2018 IEEE Intelligent Vehicles Symposium (IV)
Changshu, Suzhou, China, June 26-30, 2018

Analysis of Driver Behaviors while Using In-Vehicle Traffic Light with Partial Deployment of V2I Communication

Bo Yang, Rencheng Zheng, Tsutomu Kaizuka, and Kimihiko Nakano, *Member, IEEE*

Abstract— **An in-vehicle traffic light system was proposed to assist drivers at intersections, by displaying traffic light inside vehicles based on vehicular communication. Driving simulator experiments have demonstrated that the system can be an effective method to provide assistance for drivers. However, previous studies assumed that all the vehicles were equipped with vehicular communication devices and the proposed in-vehicle traffic light, which is still impossible in the actual driving environment. Therefore, it is necessary to evaluate the availability of the system in a driving condition when both in-vehicle traffic light equipped and unequipped vehicles exist. This study implemented the in-vehicle traffic light system with a real electric vehicle at a signalized intersection, based on V2I communication. An experiment involving 12 participants and two vehicles were performed, to analyze the influences on driver behaviors while applying the in-vehicle traffic light in a partial deployment environment. It was observed that the application of in-vehicle traffic light in a preceding vehicle could significantly reduce the maximum deceleration of its following vehicle, even when the following vehicle was unequipped with the system.**

I. Introduction

It has become much easier for vehicles to gather traffic information at intersections with the rapid development of vehicular communication. An in-vehicle traffic light system was then proposed to assist drivers in passing through intersections, by displaying virtual traffic light information inside vehicles, based on V2X communication [1, 2]. Previous driving simulator studies assumed that all the vehicles were equipped with the proposed system, which would require a full deployment of V2X communication. However, the deployment process of the vehicular communication may last for decades. To investigate the availability of the proposed system in a partial deployment environment, this study firstly implemented the in-vehicle traffic light system with real electric vehicles at a signalized intersection. A driving experiment with 12 participants and two vehicles was then performed to investigate how an in-vehicle traffic light equipped vehicle would influence the driver behaviors of its following vehicle, which was unequipped with the proposed system.

*Research supported by the special fund of Institute of Industrial Science, the University of Tokyo.

Bo Yang is with the Institute of Industrial Science, the University of Tokyo, Tokyo, 153-8505 Japan (+81-3-5452-6884; e-mail: b-yang@iis.u-tokyo.ac.jp).

Rencheng Zheng and Tsutomu Kaizuka are with the Institute of Industrial Science, the University of Tokyo, Tokyo, 153-8505 Japan (e-mail: my_topzrc@yahoo.co.jp, tkaizuka@iis.u-tokyo.ac.jp).

Kimihiko Nakano is with the Interfaculty Initiative in Information Studies, the University of Tokyo, Tokyo, 153-8505 Japan (e-mail: knakano@iis.u-tokyo.ac.jp).

Previous studies on driver assistance systems normally applied sensors and cameras to obtain necessary traffic information at intersections [3-5]. However, the usage of sensors and cameras might have some disadvantages, including the limited operating distances and high time delays. Recently, the popularization of vehicular communication technologies provides a promising method to solve these problems, making the information exchange at intersections easier and faster. Meanwhile, more and more in-vehicle displays are invented and have been accepted as an important way to provide information for drivers. The in-vehicle traffic light concept was then proposed, based on the developments of vehicular communication and in-vehicle displays [1].

Most of the studies on the in-vehicle traffic light were focused on the feasibility problems, including the communication delay issue and the loss of protocol messages [6-8]. As for the applications of in-vehicle traffic light, some traffic simulations and driving simulator experiments were performed. For the results of traffic simulations, it was found that the flow rate of traffic stream in an urban area might be improved by more than 60%, with the application of in-vehicle traffic light [9]. Moreover, it was reported that the amount of carbon dioxide emissions might be reduced by 18%, when the in-vehicle traffic light was applied [10]. Therefore, it was considered that the traffic efficiency at intersections might be significantly improved by using the in-vehicle traffic light.

For the research on the analysis of in-vehicle traffic light in driving simulator experiments, our previous driving simulator study demonstrated that undesired braking and accelerating operations could be significantly reduced with the guidance provided by the in-vehicle traffic light at signalized intersections [2]. As for the usage of in-vehicle traffic light at unsignalized intersections, we also performed a driving simulator study, in which we concluded that driving safety might be significantly improved by the in-vehicle traffic light, without increasing the level of driver distraction [11-13].

However, these studies assumed that all the vehicles had already been equipped with the vehicular communication devices, which were necessary for the implementation of in-vehicle traffic light. On the other hand, it is considered that the full deployment of vehicular communication devices will still cost more than decades [14]. Therefore, it is necessary to analyze the effectiveness of the proposed system, especially the influences on driver behaviors, in a driving condition when the in-vehicle traffic light unequipped vehicles exist. This research will focus on the analysis of partial application of in-vehicle traffic light at signalized intersections. The implementation of the system will mainly rely on the V2I communication between the intersection and vehicles.

This paper will first present the methodology of in-vehicle traffic light for signalized intersections, and introduce the detailed information of implementing the in-vehicle traffic light with a real vehicle. Afterwards, the information of the driving scenario and evaluation indexes will be described. Finally, the results of driver behaviors will be provided, and the paper will be concluded with the implications of this study.

II. Methodology

A. In-Vehicle Traffic Light for Signalized Intersections

At a signalized intersection, the in-vehicle traffic light is proposed to display the predicted ground traffic light information for drivers.

As shown in the Fig. 1, vehicles *A* and *B* are approaching to a signalized intersection. With the application of V2I communication, the signal cycle information of the ground traffic light can be transferred to the vehicles. Meanwhile, the time-to-intersection of the vehicles can be estimated in real time, using the distances to the intersection and the speeds of the vehicles.

$$T_i(t) = \frac{D_i(t)}{V_i(t)} \tag{1}$$

where $T_i(t)$ represents the time-to-intersection, $D_i(t)$ is the distance to intersection and $V_i(t)$ is the speed of the vehicle at time *t*.

After comparing the obtained signal cycle information of ground traffic light with the calculated time-to-intersection, the ground traffic light when the vehicle arrive at the intersection can be predicted and then be displayed to drivers with an in-vehicle display.

As shown in the Fig. 1, for the vehicle *A*, a red in-vehicle traffic light is displayed as the ground traffic light is predicted to be red when it arrives at the intersection. However, for the vehicle *B*, although the ground traffic light which controls the road is still in the red phase, a green in-vehicle traffic light is presented to the driver, which means that the ground traffic light will turn green when the vehicle *B* finally reaches the intersection.

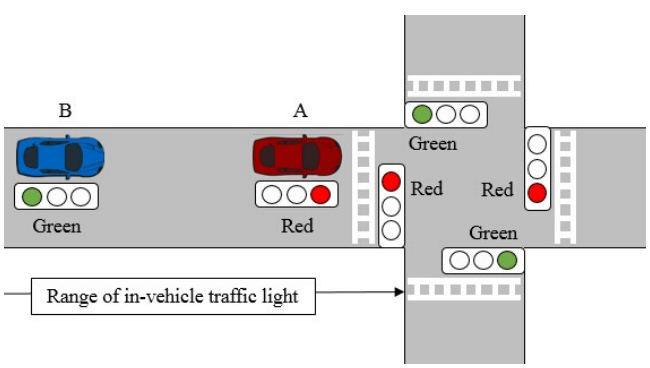

Fig. 1. In-vehicle traffic light for signalized intersections.

B. Implementation of In-Vehicle Traffic Light

For the system diagram of in-vehicle traffic light with a real vehicle, as shown in the Fig. 2, when a vehicle equipped with the in-vehicle traffic light is approaching an intersection, the V2I communication with the ground traffic light will be firstly established, using the 700 MHZ band. Then the on-board unit of the vehicle, as shown in the Fig. 3, will receive the signal cycle information of the ground traffic light and send the obtained information to an in-vehicle laptop computer, in which the program of the in-vehicle traffic light is installed. Meanwhile, for the collection of the speed and location information of the vehicle, as shown in the Fig. 3, a Globalsat BU-353S4 GPS receiver was applied. The receiver has an update rate of 20 Hz. The accuracy of position can be below 2.5 meters and the accuracy of speed is 0.1m/s.

With the obtained speed and location information, the time to arrival at the intersection of the vehicle will be estimated with the program of in-vehicle traffic light. Finally, by comparing the calculated arrival time with the signal cycle of the ground traffic light, the predicted traffic light information will be displayed to drivers with an in-vehicle display if the vehicle has entered the range of the in-vehicle traffic light.

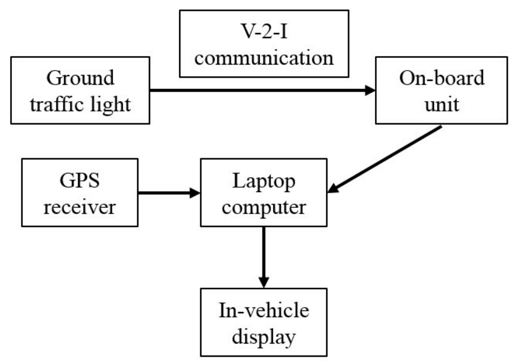

Fig. 2. System diagram of in-vehicle traffic light with a real vehicle.

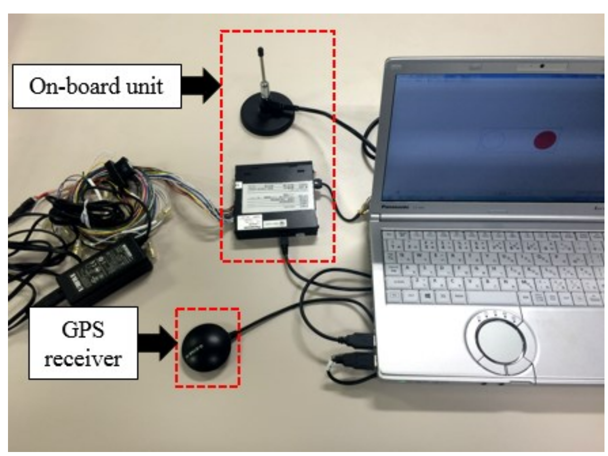

Fig. 3. On-board unit and GPS receiver for in-vehicle traffic light.

III. Experiment

This experiment was approved by the Ethical Examination Committee of the Office of Life Science Research Ethics and Safety at the University of Tokyo.

A. Participants

Twelve healthy participants took part in the driving experiment. The participants were with a mean age of 24.3 years old, range from 22.1 to 26.5 years old. All the participants had a valid driving license, with a mean driving frequency of 1.8 times per week, range from1.0 to 3.0 times per week, and an average driving experience of 3.4 years, range from 1.2 to 6.1 years. Meanwhile, a driving training of the experimental vehicle was provided for all the participants.

B. Experimental Apparatus

To investigate the influence on driver behaviors of in-vehicle traffic light in a partial deployment environment, two super compact electric vehicles, produced by Toyota Body Company, were used in the experiment. As shown in the Fig. 4, the length, width and height of the vehicle were 2.3, 1.1 and 1.5 meters, respectively. The maximum speed of the vehicle can be 60 km/h.

For the display of the in-vehicle traffic light, as shown in the Fig. 5, an 8-inch display was chosen for this experiment (LCD-8000V, Century Company). A non-glare panel was adopted with the display, making it easier to be observed by the participants. As for the position of the display, it was positioned according to the guideline of in-vehicle display systems.

C. Driving Task

The experiment was conducted in the Chiba experimental campus of the University of Tokyo. There was no interfering objects, including tall buildings, around the experimental area, which assured the availability of the GPS information.

The driving route was presented in the Fig. 6. There was one signalized intersection on the track. To avoid the influences of pedestrian traffic light on the drivers, the pedestrian traffic light at the intersection was turned off during the experiment. Meanwhile, to evaluate how an in-vehicle traffic light equipped vehicle influences the driver behaviors of its following vehicle, two same vehicles were placed in a row. The preceding car started 50 meters away from the intersection, and the following car started 10 meters behind the preceding car, taking into account the minimum stopping distance, to keep driving safety. Considering the speed limit of the campus, participants were required to drive with a speed limit of 20 km/h.

Twelve experimental conditions were prepared for every participant, as shown in the Table. 1. It was designed based on three factors: either pass through or stop at the intersection (a pass scenario or a stop scenario), the place of driver (in the preceding vehicle or following vehicle), and the deployment conditions of in-vehicle traffic light (both the two vehicles unequipped, only the preceding vehicle equipped, and only the following vehicle equipped).

Pass Scenario: In the pass scenario, the ground traffic light would turn from red to green just before the vehicles arrived at the intersection.

Stop Scenario: In the stop scenario, the ground traffic light would change from green to red when the vehicles reached the intersection.

The twelve participants were divided randomly into six groups. Every group has two participants, of which one drove the preceding vehicle, and the other drove the following vehicle. And the experiment was conducted considering counterbalancing.

D. Dependent Measures and Evaluation Indexes

To evaluate the driving operations of the participants, the acceleration data of the vehicles were recorded with a wireless motion sensor. The range of the motion sensor was ± 16 G, and the sampling frequency was set as 20 Hz. Moreover, the experiment time, the location and speed information were also recorded with the GPS receivers.

Meanwhile, the motion sensors and GPS receivers were fixed on each vehicle, and were simultaneously controlled by a laptop computer. Therefore, all the information of the two vehicles could be recorded at the same time.

Fig. 4. Electric vehicle used as the experimental platform.

Fig. 5. Display for the in-vehicle traffic light.

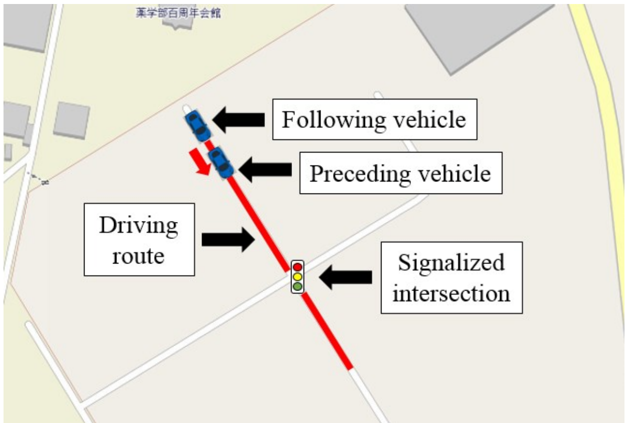

Fig. 6. Driving route of the experiment (based on open street map).

TABLE 1. EXPERIMENTAL CONDITIONS

No.	Equipment of In-Vehicle Traffic Light for Participant			
	Scenario	*Place of driver*	*Preceding*	*Following*
1	Pass	Preceding	Unequipped	Unequipped
2	Pass	Following	Unequipped	Unequipped
3	Pass	Preceding	Equipped	Unequipped
4	Pass	Following	Equipped	Unequipped
5	Pass	Preceding	Unequipped	Equipped
6	Pass	Following	Unequipped	Equipped
7	Stop	Preceding	Unequipped	Unequipped
8	Stop	Following	Unequipped	Unequipped
9	Stop	Preceding	Equipped	Unequipped
10	Stop	Following	Equipped	Unequipped
11	Stop	Preceding	Unequipped	Equipped
12	Stop	Following	Unequipped	Equipped

For the evaluation of driving operations in the pass scenario, two indexes—maximum deceleration and travel time were applied. The maximum deceleration was defined as the maximum value of the recorded deceleration when the vehicle was approaching the intersection. As for the travel time, it was defined as the period from the starting time to the moment when the vehicle crossed the intersection. For the stop scenario, the maximum deceleration index was used to evaluate the driving operations.

E. Data Analysis

Statistical analysis was conducted to distinguish that whether the usage of in-vehicle traffic light significantly influenced the driver behaviors of the 12 participants for both the preceding and following vehicles. The significance level was set at 0.05.

For the evaluation of maximum deceleration and travel time, a one-way repeated measures ANOVA was applied, with the deployment conditions of in-vehicle traffic light (both the two vehicles unequipped, only the preceding vehicle equipped, only the following vehicle equipped) as the within-participant factor. And the Bonferroni correction was applied as the adjustment method.

IV. RESULTS

The results of maximum deceleration and travel time were presented for both the preceding and the following vehicles in the pass scenario. For the two vehicles in the stop scenario, the results of maximum deceleration would be explained.

A. Results of pass scenario

Maximum Deceleration: For the maximum deceleration of the preceding vehicle in the pass scenario, the results were provided in the Fig. 7. The data satisfied the requirement of homogeneity of variance ($p > 0.05$). It can be observed that, if the preceding vehicle itself was in-vehicle traffic light equipped, the maximum deceleration could be significantly reduced, compared to the condition when both the two vehicles were without in-vehicle traffic light ($p < 0.001$). And for the preceding vehicle, there was no difference between the conditions when only the following vehicle used the in-vehicle traffic light and that when both the two vehicles were unequipped ($p = 1.00$). It could be concluded that, in the pass scenario, the maximum deceleration of the preceding vehicle significantly decreased by applying the in-vehicle traffic light.

The results of the following vehicle in the pass scenario were presented in the Fig. 8. The data satisfied the requirement of homogeneity of variance ($p > 0.05$). When the following vehicle was equipped with in-vehicle traffic light, the maximum deceleration significantly decreased, compared to the condition when both the two vehicles were unequipped ($p = 0.001 < 0.05$). Moreover, for the following vehicle, compared to the condition when both the two vehicles were without in-vehicle traffic light, the maximum deceleration was also significantly reduced even when only its preceding vehicle used the in-vehicle traffic light ($p < 0.001$).

The result suggested that, for a following vehicle, the application of in-vehicle traffic light could significantly reduce the maximum deceleration. Furthermore, even the following vehicle itself was without in-vehicle traffic light, the maximum deceleration could also be significantly reduced if its preceding vehicle was in-vehicle traffic light equipped.

Travel Time: For the travel time of the preceding vehicle, the results can be observed from the Fig. 9. The data satisfied the requirement of homogeneity of variance ($p > 0.05$). When the preceding vehicle was equipped with in-vehicle traffic light, the travel time was significantly reduced, compared to the condition when both the two vehicles were unequipped ($p < 0.001$). And for the preceding vehicle, there was no significant difference between the conditions when only the following vehicle used in-vehicle traffic light and that when both the two vehicles were without in-vehicle traffic light ($p = 1.00$).

It was indicated that the travel time of a preceding vehicle could be significantly reduced with the application of in-vehicle traffic light in the pass scenario.

As shown in the Fig. 10, for the travel time of the following vehicle, the data satisfied the requirement of homogeneity of variance ($p > 0.05$). Surprisingly, when only the following vehicle was equipped with in-vehicle traffic light, there was no significant difference in travel time, compared to the condition when both the two vehicles were unequipped (p = 1.00). However, for the following vehicle, compared to the condition when both the two vehicles were without in-vehicle traffic light, the travel time significantly deceased if the preceding vehicle was equipped with in-vehicle traffic light ($p = 0.003 < 0.05$).

The results indicated that, for a following vehicle, the travel time could be significantly reduced if its preceding vehicle was in-vehicle traffic light equipped. However, no significant reduction in travel time could be observed even when the following vehicle was equipped with in-vehicle traffic light if its preceding vehicle was in-vehicle traffic light unequipped.

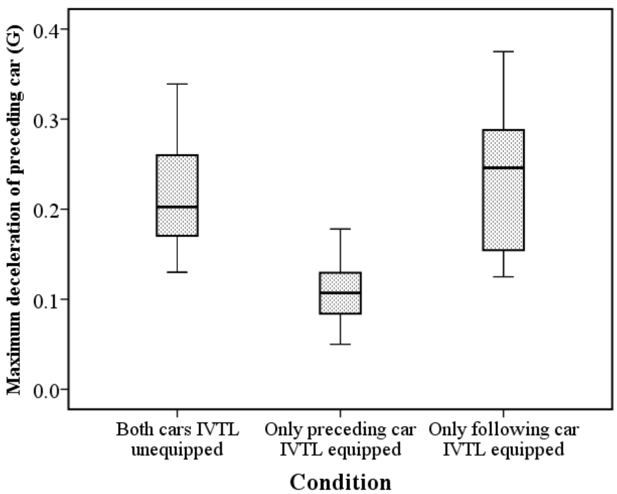

Fig. 7. Result of maximum deceleration for the preceding vehicle in the pass scenario. IVTL is short for in-vehicle traffic light.

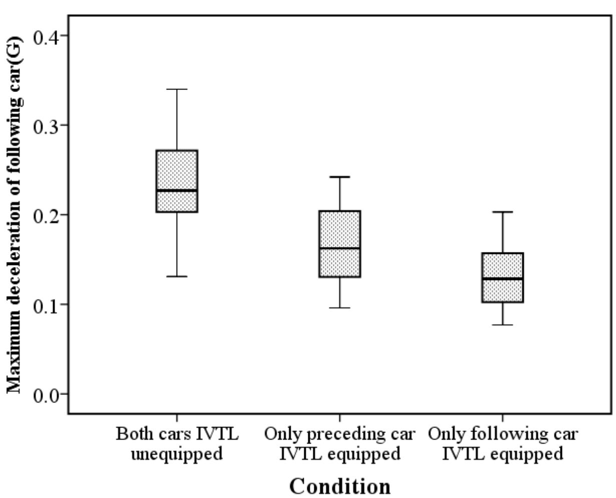

Fig. 8. Result of maximum deceleration for the following vehicle in the pass scenario. IVTL is short for in-vehicle traffic light.

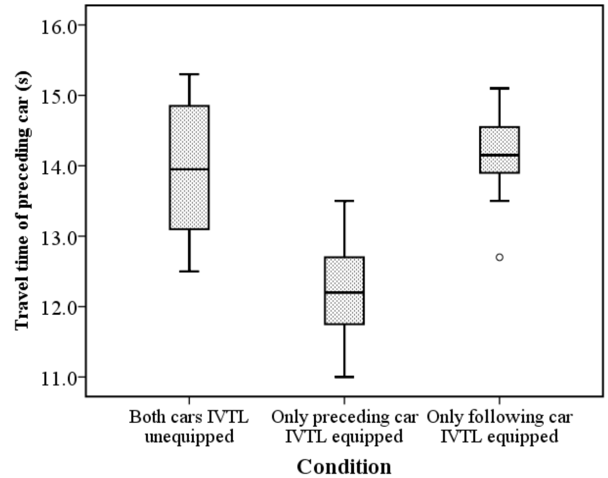

Fig. 9. Result of travel time for the preceding vehicle in the pass scenario. IVTL is short for in-vehicle traffic light. Mild outlier is indicated by a circle (calculated as 1.5-3x the interquartile range).

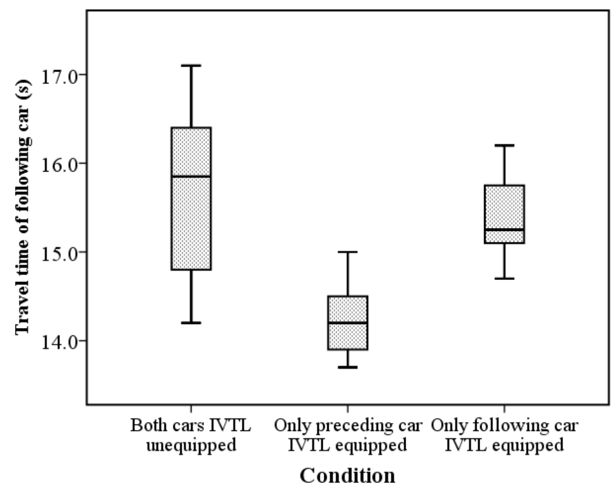

Fig. 10. Result of travel time for the following vehicle in the pass scenario. IVTL is short for in-vehicle traffic light.

B. *Results of stop scenario*

The results of maximum deceleration for the preceding vehicle in the stop scenario were shown in the Fig. 11. The data satisfied the requirement of homogeneity of variance ($p > 0.05$). When only the preceding vehicle was equipped with in-vehicle traffic light, the maximum deceleration was significantly reduced, compared to the condition when both the two vehicles were unequipped ($p = 0.042 < 0.05$). And for the preceding vehicle, there was no significant difference between the conditions when only the following vehicle was equipped and that when both the two vehicles were unequipped (p = 1.00).

It was suggested that the application of in-vehicle traffic light could significantly reduce the maximum deceleration for a preceding vehicle in the stop scenario.

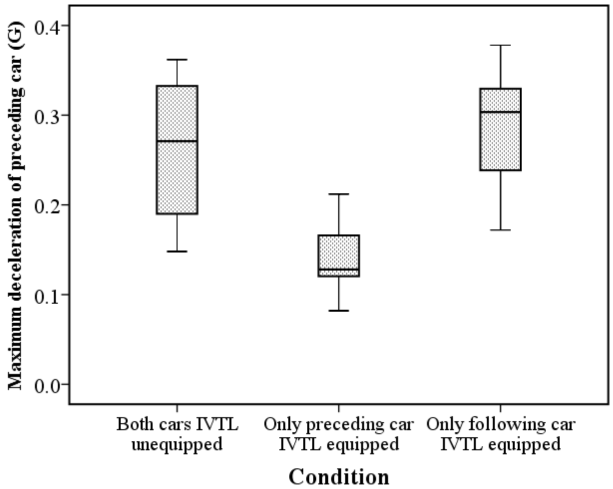

Fig. 11. Result of maximum deceleration for the preceding vehicle in the stop scenario. IVTL is short for in-vehicle traffic light.

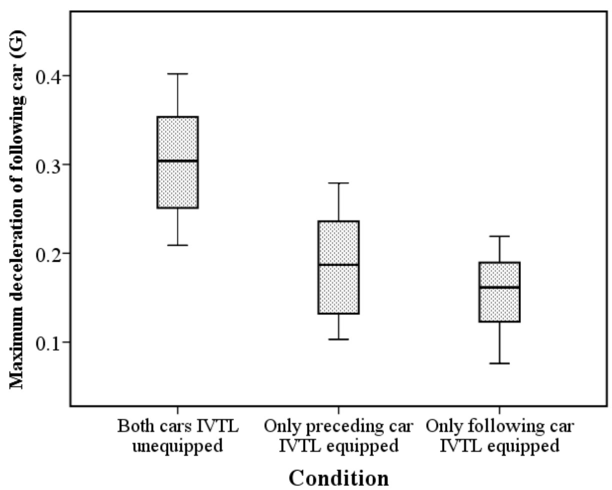

Fig. 12. Result of maximum deceleration for the following vehicle in the stop scenario. IVTL is short for in-vehicle traffic light.

As presented in the Fig. 12, for the results of maximum deceleration of the following vehicle, the data also satisfied the requirement of homogeneity of variance ($p > 0.05$). When only the following vehicle was in-vehicle traffic light equipped, the maximum deceleration significantly decreased, compared to the condition when both the two vehicles were unequipped ($p = 0.002 < 0.05$). However, for the following vehicle, there was no significant difference between the conditions when the vehicle itself used in-vehicle traffic light and that when only its preceding vehicle was equipped with in-vehicle traffic light ($p = 0.59$). It was indicated that, for a following vehicle, the maximum deceleration significantly decreased when in-vehicle traffic light was applied in it. Interestingly, a significant reduction of maximum deceleration could also be observed when only its preceding vehicle was in-vehicle traffic light equipped.

V. CONCLUSION

This study implemented an in-vehicle traffic light system with real electric vehicles, based on V2I communication at a signalized intersection. An experiment involving 12 participants was performed to evaluate the influences on driver behaviors when the proposed system was applied in a partial deployment environment.

It was observed that for an in-vehicle traffic light equipped vehicle, the maximum deceleration was significantly reduced. Meanwhile, the application of in-vehicle traffic light in a preceding vehicle could significantly reduce the maximum deceleration of its following vehicle, even when the following vehicle was system unequipped. The results indicated that the proposed in-vehicle traffic light could still be applicable in a driving condition when both in-vehicle traffic light equipped and unequipped vehicles exist.

REFERENCES

[1] O. K. Tonguz, “Biologically inspired solutions to fundamental transportation problems,” IEEE Communications Mag., vol. 49, no. 11, 2011, pp. 106–115.

[2] B. Yang, R. C. Zheng, Y. D. Yin, S. Yamabe, and K. Nakano, “Analysis of influence on driver behaviour while using in-vehicle traffic lights with application of head-up display,” IET Intell. Transp. Syst., vol. 10, no. 5, 2016, pp. 347–353.

[3] A. Menon, C. Gorjestani, C. Shankwitz, and M. Donath, “Roadside range sensors for intersection decision support,” the 7th IEEE Int. Conf. on Intell. Transp. Syst., Washington D. C. USA, 2004, pp. 210-215.

[4] J. A. Jang, K. Choi, and H. Cho, “A fixed sensor-based intersection collision warning system in vulnerable line-of-sight and/or traffic-violation-prone environment,” IEEE Trans. Intell. Transp. Syst., vol. 13, no. 4, Dec. 2012, pp. 1880–1890.

[5] Federal Highway Administration, “The design of a minimal sensor configuration for a cooperative intersection collision avoidance system” U.S. Department of Transportation, 2010, pp. 1–61.

[6] A. Bazzi, A. Zanella, and B. M. Masini, “A distributed virtual traffic light algorithm exploiting short range V2V communications,” Ad Hoc Networks, vol. 49, 2016, pp. 42–57.

[7] T. Neudecker, N. An, O. K. Tonguz, T. Gaugel, and J. Mittag, “Feasibility of virtual traffic lights in non-line-of-sight environments,” Proc. the ninth ACM int. workshop on Vehicular inter-networking, syst., and applications, Low Wood Bay, UK, June 2012, pp. 103-106.

[8] N. Fathollahnejad, E. Villani, R. Pathan, R. Barbosa, and J. Karlsson, “On reliability analysis of leader election protocols for virtual traffic lights,” 43rd IEEE/IFIP Confer. Dependable Syst. and Networks Workshop, Budapest, Hungary, June 2013, pp.1-12.

[9] M. Ferreira, R. Fernandes, H. Conceição, W. Viriyasitavat, and O. K. Tonguz, “Self-organized traffic control,” ACM Int. Workshop Veh. InterNETwork, New York, United States, September 2010, pp. 85–90.

[10] M. Ferreira and P. M. Ore, “On the impact of virtual traffic lights on carbon emissions mitigation,” IEEE Trans. Intell. Transp. Syst., vol. 13, no. 1, 2012, pp. 284–295.

[11] B. Yang, R. C. Zheng, and K. Nakano, “Application of in-vehicle traffic lights for improvement of driving safety at unsignalized intersections,” Proc. IEEE Intell. Veh. Symp., Seoul, Korea, June 2015, pp. 628–633.

[12] B. Yang, R. C. Zheng, K. Shimono, T. Kaizuka, and K. Nakano, “Evaluation of the effects of in-vehicle traffic lights on driving performances for unsignalised intersections,” IET Intell. Transp. Syst., vol. 11, no. 2, 2017, pp. 76-83.

[13] B. Yang, R. C. Zheng, T. Kaizuka, and K. Nakano, “Influences of waiting time on driver behaviors while implementing in-vehicle traffic light for priority-controlled unsignalized intersections,” Journal of Advanced Transp., ID 7871561, 2017, pp. 1-12.

[14] The New York Times, available at https://www.nytimes.com/aponline/2016/12/13/us/politics/ap-us-talking-cars.html?_r=0, accessed on 30th, July, 2017.