxon Signed Rank Test result for scenario 2, for the whole acceleration\deceleration profile, shows that the difference is not significant at the 95% confidence level, as the *p*-value is 0.0534, which is very close to the significance threshold. In fact, this difference is significant at the 90% confidence level. When the deceleration rates just before the intersection (i.e., 50 meters before the intersection) were analyzed separately, using the same test, the difference between the deceleration rates with the message and without the message is significantly different at the 95% confidence level and the *p*-value is 0.0277. This result implies that the message has a significant effect on changing the driver's deceleration behaviour near the intersection as the deceleration with the message was smoother (i.e. less deceleration values) than without the message as shown in Figure 6.

5. CONCLUSIONS

This paper provides a proof-of-concept of the V2I communication architecture and analyzes the change in driver behaviour due to an advisory message and evaluates the impact of this message on behaviour using a real-life test case. The advisory message is an audible message sent to the driver using a smartphone application that is based on the GLOSA application. The SPaT is sent from RSU to OBE on the vehicle, which in turn is sent from the OBE to the smartphone via Bluetooth. The smartphone application processes the remaining time of green or red when the smartphone receives the data from the OBE, using the vehicle speed and distance to the intersection. Consequently, the smartphone will relay the audible message to the driver based on the processed data.

A four-hour field test was executed at an urban intersection in order to evaluate the change in a driver's behaviour due to the message. The test was divided into two cases, which are driving the vehicle with and without the audible message. Two scenarios were tested using the collected data. The first scenario involves a vehicle approaching the intersection at the green onset so the driver will travel through the intersection without having to stop. The second scenario involves a vehicle approaching the intersection at the red onset, therefore requiring the driver to come to a complete stop. Comparisons between the speed profiles, maximum speed, and acceleration\deceleration profiles when the message is on and off were conducted. The results show that the differences between the speed profiles and maximum speeds for both cases (i.e., with and without the message) are significant. The difference between the acceleration\deceleration profiles for both scenarios is not significant, while the difference in the deceleration rate starting from 50 m before the intersection was significant.

In summary, this paper confirms that an audible advisory message sent to the driver through V2I communication can significantly affect the driver's behaviour. The findings showed that the average and maximum speeds were reduced as a consequence of driving through the intersection and also due to the decrease in deceleration values just before stopping at the intersection during the red phase. However, this study has several limitations, which are related to the fact that only one connected vehicle was tested with no preceding vehicles. Consequently, the results are based on changes in a single driver. Further testing is required to validate the results of this study. Nevertheless, the limited results from this study show how CV-V2I technologies can have a huge impact on changing driver behavior.

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