AHS Safety Service Utilizing an ITS On-Board Unit for Driving Support in Merging Sections

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Summary

The merging section is the second highest accident-prone location on Japanese urban expressways after the sharp curve section. As safety countermeasures for the merging section, there are rising expectations for soft safety measures to supplement the physical countermeasures which require enormous cost and time. Meanwhile, the use of the DSRC roadside unit and ITS on-board equipment that were developed through the joint studies of the Ministry of Land, Infrastructure and Transport and private companies is making it more and more possible to take safety measures which are more efficient than the existing stand-alone vehicle systems. The authors are conducting field tests on the merging sections of the Tokyo Metropolitan Expressway – a major urban expressway in Japan, and developing a service that will assist safe driving on merging sections through a cooperative vehicle-highway system. In developing the service, the service requirements and system configuration for its realization were explored. A pilot study was conducted to verify the effectiveness and other elements of the service to introduce the service on the Tokyo Metropolitan Expressway, through a traffic flow simulation, driving simulator trial, test course trial, and expressway trial.

1. Introduction

The merging section is the second highest accident-prone location on Japanese urban expressways after the sharp curve section. Several measures have already been taken to address this issue, such as danger warning signs, pavement markings, variable message signs, and lane regulations, but users’ needs for improvements are not fully met in some sections. Due to the enormous cost and time required of physical countermeasures, high expectations are held for the use of intelligent transport systems (ITS) as a soft countermeasure.

In recent years, the comprehensive uses of various media have expanded, including the
acceleration of the communication speed of road-to-vehicle communication. As a result, in addition to existing services based on stand-alone vehicle systems (infrastructures), the introduction of safe cruise-assist systems on merging sections based on cooperative vehicle-highway systems is becoming possible. The authors established the concept of the service and conducted a pilot study, with a view to realizing merging section Advanced cruise-assist Highway System (AHS) safety services which utilize ITS on-board equipment that makes cooperative vehicle-highway systems possible.

2. Significance of merging section cruise-assist services

In terms of road structure, around 30 percent of all accidents on the Tokyo Metropolitan Expressway are concentrated on curves with a radius of 200m or less and merging sections (16% of total expressway length)

Furthermore, curves with a radius of 200m or less and merging sections account for a high share of all expressway accidents; the accident rate is about twice as high as the average on curves and about 1.6 times as high on merging sections (Fig. 1).

Limited visibility of the road ahead and merging side are the causes of frequent accidents on steep linear curves and merging sections, and safety measures are urgently needed.

3. Merging section cruise-assist AHS safety services: Overview of basic configuration of system

(1) Service selection

Table 1 outlines a list of services which are believed to be effective for merging assistance if provided to vehicles on the mainline and merging vehicles.

Among these, the service that informs a vehicle on the mainline about an approaching merging vehicle was selected as the first merging section cruise-assist service to be started. The reasons are that: the objective of this service is to give advance warning in order to prevent the oversight of merging vehicles that are hard to see, etc.; and the impact of over-reliance on the service is little when it fails to detect a merging vehicle.

The basic framework of the merging section cruise-assist AHS safety service is as shown in Figure 2. The following is an overview of the service:

A) The system detects a merging vehicle and prompts a warning to the vehicle on the mainline at an appropriate timing according to the speed of the merging vehicle. Ultrasonic detectors will be used to identify the speed.
Table 1 List of AHS safe merging assistance services

<table>
<thead>
<tr>
<th>Service</th>
<th>Predicted effects</th>
<th>Predicted limits</th>
<th>Predicted adverse effects (negative check)</th>
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<tbody>
<tr>
<td></td>
<td>Action for merging lane</td>
<td>Action for mainline</td>
<td></td>
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<tr>
<td>Gap notification service</td>
<td>-</td>
<td>Merging vehicle can merge at ease. Particularly beneficial for unskilled drivers.</td>
<td>Will not be effective if roads are congested.</td>
</tr>
<tr>
<td>Vehicle notification service</td>
<td>(Detects that a vehicle is approaching merge taper on the mainline and gives notification thereof to the vehicle attempting to merge)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>&quot;Adjust speed with mainline&quot; service</td>
<td>(Detects that a vehicle is approaching from the merging lane and gives notification thereof)</td>
<td>Driver can merge smoothly by driving at the same speed. Beneficial for those who are not used to driving in that area but are nonetheless skilled drivers.</td>
<td>-</td>
</tr>
<tr>
<td>&quot;Harmonize speed&quot; service</td>
<td>(Share speed information with each other and harmonize speed)</td>
<td>Driver can merge smoothly by driving at the same speed. Beneficial for those who are not used to driving in that area but are nonetheless skilled drivers.</td>
<td>Difficult method to realize.</td>
</tr>
<tr>
<td>&quot;Vehicle approaching&quot; service</td>
<td>(Detects that a vehicle is approaching on the mainline and gives notification thereof to the vehicle attempting to merge)</td>
<td>Warning prompts enable the merging vehicle to merge with close attention on the mainline vehicle. Effective when mainline has little traffic.</td>
<td>Warning prompts may be bothersome when mainline has heavy traffic.</td>
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<td></td>
<td>(Right/left) &quot;Merging vehicle not approaching&quot; service</td>
<td>(Detects that a vehicle is not approaching from the merging lane and gives notification thereof to the vehicle on the mainline)</td>
<td>Can drive down the mainline at ease.</td>
</tr>
<tr>
<td></td>
<td>(Right/left) &quot;Merging vehicle intruding&quot; service</td>
<td>(Detects a vehicle approaching from the merging lane and gives notification of the intrusion to the mainline vehicle just before the merge)</td>
<td>The mainline vehicle will decelerate or change lanes, and the increased gap will make merging easier.</td>
</tr>
<tr>
<td></td>
<td>(Right/left) &quot;Merging vehicle approaching&quot; service</td>
<td>(Detects that a vehicle is approaching from the merging lane and gives notification thereof to the vehicle on the mainline)</td>
<td>Through the warning prompts, mainline vehicle will pay greater attention to merging vehicle. If possible, vehicle may change lanes in advance.</td>
</tr>
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<td></td>
<td>(Right/left) &quot;Merging section coming up&quot; service</td>
<td>(Gives notification of upcoming merging section)</td>
<td>Can drive carefully on the merging section and change lanes in advance. Particularly beneficial for unskilled drivers</td>
</tr>
<tr>
<td>Synchronize and merge service</td>
<td>(Share location and speed information with each other and merge by synchronizing)</td>
<td>Enables smooth integration.</td>
<td>Difficult method to realize.</td>
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</table>

B) The vehicle on the mainline will be warned by road-to-vehicle communication: specifically, through a dedicated short range communications (DSRC) roadside wireless unit and wireless communication system between ITS on-board equipment (5.8GHz).

C) Warning sounds, audio, and video will be used for the human machine interface (HMI), which allows drivers to be warned. If traffic into the merging section is detected, a warning will be prompted about the merging vehicle (Pattern A). Even if this is not the case, information will be provided which informs drivers about the existence of merging section (Pattern B). This will promote drivers to pay a certain level of attention to their driving even when a merging vehicle is not present. In addition, drivers will be able to distinguish when information about a merging vehicle cannot be provided due to a system failure. To avoid adverse effects on the traffic flow caused by
drivers moving to the passing lane when traffic is or may be congested, information about a merging section (Pattern B) will be provided whether or not a merging vehicle is present (Fig. 3).

(2) The rationale behind the information provision point

The information provision point was determined based on the idea that if a driver is able to acknowledge and make a decision about the information being provided by the tip of the gore point, he/she will have enough time, including his/her reaction time, to avoid the joining traffic in a situation where both are visible to each other. On the basis of this notion, it was decided that information will be transmitted to vehicles at least four seconds before they reach the tip of the gore point. The rationale behind the four seconds is as shown in Figure 4. If vehicles targeted by this service are assumed to be travelling at a maximum speed of 90km/h, the DSRC must be set up to transmit information at least 100m prior to the tip of the gore point.

4. Selecting the study locations

The Tokyo Metropolitan Expressway, which is the largest urban expressway in Japan, was chosen to be the first area in which the service will be introduced. Taking into account various factors such as road structure and accident frequency, the following areas were selected for getting the project underway: the Higashi Ikebukuro ramp merging section for merge ramps (No. 5 Ikebukuro Route, outbound) and the Tanimachi Junction...
(JCT) merging section for merge junctions (Inner Circular Route, clockwise) (Fig. 5).

At the Higashi Ikebukuro ramp merging section, the vehicle on the mainline and merging vehicle both have poor visibility before the merge, and furthermore, adequate length is not allotted for the merge taper. As such, it is a heavily stressful area for drivers who are not used to driving in this section. The Tanimachi JCT merging section has heavy traffic where the No. 3 Shibuya Route merges with the Inner Circular Route and is an area where many merging-related accidents occur.

5. Pilot study of the service

The merging area cruise-assist AHS safety service study is comprised of the following three assessments: assessment of service performance (whether predictions about the traffic condition of the merging section are accurately reflected in the service), assessment of driver receptivity, and assessment of service effects. The findings of the pilot study, which was conducted in the following order to makes these assessments of the Higashi Ikebukuro ramp merging section (outbound), are illustrated below.

(1) Traffic simulation (service performance assessment)

A pilot study of the service performance was hypothetically carried out on the assumption that a merging vehicle was detected and the service was provided to passing vehicles on the mainline, using actual measurements of the merging vehicle’s trajectory and the mainline vehicles’ speed distribution.

In terms of providing the service, it is necessary to establish the start and end periods for the provision of accurate information according to the vehicle crossing situation. That is, only when merging traffic is anticipated shall information be provided appropriately under Pattern A. This relationship is shown in Table 2.

<table>
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<tr>
<th>Merging situation after information provision</th>
<th>Evaluation by information pattern</th>
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<tr>
<td></td>
<td>Pattern A</td>
</tr>
<tr>
<td>Warning needed</td>
<td>☐ Appropriate information provision. Should maximize its use.</td>
</tr>
<tr>
<td></td>
<td>☐ No problems with giving warnings of merging vehicle.</td>
</tr>
<tr>
<td>Aware of merging</td>
<td>☐ Its use should be sufficiently held off since warnings of merging vehicle become excess information provision.</td>
</tr>
<tr>
<td>Unaware of merging</td>
<td>☐</td>
</tr>
</tbody>
</table>

* ☐ : Item of first priority for minimizing  ☐ : Item of second priority after ☐ for minimizing
In regard to this service of detecting the speed of the merging vehicle using an ultrasonic detector and providing information to mainline vehicles according to the detected speed, the aptness of the judgments made by the service was verified by conducting a simulation of the service using actual video/measurement data. The findings of this test are shown in Figures 6 and 7. Because it is impossible to predict the acceleration and deceleration behavior of vehicles after they have passed the detector, it is impossible to provide information that is complete. Nevertheless, it was confirmed that it was possible to contain “ ” to 26 percent, or a range that will not pose problems from a practical standpoint, while keeping “▲” down to a minimum (0.4 percent), through the information provision start and end periods which had been established. Furthermore, it was ascertained that detecting the speed of the merging vehicle reduces excess information provision by over 20 percent. In addition, the utility of speed detection was also confirmed.

(2) Driving simulator (DS) trial and test course trial (driver receptivity assessment)

A DS trial was conducted with general trial subjects to confirm the receptivity of drivers in advance. From various standpoints, such as comprehension of the information provided, whether or not drivers look at the screen for a long time, whether or not drivers suddenly brake because of the information provided, among other factors, it was confirmed that it was appropriate to display the information on the screens of car navigation systems. In addition, a similar confirmatory trial was conducted at a test course of the National Institute for Land and Infrastructure Management (NILIM) (Fig. 8), the test of drivers’ receptivity was also confirmed by driving actual vehicles.

(3) Expressway trial (service performance assessment, service effectiveness assessment)

An expressway trial was conducted from April 23 to May 7, 2007 on the Higashi Ikebukuro ramp merging section (outbound) shown in Figure 7, with trial subjects who were used to driving on the Tokyo Metropolitan Expressway keeping safety in mind, upon explaining the
service to them in advance.

A) Service performance assessment

Each of the 35 trial subjects drove past the merging section five times, and a total of 175 findings were obtained. Information was provided under Pattern A on 56 occasions in total and under Pattern B 119 occasions in total. The actual merging situation (trial values) was matched with the predicted values from the traffic flow simulation; both are shown in Figures 9 and 10. In addition, Figure 11 shows the merging situation in the case of Pattern A in more detail (spatial relationship distribution with the merging vehicle).

In Figure 9, the “unaware of merging” (excess information provision) ratio (32.1 percent) was slightly higher than the predicted value (26 percent) in the traffic flow simulation. On the other hand, “warning needed” was 21.6 percent and was less than the predicted value (35.6 percent). While the predicted values do not take into account the effects of information provision on the trial subjects’ driving behavior, deceleration of the trial vehicles due to information provision was observed in the trial involving actual vehicles. As a result, aggressive merging itself was reduced through the provision of this service and it is believed that this is showing how the service contributes to safety improvement.

Meanwhile, in Pattern B (Figure 10), the 119 trials did not generate a “warning needed” (mainline vehicle and merging vehicle approach each other on the merging section) case (information provision leak) with the merging vehicle. It was confirmed that performance was better than the predicted value.

B) Trial subjects’ assessment of the service (by a survey)

The 35 trial subjects who experienced the service were surveyed after the trial, and their assessments of the effectiveness of the service were studied. Figure 12 shows the results for the question, “Will it be useful for safe driving?”

Over 90 percent of the trial subjects gave positive responses. As to the reasons for responding otherwise, most gave responses such as, “I received the information but did not
need it since sometimes there were no merging vehicles.” Even in actual road trials, the acceptability and effectiveness of the service were basically confirmed.

In addition, Figure 13 shows the results to the question, “When you encountered a merging vehicle, how much danger did you feel?” – comparing the case when the service was not offered and the case when it was. The “no danger” share was 48 percent, whereas the share when the service was offered was a very low 12 percent. It shows that the merging assistance service has the effect of bringing a certain level of tension to the driver.

**6. Conclusion**

This paper presented an overview of the merging section AHS safety service system and reported on the pilot study that was conducted, that the service is indeed effective in line with expectations. The plan for the coming months and years is to conduct further tests for putting the system into practice. In addition to the merge ramp on which the pilot study was conducted, the plan is also to go forward with another pilot study on the junction merging section.

It is furthermore foreseeable that enhancement of the merging assist system will lead to the development of: a two-step information provision mechanism combined with the advance information provision which displays the existence of merging section-related services; information provision to the merging vehicle; and information provision that assists the attunement and merging of a mainline vehicle and merging vehicle. These developments will be explored one by one in the years ahead.