Evaluation of the effects of in-vehicle traffic lights on driving performances for unsignalled intersections

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Abstract: Ground traffic lights are essential for maintaining traffic efficiency and safety at intersections. However, unsignalled intersections are still frequent in actual traffic environments. With the development of new forms of vehicular communication, in-vehicle traffic lights can assist drivers at unsignalled intersections. The authors proposed two types of in-vehicle traffic lights to assist drivers; these corresponded to two-way and all-way stop-controlled intersections. They adopted gap acceptance theory and a first-come-first-served strategy to determine passing priority for the two types of intersections, respectively. They then conducted a driving simulator experiment involving 23 participants, to investigate driver behaviours elicited by the proposed system. They prepared four experimental conditions with combinations of in-vehicle traffic lights and auditory warnings. The authors’ experimental results indicated that in-vehicle traffic lights were associated with significantly longer post-encroachment times and a significantly shorter maximum brake stroke. In terms of eye-gaze behaviours, the percentage of gaze concentration to the road centre area and mean glance durations were deemed acceptable for the avoidance of visual distraction, when in-vehicle traffic lights were presented via a head-up display. Therefore, their analysis of driver behaviours indicates that in-vehicle traffic lights can effectively provide driver assistance at unsignalled intersections.

1 Introduction

The improvement of traffic efficiency and safety at unsignalled intersections is an urgent issue that requires attention [1]. Recently, the novel concept of virtual traffic lights has been proposed as a way to resolve the issue, based on vehicle-to-vehicle and vehicle-to-infrastructure communication technologies. Virtual traffic lights involve the presentation of traffic light information inside vehicles, instead of via ground traffic lights [2]. In this study, given the application of vehicle-to-vehicle communication technologies at unsignalled intersections, we developed an in-vehicle traffic light system to assist drivers at two-way and all-way stop-controlled intersections. We used a driving simulator to investigate this system and its influence on driver behaviours.

Driver assistance systems for unsignalled intersections normally relied on the application of sensors and cameras [3, 4]. A cooperative collision warning system was proposed to provide warning information to drivers at unsignalled intersections, using ubiquitous sensor network [5]. Results indicated that the system successfully forecasted dangerous situations up to 94.3%. For the usage of cameras, an automatic conflict detection method using image sequences was proposed for unsignalled intersections, which could detect traffic collisions more accurately and effectively [6]. Compared to the above previous studies, virtual traffic lights were proposed based on vehicle-to-x communications, which had the advantages of minimising time delays and expansion of operating distances. Furthermore, according to a traffic simulation study, the application of virtual traffic lights may increase traffic flow rates in urban areas by more than 60% [7]. Virtual traffic lights were also associated with a 18% reduction in carbon dioxide emissions in another traffic simulation study [8].

Even when only 40% of vehicles were equipped with virtual traffic lights, one simulation study with all-way stop-controlled intersections found a 14.3% increase in the capacity of intersections and a 40.3% reduction in the average trip duration [9]. The above simulation studies suggest that virtual traffic lights have great potential in improving traffic efficiency. However, it is required to investigate the practicality of this approach in driving conditions.

We refer to virtual traffic lights applied in driving conditions as in-vehicle traffic lights, to be distinguished from those used in traffic simulations. For the application of in-vehicle traffic lights at signalised intersections, it was found that when the real-time state of conventional traffic lights was projected on the windshield to drivers, the driving performances using virtual traffic lights did not significantly differ from the performances using conventional traffic lights [10]. We also conducted a previous driving simulator study, in which we proposed an in-vehicle traffic light system that was based on vehicle-to-infrastructure communications. The purpose of this system was to provide real-time or predicted traffic light information for drivers at signalised intersections. We verified that providing the predicted information could significantly reduce disruptive braking and accelerating operations [11]. However, it remains unclear for the effects of in-vehicle traffic lights on driver behaviours at unsignalled intersections.

For the application of in-vehicle traffic lights at unsignalled intersections, we conducted a preliminary driving simulator experiment in which we briefly investigated driving operations, including speed variance and brake stroke [12]. However, it is still necessary to evaluate the driver distraction elicited by the in-vehicle traffic lights by analysis of driver behaviours. Driver behaviours are of great importance in the evaluation of newly proposed driver assistance systems [13]. An examination of 474 traffic accidents revealed that all accidents were associated with errors that arose as a consequence of distraction [14]. Indeed, one of the functions of driver assistance systems is to minimise driver distraction. This is especially challenging in the design of driver assistance systems that display information via a visual modality, as this may increase visual distraction [15]. The extent of visual distraction induced by visual-based driver assistance systems can be studied by analysing eye-gaze behaviours [16]. Recent studies have demonstrated that non-intrusive eye-gaze tracking technology can produce accurate measurements of eye-gaze behaviours [17]. Such non-intrusive technology has already been used to analyse eye-gaze behaviours while participants interacted with navigation.
systems [18]. To accurately evaluate the degree of visual distraction elicited by the proposed in-vehicle traffic lights, we used eye-gaze tracking technology to measure the eye-gaze behaviours of drivers.

The objective of this study was to further provide an insight into the influences of in-vehicle traffic lights on driving performances at unsignalised intersections, and validate the proposed system via analysis of driving operations and eye-gaze behaviours.

In this paper, we first present the design of an in-vehicle traffic light system for actual two-way and all-way stop-controlled intersections, and then provide the detailed methods of a driving simulator experiment. Afterwards, we present the results and discuss our findings regarding driving operations and eye-gaze behaviours. We conclude with the implications and limitations of this study.

2 In-vehicle traffic lights

2.1 Two-way stop-controlled intersections

At a two-way stop-controlled intersection, the roads that are not controlled by stop signs are defined as the major roads. Conversely, the stop-controlled roads are referred to as the minor roads. Vehicles on the major roads have priority and are able to pass through the intersection first. The difference in priority between vehicles on major and minor roads is an important factor in the design of in-vehicle traffic lights.

This study assumed that all the vehicles were equipped with vehicle-to-vehicle communications and in-vehicle traffic lights. For the two-way stop-controlled intersection, it was assumed as an intersection with a one-way major road and two minor ones. As a limitation, the case when two minor-road vehicles simultaneously enter the intersection was not studied. The range of in-vehicle traffic lights was set at 80 m, in consideration of the quality of vehicular communications and the speed limit of the driving route [19].

For vehicles that are beyond the range of in-vehicle traffic lights or that have passed through the intersection, no in-vehicle traffic light is displayed. For minor-road vehicles within the range of in-vehicle traffic lights that have not yet arrived at the intersection, a red light is displayed to remind drivers to stop at the stop line before crossing the upcoming intersection. For minor-road vehicles within the range of in-vehicle traffic lights and minor-road vehicles that have reached the intersection, the signals given by the in-vehicle traffic lights are determined based on gap acceptance theory. If \( F(x) \) is the function controlling the in-vehicle traffic lights at a two-way stop-controlled intersection, where \( F(x) = 1 \) represents a green light, \( F(x) = 0 \) represents a blinking yellow light, and \( F(x) = -1 \) is a red light, the in-vehicle traffic lights can be expressed as follows:

\[
F(x) = P \cdot M(x) + (1 - P) \cdot N(x) \tag{1}
\]

where \( x \) is a major-road gap for the waiting minor-road vehicles; \( P \) is a parameter for distinguishing which road a vehicle is on (\( P = 1 \) for major-road vehicles and \( P = 0 \) for minor-road vehicles); and \( M(x) \) and \( N(x) \) are functions that control the traffic lights for major-road vehicles and the waiting minor-road vehicles, respectively,

\[
M(x) = \begin{cases} 
1, & N(x) \neq 1 \\
0, & N(x) = 1 
\end{cases} \tag{2}
\]

\[
N(x) = \begin{cases} 
-1, & x < C_{gap} \\
1, & x \geq C_{gap} 
\end{cases} \tag{3}
\]

where \( C_{gap} \) represents the critical gap, which is defined as the minimum time gap on the major road that will allow intersection entry for a minor-road vehicle:

\[
x = \frac{L_m(t)}{v_m(t)} \tag{4}
\]

where \( L_m(t) \) and \( v_m(t) \) refer to the instantaneous distance to the intersection and the current velocity of the upcoming major-road vehicle at time step \( t \), respectively.

In this study, the critical gap was set as 6.5 s, which was considered safe by drivers for both left and right turns [20]. As shown in Fig. 1, the minor roads are controlled by stop lines. For Fig. 1a, if the gap on the major road is less than 6.5 s, a green light is displayed to major-road vehicles within the range of in-vehicle traffic lights, and a red light is presented to the waiting minor-road vehicle. As shown in Fig. 1b, if a gap greater or equal to 6.5 s appears, the red light displayed to the waiting minor-road vehicle will turn green, permitting it to enter the intersection, and the green light presented to major-road vehicles will turn to a blinking yellow light, for warning drivers to proceed with caution.

2.2 All-way stop-controlled intersections

At an all-way stop-controlled intersection, all roads are controlled by stop signs, and vehicles approaching from all directions are required to stop before proceeding through the intersection. It was assumed that only one vehicle would be allowed to enter the all-way stop-controlled intersection at a time. In this situation, the in-vehicle traffic light system was designed based on a first-come-first-served strategy. Thus, the passing priority is decided by the order in which vehicles arrive, without other biases or preferences.

If function \( F(y) \) is applied for the control of in-vehicle traffic lights at an all-way stop-controlled intersection, where \( F(y) = 1 \) is a green light, \( F(y) = -1 \) represents a red light, and \( y \) is used to judge whether a vehicle has reached the intersection, then \( y = 1 \) for vehicles arriving at the intersection, or \( y = 0 \).

If one vehicle arrives at the intersection earlier than other vehicles, the in-vehicle traffic lights are designed to function as follows:

\[
F(y) = \begin{cases} 
1, & y = 1 \\
-1, & y = 0 
\end{cases} \tag{5}
\]
The in-vehicle traffic light system was composed of a display and a laptop computer, and used by the program of in-vehicle traffic lights to calculate the distance between the vehicle driven by the participants and the upcoming intersection. If the vehicle had entered the range of in-vehicle traffic lights, the position and speed information of all the other vehicles around the upcoming intersection would be analysed to evaluate the traffic condition, and then the appropriate colour of light would be presented to drivers by the display.

As presented in Fig. 3, a red in-vehicle traffic light was displayed using a head-up display iHUD (Springteq Electronics Corporation, New Taipei, Taiwan). The position of the head-up display was determined according to the guidelines for placement of in-vehicle display systems [21].

To investigate the influence of in-vehicle traffic lights with and without auditory cues on driver behaviours, we incorporated an auditory warning system in the driving simulator, which provided audio messages such as ‘Please stop the car’ and ‘Please start the car’ spoken in Japanese.

3.3 Task description

Fig. 4 shows the driving route used in this experiment, which is highlighted in red on the map. There are six unsignalled intersections in the track, including five two-way stop-controlled intersections, I–V, and one all-way stop-controlled intersection, VI.

After departing from the start point, participants were required to move forward on the major road through intersections I and II. After completing a right-turn from the minor road to the major road at intersection III, participants crossed intersection IV on the major road and performed a left turn from the major road to a minor road at intersection V. Finally, they passed through intersection VI and stopped at the end point.

3.4 Experimental conditions

The experiment was performed under four conditions, as presented in Table 1. There were two in-vehicle traffic light conditions: light-off and light-on, and two auditory warning conditions: audio-on and audio-off. All participants received driving simulator training before the experiment, and were required to drive under all four conditions in random order with a speed limit of 40 km/h.

3.5 Measured variables

We collected operational and driving data, including the positions, driving velocities and brake strokes of vehicles to evaluate the driving operations at intersections III and VI. As shown in Fig. 4, among all the two-way stop-controlled intersections I–V, participants were on the major roads which were...
not controlled by stop lines at intersections I, II, IV and V. Thus, participants had the passing priority at these intersections. However, for intersection III, participants were on the minor road which was controlled by a stop line. They had to enter the intersection from the minor road to the major road. Therefore, intersection III was the only one two-way stop-controlled intersection where the participants had no passing priority. Driving across intersection III was thus considered to be more challenging than driving at intersections I, II, IV, and V. We used two indices – post-encroachment time and maximum brake stroke – to evaluate the driving operations at intersection III.

Post-encroachment time is defined as the time lag between the passage of an offending vehicle and that of a conflicting vehicle in a conflict area [22]. The offending and conflicting vehicles in this experiment referred to the upcoming major-road vehicle and the vehicle operated by participants, respectively. The post-encroachment time could be calculated as follows:

\[
T_p = \frac{L_n}{v_n}
\]

where \(T_p\) is the post-encroachment time, and \(L_n\) and \(v_n\) are the instantaneous distance to the conflict area and the current velocity of the upcoming major-road vehicle, respectively.

The brake stroke variable represented the extent of brake pedal stroke during each trial, and we used its maximum value to evaluate braking performance. The brake stroke data, which ranged from 0 to 1, was recorded by the driving simulator.

Intersection VI was the only all-way stop-controlled intersection in the driving route. We used two indexes, maximum brake stroke and stopping type, to evaluate the driving operations at intersection VI.

The drivers’ stopping type at all-way stop-controlled intersections can be classified as either a complete stop or no stop. A complete stop was defined as the condition in which a vehicle reached a velocity of zero before crossing the stop line. Therefore, we were able to calculate the percentage of complete stops based on the position and velocity of the simulated vehicle driven by participants.

3.6 Eye-gaze measurement

For the evaluation of eye-gaze behaviours, eye-gaze vectors and eye positions were recorded using a Smart Eye Pro system. This enabled us to calculate two measures – percent road centre and mean glance duration. The percent road centre refers to the percentage of gaze that falls within the road centre area, which is a circular region with an eight-degree radius located around the driver’s most frequent fixation point. The mean glance duration refers to the average value of the glance duration from the instant when the gaze moved to the head-up display to the instant that the gaze moved away from it.

3.7 Subjective evaluation

We asked participants to complete a 5-point scale measurement questionnaire to investigate safety, acceptability, and fatigue. Evaluation scores ranged from 1 to 5: 1 = very low, 2 = low, 3 = average, 4 = high, and 5 = very high.

3.8 Data analysis

For the post-encroachment time, maximum brake stroke, and percent road centre, we conducted a two-way repeated measures ANOVA with the in-vehicle traffic lights (light-off or light-on) and auditory warnings (audio-off or audio-on) as two within-subject factors. The significance level was set at 0.05. Therefore, we used a 2 × 2 factorial design with the combination of light-off or light-on and audio-off or audio-on.

For the mean glance duration, we conducted a one-way repeated measures ANOVA with auditory warnings (audio-off or audio-on) as the within-subject factor.

Finally, we conducted a Friedman one-way non-parametric ANOVA and a Wilcoxon signed-rank test to analyse the results of the subjective evaluation.

4 Results

4.1 Post-encroachment time

As shown in Fig. 5a, in terms of post-encroachment time, we found significant main effects of the in-vehicle traffic lights \(F[1, 22] = 43.09, p < 0.001\) and the auditory warnings \(F[1, 22] = 5.99, p = 0.023 < 0.05\). However, we also observed a significant interaction between the in-vehicle traffic lights and the auditory warnings \(F[1, 22] = 19.56, p < 0.001\). Therefore, it was necessary to perform pairwise comparison to analyse the effects of in-vehicle traffic lights on post-encroachment time.

The pairwise comparison analysis revealed that, when there was no auditory warning (audio-off conditions), driving safety might be significantly improved by applying in-vehicle traffic lights as the post-encroachment time was significantly longer for the light-on condition compared with the light-off condition \((p < 0.001)\). Likewise, when auditory warnings were provided (audio-on conditions), the in-vehicle traffic lights should also be applied to improve driving safety since a significantly longer post-encroachment time was also found for the light-on condition compared with the light-off condition \((p < 0.01)\).

The results indicated that post-encroachment time was significantly improved by the application of in-vehicle traffic lights. Moreover, the influence of in-vehicle traffic lights on post-encroachment time was not significantly affected by the usage of auditory warnings.

4.2 Maximum brake stroke

As presented in Fig. 5b, for the maximum brake stroke at intersection III, which was a two-way stop-controlled intersection, a non-significant interaction existed between the in-vehicle traffic lights and the auditory warnings. We found a significant main effect of the in-vehicle traffic lights \(F[1, 22] = 4.52, p = 0.045 < 0.05\) and a non-significant main effect of the auditory warnings.
which means that the maximum brake stroke would be significantly influenced by the usage of in-vehicle traffic lights, while not by auditory warnings. According to the pairwise comparison analysis, when there was no auditory warning (audio-off conditions), the in-vehicle traffic lights should be employed to reduce maximum brake stroke as a significantly lower maximum brake stroke was observed for the light-on condition compared with the light-off condition ($p = 0.018 < 0.05$).

As shown in Fig. 5c, for the maximum brake stroke at intersection VI, which was an all-way stop-controlled intersection, we also found a non-significant interaction between the in-vehicle traffic lights and the auditory warnings. We observed a significant main effect of the in-vehicle traffic lights ($F[1, 22] = 4.50, p = 0.045 < 0.05$) and a non-significant main effect of the auditory warnings. According to the pairwise comparison analysis, when no auditory warning was offered to drivers (audio-off conditions), the maximum brake stroke could be significantly reduced by applying in-vehicle traffic lights since the maximum brake stroke was significantly lower for the light-on condition compared with the light-off condition ($p = 0.002 < 0.05$).

These results suggest that the maximum brake stroke was significantly decreased by the in-vehicle traffic lights. Furthermore, we did not observe a significant difference in the maximum brake stroke between the conditions in which the in-vehicle traffic lights were used with or without auditory warnings.

### 4.3 Stopping types

At the all-way stop-controlled intersection (intersection VI), the participants made a complete stop 69.57% of the time in the light-off with audio-off condition. In contrast, the participants performed complete stops 82.61% of the time in the light-on with audio-off condition, and 86.96% of the time in the light-on with audio-off condition. For the light-on with audio-off condition, the participants performed a complete stop 91.30% of the time before crossing the stop line.

### 4.4 Eye-gaze behaviours

As presented in Fig. 6a, for the percent road centre, we found a non-significant interaction between the in-vehicle traffic lights and the auditory warnings. In addition, we found non-significant main effects of the in-vehicle traffic lights and the auditory warnings. Thus, the percentage of the participant's gaze falling within the road centre area was not significantly affected by the application of in-vehicle traffic lights and auditory warnings, although an increasing trend was observed in the audio-on conditions.

As shown in Fig. 6b, for the mean glance duration to the head-up display, we found no significant difference between the light-on with audio-off and light-on with audio-on conditions. Meanwhile, the maximum values of mean glance duration under both conditions were smaller than 0.6 s.

### 4.5 Subjective evaluation

As demonstrated in Fig. 7a, for the safety evaluation scores, we found a significant main difference among the four conditions ($F_r [3, 23] = chi-squared = 34.42, p < 0.001$). Furthermore, when there was no auditory warning, drivers felt much safer to be assisted by the in-vehicle traffic lights as the pairwise comparison analysis
revealed a significantly higher score in the light-on with audio-off condition compared with that in the light-off with audio-off condition ($z[23] = -3.83$, $p < 0.001$).

As shown in Fig. 6, for the acceptability evaluation scores, a significant main difference was also found among the four conditions ($F_r[3, 23] = chi-squared = 48.11, p < 0.001$). Moreover, when auditory warnings were not applied, the usage of in-vehicle traffic lights was highly regarded by drivers as a significantly higher score was found in the light-on with audio-off condition.

Fig. 6  Eye-gaze behaviours. Circles: mild outliers calculated as $1.5 - 3 \times \text{the interquartile range}$
(a) Percent road centre, (b) Mean glance duration to the head-up display

Fig. 7  Evaluation scores ranging from 1 to 5: 1 = very low, 2 = low, 3 = average, 4 = high, and 5 = very high. Circles: mild outliers calculated as $1.5 - 3 \times \text{the interquartile range}$
(a) Score of safety, (b) Score of acceptability, (c) Score of fatigue
compared with that in the light-off with audio-off condition ($c_{[23]} = −3.93$, $p < 0.001$).

As illustrated in Fig. 7c, for the fatigue evaluation scores, we found a significant main difference among the four conditions ($F_{[3, 23]} = \text{chi-squared} = 39.85$, $p < 0.001$). Meanwhile, for the conditions without auditory warnings, drivers found it much more difficult to feel fatigued with driving when they were assisted by in-vehicle traffic lights, since a significantly higher score was observed in the light-on with audio-off condition compared with that in the light-off with audio-off condition ($c_{[23]} = −3.56$, $p < 0.001$).

These results indicate that the in-vehicle traffic lights were evaluated as performing well in terms of safety, acceptability, and fatigue. In addition, the subjective evaluation scores did not significantly increase when the in-vehicle traffic lights were supplemented with auditory warnings.

5 Discussions

To validate the proposed in-vehicle traffic light system in assisting drivers at unsignalised intersections, driving operations and eye-gaze behaviours were analysed using carefully selected indexes. Of the available indexes for evaluating driving operations, we used post-encroachment time to evaluate driving safety when participants were inside intersections, and the maximum brake stroke to analyse braking performance before entering intersections. However, it was difficult to calculate the post-encroachment time for intersection VI, because of the low traffic flow at all-way stop controlled intersections. A field study reported that the number of conflicts at unsignalised intersections could be reduced when drivers completed stops at the stop line [23]. Therefore, we analysed stopping types to investigate driving safety at intersection VI. For the evaluation of eye-gaze behaviours, we chose to assess percent road centre as it is sensitive to visual distraction, and is the only measure that can be used to compare both visual and auditory tasks with respect to baseline driving performance [24–26].

As shown in Fig. 5a, the improvement of post-encroachment time with the application of in-vehicle traffic lights suggests that the driver assistance provided by the proposed system was effective at unsignalised intersections. A previous study found that drivers who drove a vehicle with an intersection collision warning system had a shorter response time [27]. Therefore, it is possible that the in-vehicle traffic lights, working as one type of visual warning signal, shortened the response time of drivers to an appropriate gap on the major road, which contributed to a longer post-encroachment time.

As presented in Figs. 5b and c, we observed a significant decrease in maximum brake stroke when participants had access to the in-vehicle traffic lights. A previous study reported that an increase in the brake stroke significantly deteriorated vehicle performance during an emergency stop [28]. Our results regarding maximum brake stroke imply that driving safety could be significantly improved during the braking period when an emergency stop is required. In terms of stopping types, more participants performed a complete stop when they had access to the in-vehicle traffic lights, which suggests that the conflict risk at unsignalised intersections might be reduced by applying the proposed system.

As shown in Fig. 6a, the mean percent road centre values were between 60 and 70% for all the conditions in this experiment. A previous study reported that percent road centre values for attentive drivers were around 70–80% [29]. Another study stated that the percent road centre value under normal conditions was 75% [30]. The percent road centre values obtained in this research were slightly smaller than those in the two previous studies. However, the percent road centre is generally lower during a general driving session, ranging from 44 to 73% [24]. Therefore, we considered our percent road centre data to be valid for evaluation. Moreover, the non-significant main effect of the in-vehicle traffic lights suggests that no significant increase in visual distraction was induced by the proposed system. Furthermore, the maximum percent road centre values in all the conditions were around 80%.

One study suggested that a percent road centre value of more than 92% could be an indication of cognitive distraction [26]. The percent road centre data in this experiment indicated that the in-vehicle traffic lights did not increase the level of cognitive distraction.

For the results of mean glance duration, the mean values in the two conditions were around 0.4 s, as presented in Fig. 6b. As a comparison, the mean glance duration to an in-vehicle analogue speedometer was between 0.4 and 0.7 s [31]. Moreover, an on-road driving study reported that the mean glance duration to an in-vehicle driving aid system was 0.43 s [32]. In addition, according to a report from the Federal Highway Administration, a mean glance duration away from the roadway of less than 1 s is considered acceptable [33]. Therefore, the mean glance durations to the head-up display in our study were deemed reliable and did not appear to affect driving safety.

As a driving simulator study, this experiment has an advantage of providing exactly the same experimental condition for every participant, although a real-world driving experience cannot be replicated precisely by a driving simulator. In addition, the trends observed in driving simulator experiments have generally been demonstrated in on-road experiments [34].

6 Conclusion

In this study, we tested the applicability of an in-vehicle traffic light system to assist drivers in passing through unsignalised two-way and all-way stop-controlled intersections. Specifically, we used a driving simulator to analyse the influences of the proposed system on driving operations and eye-gaze behaviours.

Our experimental results demonstrated that the in-vehicle traffic light system significantly improved post-encroachment time and decreased maximum brake stroke, which implies that driving safety was enhanced. In terms of eye-gaze behaviours, the percent road centre and mean glance duration values indicated that the system did not present an increase in visual distraction. The proposed in-vehicle traffic lights were therefore deemed to be reliable in terms of providing driver assistance at actual unsignalised intersections.

This study may offer theoretical references for the design and evaluation of visual-based driver assistance systems, and may considerably broaden the scope for the application of in-vehicle traffic lights in real traffic environments. As this experiment assumed a 100% penetration rate of in-vehicle traffic lights, the influence of the proposed system on driver behaviours in a partial deployment scenario is an interesting topic for future study.

7 Acknowledgment

This study was supported by the Next-Generation Energies for Tohoku Recovery Project.

8 References


