Research Paper

Safety Effect of Traffic Signal Prediction Systems

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ABSTRACT: The development of automated driving technology has been gaining momentum in recent years. Some of the technologies receiving attention involve using a communications system to get information on hazards in blind spots that are hard for the vehicle’s autonomous sensors to detect, or to get advance traffic signal information. Traffic Signal Prediction Systems (TSPS) are one kind of system using such communications technology. Field operation tests were carried out on public roads in 2014-2015 to bring these systems closer to practical application. The tests suggested the number of traffic accidents would decline with the implementation of TSPS, since vehicles would come to a “slow stop” more often and encounter the dilemma zone less often. The tests and traffic flow simulation also indicated that this would have little effect on travel time. There was also concern that advising drivers to release the accelerator while the light was still green would increase the incidence of acceleration to try to get through the intersection before the green light ends. As the system was used, however, it was confirmed that the operation decreased. From the questionnaire to those who participated in this tests, this system was evaluated that information support is easy to understand and is a useful.

KEY WORDS: safety, active safety, infrastructure-to-vehicle communication, Traffic Signal Prediction Systems [C1]

1. Introduction

In recent years, society has encountered the issue of traffic accidents caused by elderly drivers or drivers who have a medical crisis and become unable to control their vehicles while on the road. According to the Institute for Traffic Accident Research and Data Analysis (ITARDAs) 1), traffic accidents involving elderly drivers aged 75 and older are increasing year by year. Compared with other age groups, though the proportion of elderly group is still small, it cannot be overlooked giving the aging society of the future. In addition, comparing traffic accidents involving the elderly drivers by type of accident, the percentage of broadside accidents is higher than in other age groups. The reason for this is considered to be that the driving in the living area is increased, make it easier for people to believe that a car does not come from usual experience. On the other hand, in traffic accident occurred at an intersection with traffic lights, ignoring a traffic light due to overlooking the light is higher than other age groups. In order to prevent such a traffic accident, new technology development such as a driver’s recognition assistance and danger avoidance is required.

In response to this situation, the automobile industry is engaged in a flurry of technical development of automated braking and automated driving systems using autonomous on-board sensors such as cameras and radar. However, in a system using the autonomous sensor, since it is impossible to control a vehicle unless the other vehicle or a pedestrian has been detected, depending on the situation, avoidance cannot be made in time. In addition, while automated driving on ordinary roads requires that the vehicle be able to recognize traffic signals, autonomous sensors can only determine the current color of the signal. As a result, the vehicle may have to brake hard depending on its position and speed at the point when the signal changes from green to yellow, and this can be uncomfortable for passengers. Ideally, vehicles would have a technology that enables them to receive other vehicles and advance traffic signal information. As a result, the vehicles can start control the vehicle while having a time margin, and can realize smooth driving.

Since 2011, the UTMS Society of Japan 2) has been developing a Traffic Signal Prediction Systems (TSPS) that supports driving with advance traffic signal information acquired by vehicle-to-infrastructure communication. 3) This system only provides driving support information to drivers and does not control vehicles, but it is expected to smooth out the flow of traffic at intersections, enhance in-use fuel economy, and have such safety benefits as preventing rear-end collisions. In collaboration with the UTMS Society of Japan, Honda has planned and conducted tests on public roads in three stages so far to put this system into practical use. The first stage was conducted in a suburban setting and the second stage in an urban setting to verify system effectiveness and driver acceptance of it, assuming advance traffic signal information were to be distributed. Finally, in the third stage, advance traffic signal information was actually distributed by vehicle-to-infrastructure communication and the feasibility and effectiveness of a system encompassing both infrastructure and vehicle were verified.

In this paper, we discuss the nature of the field operation tests conducted in 2014-2015 as the final step of this process 4), and describes the safety benefits of the system.

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2. System overview

Fig. 1 illustrates the system configuration. The traffic control center generates traffic signal control information, taking traffic conditions into account. The control information is used to control the traffic signal lights. At the same time, it is also distributed to vehicles as advance traffic signal information by means of infrared (IR) beacons installed at the roadside. Intersection coordinates and the road distance from IR beacon to intersection are also distributed with that information. Information on multiple signals can be distributed from a single IR beacon. The on-board system receives the distributed information through the on-board IR beacon unit, and then the car navigation system or other such on-board electronic control unit (ECU) utilizes that information, together with the vehicle position, vehicle speed, and other such vehicle information, to support the driver.

2.1. System’s support and effectiveness

The system provides three kinds of support. The first is Passing Support. Passing Support functions when a vehicle will be able to pass through the intersection on a green light, and provides the range of speed at which the vehicle will be able to pass through without stopping. For example, if the scenario is one in which maintaining the present speed will cause the vehicle to stop at a red traffic signal, then heeding the support and adjusting the vehicle speed early on will enable the vehicle to pass through the intersection smoothly, without stopping (see Fig. 2). The result is to minimize unnecessary acceleration or deceleration. Additionally, by providing the range of speed at which the vehicle will be able to pass through the intersection without stopping, this support reduces driver anxiety that a signal that is currently green might soon change to red.

The second support, Stopping Support, encourages the driver to release the accelerator early on when the vehicle cannot avoid having to stop at a red light. Releasing the accelerator early on and coming slowly to a stop lowers the potential of a rear-end collision by a following vehicle (Fig. 3). Additionally, while the vehicle is coasting (cruising without the driver’s foot on the accelerator), it does not consume fuel, so this can help improve fuel economy.

The third support is Starting Support. When the vehicle stops at a red light, the system tells the driver how much longer the light will be red. This minimizes delay in starting the car moving again when the signal turns green (Fig. 4). This function can also reduce the frustration of waiting for the light to turn green, much like the indicators of waiting time at pedestrian crossing signals that have been introduced in recent years.

3. Overview of testing

The field operation tests were conducted on arterial roads in Utsunomiya City, Tochigi Prefecture. Table 1, Fig. 5, and Fig. 6 give an overview of the route. As Fig. 6 shows, on the western part of the route are city streets, while on the eastern part are suburban roads with good visibility.

| Traffic environment       | City streets to suburban roads |
|---------------------------|-------------------------------|
| Distance                  | Approximately 3.6 km one way  |
| Number of traffic lanes    | Two lanes per side            |
| Speed limit               | City streets 50 km/h, suburban roads 60 km/h |
| Number of intersections with traffic signals | Eastbound 9, westbound 8 |
| Number of IR beacons      | Eastbound 3, westbound 3      |
| Traffic signal control system | Central control, system control |
The test subjects were recruited from all employees of Honda R&D and we determined all of 66 people as the test subjects.

The onboard unit used in the tests was based upon a smartphone, as shown in Fig. 7. The configuration of the unit made it easy for subjects to mount in the vehicle. The components of the system were an onboard IR beacon unit, Bluetooth module, and smartphone. Information distributed from roadside IR beacon units is acquired by the onboard IR beacon unit and transmitted by serial communication and Bluetooth communication to the smartphone. The location and speed acquired from the built-in GPS module in the smartphone, together with the information distributed from roadside units, are processed by the smartphone, which then displays support information on its screen.

Information acquired by the smartphone and the processed content are temporarily saved in the smartphone. The information is transmitted to a server after driving through the test route.

On-board units were installed in subjects’ vehicles. Subjects used the equipment for one month without support (i.e., information was not provided), and subsequently used it for one month with support.

4. Experiment results

The amount of data collected is shown in Table 2. The next section discusses results of the verification of the system’s safety benefits as based on this data.

| Table 2 Amount of data collected |
|----------------------------------|
|                                  |
| With support | Without support | Total  |
|-----------------|-----------------|--------|
| Number of trips taken on test route | 809 | 956 | 1,765 |
| Total distance driven | 2,799km | 3,315km | 6,114km |
| Total time measured | 112.8h | 135.5h | 248.3h |
| Total times that intersections were passed | 6,797 | 8,101 | 14,898 |

4.1. Changes in acceleration and deceleration behavior

The system was designed to minimize unnecessary acceleration and deceleration on the driver’s part by providing operating support with future information about signals. Research by Maji et al. suggests that being conscientious about slowly starting and stopping and practicing slow acceleration and deceleration are effective ways of reducing traffic accidents. Therefore, if the system leads drivers to accelerate and decelerate more slowly, it too will likely be effective in reducing accidents. Fig. 8 shows the evaluation results of difference between with support and without support in frequency of acceleration and deceleration. The graph indicates that the frequency of mild acceleration decreased while that of mild deceleration increased. This is likely because Stopping Support caused the travel distance during which the driver’s foot was off the accelerator to be longer, so the frequency of mild acceleration to maintain speed was diminished. In other words, there was a change to “slow stopping.” Based on this, it is conjectured that this system also will help reduce traffic accidents.

4.2. Avoiding signal dilemmas

Traffic control systems that control signals are constantly becoming more advanced as developers seek to optimize traffic flow. One way in which these systems have advanced is in dilemma inducement control. This control lengths green lights when there are vehicles in the dilemma zone or option zone. The
The dilemma zone is the zone in which, faced with a yellow light, the vehicle can neither pass the stop line before the yellow light is over nor stop at the stop line without hard braking. The option zone is that in which both of the above are possible. The relationship specifically shown in Fig. 9 is known to researchers. The two zones are defined by two boundaries: the distance required to stop from the vehicle speed at the moment when the light turns yellow (Eq. 1), and the distance the vehicle will travel, if it maintains its current speed, by the time the light changes from yellow to red (Eq. 2). The graph in Fig. 9 shows what the two zones would be if driver reaction time is 0.75 seconds, deceleration is 0.2 G, and the yellow light lasts 3 seconds. The objective of dilemma inducement control is to reduce the number of vehicles in these zones and thereby prevent rear-end collisions immediately after the light turns yellow and broadside collisions when a vehicle enters the intersection on a red light. A verification of the effectiveness of dilemma inducement control at intersections where it was actually implemented confirmed an approximately 41% reduction in traffic accidents.\(^{(7)}\)

\[
L_1 = \tau V + \frac{V^2}{2d} \quad (1)
\]

\[
L_2 = YV \quad (2)
\]

\(\tau\) : Driver reaction time [sec]
\(V\) : Vehicle speed [m/s]
\(d\) : Deceleration [m/s\(^2\)]
\(Y\) : Duration of yellow light [sec]

As noted above, the system uses future information about signals, and as such, the Stopping Support function advises drivers to stop slowly if the system determines the vehicle cannot enter the intersection before the green light ends. In other words, it can reduce the number of encountering the dilemma zone and is therefore likely to have the effect of reducing traffic accidents, similar to dilemma inducement control. This study therefore checked whether information support from the system reduced the number of encountering the dilemma zone. Results are shown in Fig. 10. The graph confirms that the rate of encountering the dilemma zone dropped by 0.27 points, a decline of about 0.75%. It is conjectured to have the effect of reducing traffic accidents, similar to dilemma inducement control.

![Fig. 9 Illustration of dilemma zone and option zone](image)

\(L_1 = \tau V + \frac{V^2}{2d}\) \quad (1)

\(L_2 = YV\) \quad (2)

\(\tau\) : Driver reaction time [sec]
\(V\) : Vehicle speed [m/s]
\(d\) : Deceleration [m/s\(^2\)]
\(Y\) : Duration of yellow light [sec]

In response to the above results, some may worry that travel time will be affected. Because vehicles avoid the dilemma zone by starting to decelerate earlier and then stopping, it is concerned that the number of stops will increase, and therefore so will travel time. For that reason, an evaluation was made of changes in travel time based on whether or not there was information support. The results, as shown in Fig. 11, indicated that, as expected, travel time did increase, but only by about 8 seconds, so there was no significant impact on travel time. Also, from this graph, it is found that the dispersion of the data is large. Since the traffic volume of the test route changes greatly, it is estimated that the travel time depends on the traffic volume during its traveling.

![Fig. 10 Change in rate of encountering dilemma zone](image)

**4.3. Change in travel time**

The above is a change in travel time of a single vehicle and does not show a change in the overall traffic flow. Therefore, traffic flow simulation was carried out and the influence on overall traffic flow was investigated. Table 3 shows an overview of the traffic flow simulation that was carried out.

**Table 3 Overview of traffic flow simulation**

| Simulation model       | MicroAVENUE from i-Transport Lab. Co., Ltd. |
|------------------------|---------------------------------------------|
| Evaluation section of road | Present test route                          |
| Evaluation hours       | 06:00 to 22:00                              |
| Traffic volume         | Recreates traffic volume on July 22, 2014    |
| Traffic signal control system | Reflect typical types of control applied at each intersection |
| Driving during support | Drive according to support recommendations   |

Using the traffic flow simulation described above, it was verified how the travel time and the traffic volume of the overall traffic flow varied according to the penetration rate of vehicles.

![Fig. 11 Change in travel time](image)
equipped with this system. Fig. 12 shows the results. From this result, although the travel time of the overall traffic flow also increased, the change amount was only about 20 seconds. Given that there is no change in traffic volume per hour, it can be said that the change is not a big influence.

Fig. 12 Change in travel time and traffic volume by traffic flow simulation

4.4. Change in driver behavior when advised to release accelerator

The Stopping Support function of the system advises drivers to release the accelerator if the light is currently green but the vehicle will not be able to enter the intersection while it is still green. One concern is that when given such information, the driver may actually accelerate to try to get through the intersection before the green light ends. Therefore, we compared the ratio of with support and without support that the subject accelerated 0.1 G or more against advice to release the accelerator. In the period without support, the support decision was processed, but the information was not displayed, so it is possible to make a comparison under this scenario. Results are shown in Fig. 13. The graph in part (a) of the figure shows that the incidence of such acceleration happened less often when support was being given than when it was not. Part (b) of the graph additionally shows that even within the period when support was given, the incidence of acceleration was less in the second half of the period than in the first. This indicates that, as drivers continue to use the system, they learn that when the system advises them to release the accelerator, traffic lights that are currently green will soon change to red and the driver will have to stop, so they do not accelerate.

Fig. 13 Changes in driver acceleration incidence when Stopping Support functions during a green light

4.5. Driver acceptance of this system

Finally, the acceptability of this system was evaluated from the questionnaire to the driver who cooperated with this tests. Fig. 14 shows the cumulative ratio of responses to the understandability of each information support. From these results, 80% or more said that they were easy to understand (4 or higher) for Passing Support and Starting Support, and it was highly evaluated. On the other hand, Stopping Support was a slightly low evaluation. This is considered to be because the timing to urge releasing off on the accelerator early was not optimal. The timing to urge the accelerator off earlier is judged from the vehicle speed and the traveling position and does not consider the traffic situation ahead of the preceding vehicle or the like. Then it may not be the proper timing for the driver in some cases. It is necessary to improve this point to be more appropriate timing. In addition, Fig. 15 shows the responses on regard to the usefulness of the system. Test subjects who responded with a score of 4 or higher amounted to 62% of the total, indicating a positive evaluation of the system as having value. However, as mentioned above, there are voices that want to provide information considering the traffic situation in front of the vehicle and cooperate with the autonomous system, and there is still room for improvement.

Fig. 14 Questionnaire results on the understandability of information support

Fig. 15 Questionnaire result on regard to system usefulness

5. Conclusion

To promote the practical application of the Traffic Signal Prediction Systems (TSPS), field operation tests were conducted on public roads in Utsunomiya City, Tochigi Prefecture in 2014-2015, which verified the effectiveness of such a system. The results confirmed that TSPS could lead to a reduction in traffic...
accidents as drivers more often decelerate slowly. Such a system would also lower the rate of encountering the dilemma zone, and it is conjectured that there would be a benefit similar to the traffic accident reduction effect when traffic lights were changed to add dilemma inducement control. This is a benefit of avoiding the dilemma zone and encouraging drivers to take stopping action earlier, but there is also the possibility that an increased number of stops will impact travel time. The study’s verification of travel time changes, however, showed only a slight impact of this type. In addition, even if we examine the influence on the overall traffic flow by traffic flow simulation, the change was similarly small. There was also concern that advising drivers to release the accelerator while the light was still green would increase the incidence of acceleration to try to get through the intersection before the green light ends. The frequency of such acceleration, however, was lower when such support was provided, and even within the period when such support was provided, this type of acceleration declined even more in the second half of the period than in the first. From the questionnaire to those who participated in this tests, this system was evaluated that information support is easy to understand and is a useful system. However, there are opinions that it would be better to provide information considering the traffic situation in front of the vehicle, and it is necessary to study further in the future. After noting such results, in 2016 Honda became the first auto manufacturer to market a vehicle with such a system.\(^\text{(8)}\)

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