Research on skillful drivers' merging behaviors and statistical analysis of traffic lane flow for an investigation of automatic merging assessment method

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ABSTRACT

AM (Automatic Merging) is a driving support system which helps drivers to merge into a traffic lane. It is required to set its performance assessment method to see whether it meets people's driving style of each country or region. In this paper, we propose methodologies to set suitable assessment method of AM (target performances and test conditions) which can be applied in each country or region. As for target performances, suitable ones are set by studying Japanese skillful drivers' merging behaviors on highway and on test track. As for test conditions, a new method is proposed to calculate the possibility that a merging vehicle encounters a difficult situation by analyzing traffic camera and cloud data, which allows us to set reasonable test conditions as "X%ile difficulty" of real environment. These methodologies can be applied not only in Japan but also in other countries or regions.

INTRODUCTION

Demand for AD (automated driving) is increasing rapidly. AM (Automatic Merging) is one of the most complex functions of AD. It helps drivers to merge into a traffic lane, and it is the essential function to achieve automated driving from entrance to exit of highway. Various kinds of researches on function of AM have been reported [1] [2] [3]. Then performance of AM should also be considered in order to provide reliable and comfortable AM. However, its performance assessment method hasn't been generalized yet. Additionally, it should be applied to each country or region because traffic conditions varies among them and AM interacts with other vehicles more than the other ADAS functions do. In this paper, we propose methodologies to provide an assessment method (target performances and test conditions) of AM which can be applied in each country or region. In chapter 1, AM target performances are set as "equal to skillful drivers" by modeling their merging behaviors. In chapter 2, reasonable AM test conditions are set by analyzing the traffic flow of 1st lane (the lane being merged) of real environment.

Definitions

Figure 1 shows the definitions of terms and variables. Explanations of each term/variable are listed in Table 1.

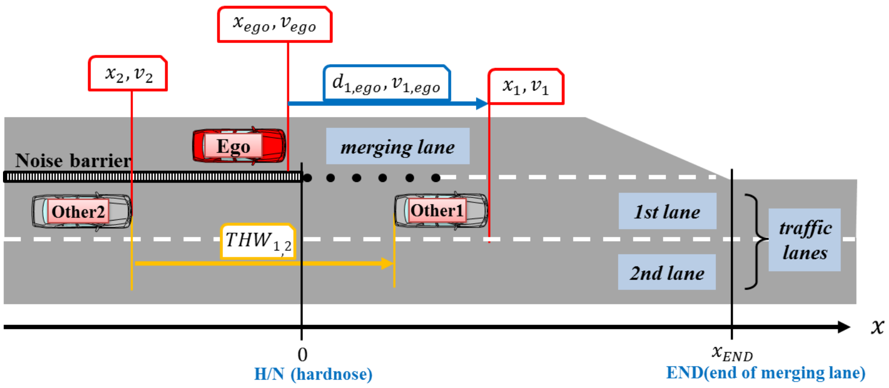


Figure 1. Definitions of terms and variables

Table 1. Definitions of terms and variables

Term/ Variable	Definition
1st lane	The nearest traffic lane to the merging lane.
END	End of merging lane.
H/N	Hardnose. In this paper, it is assumed that the ego-vehicle driver cannot see other vehicles on traffic lanes until he/she passes this point.
x_{ego}, x_1, x_2, x_{END}	Position on x-axis of each vehicle or point.
v_{ego}, v_1, v_2, v_{END}	Velocity of each vehicle or point.
$d_{A,B}$	Relative distance between each vehicle or point. *e.g.* $d_{END,ego} = x_{END} - x_{ego}$
$THW_{A,B}$	Time headway between each vehicle. *e.g.* $THW_{ego,2} = (x_{ego} - x_2)/ v_2$

1. Target performance setting by studying skillful drivers' merging behaviors

Our basic idea of target performance (T/P) is "equal to skillful drivers." Table 2 shows the list of the target performances of AM. The classification is composed of "reliability" and "comfort." "Reliability" means whether the driver can trust AM without feeling uneasy. "Comfort" means whether the driver can feel comfortable. The viewpoints are listed by discussing with skillful drivers based on each classification. Then KPIs (Key Performance Indicators) corresponding to each viewpoint were proposed. Based on these KPIs, all of the target performances were set by analyzing skillful drivers' behaviors on highway or highway-modeled test track. In this paper, "margin to other vehicles on 1st lane (static)" and "which space to merge" are explained as examples.

Table 2 List of target performance for AM

Classification	Viewpoint		KPI	Study method
Reliability	***Margin to other vehicles on 1st lane***	***(Static)***	Restricted area for other vehicles [m] (& THW[s])	Study of skillful drivers' behaviors on highway
		(Dynamic)	Minimum TTC to the other vehicles [s]	
	Margin to the lane end edge	(Static)	Restricted area for end edge[m]	
		(Dynamic)	Minimum TTC to the lane end edge[s]	
	Which space to merge (in front of / behind other vehicle)		Judgment formula composed of $d_{1,ego}$, $v_{1,ego}$, v_{ego}, x_{END}	Study of skillful drivers' behaviors on highway-modeled test track
Comfort	Longitudinal motion		Long. acceleration [m/s^2]	Study of skillful drivers' behaviors on highway
			Long. jerk [m/s^3]	
	Lateral motion		Lat. acceleration [m/s^2]	
			Lat. jerk [m/s^3]	

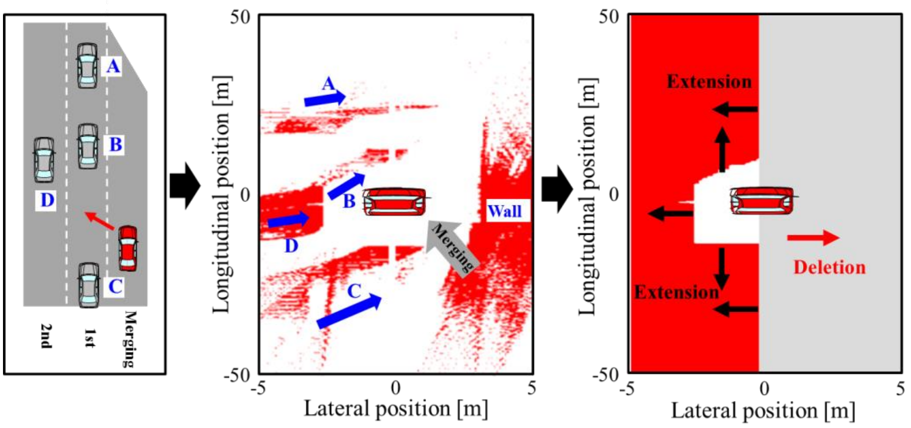
1-1. T/P example 1: Margin to other vehicles on 1st lane (static)

Concept & Data collection

This target performance provides "how close the ego-vehicle can be to other vehicles on traffic lanes." Our aim is to make the target performance as "equal to skillful drivers." Then a public road test was carried out to acquire the data of skillful drivers' behaviors. The test vehicle was equipped with external sensors such as lidar for all directions. The test was carried out mainly on Shutoko (urban highway in Tokyo) which is one of the busiest highways in Japan. Three skillful drivers who have Toyota's advanced licenses drove the vehicle. They drove not trying to make passengers feel uneasy or uncomfortable. It is because skillful drivers can drive either aggressively or smoothly, and obviously AM should follow the latter way. Additionally, we tried to record if the driver or the passengers (who are also skillful drivers) judged the merging behavior was not ideal, but eventually it never occurred. The test was carried out for three days, and 102 merging cases were collected. In this paper, 22 cases of stop & go traffic jam situation are excluded because the driver's strategy would be different from that of non-traffic jam situation.

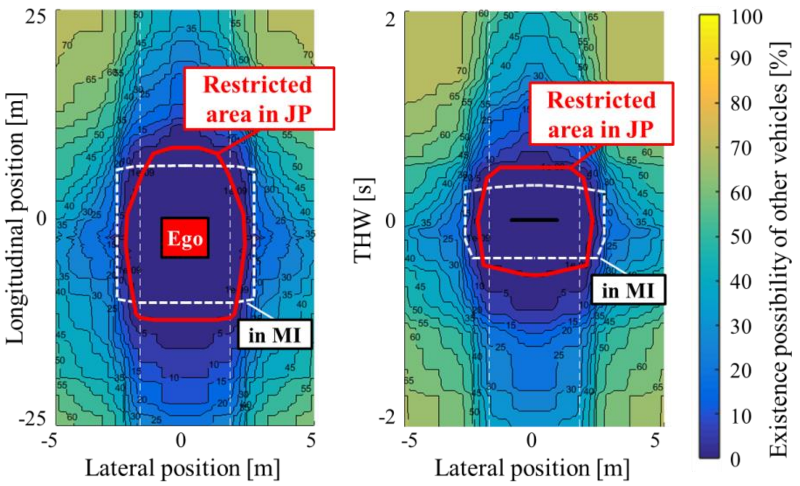
Analysis & Result

We set the target performance as the "minimum margin area" of the skillful drivers' merging behaviors. As a first step, we analyzed the skillful drivers' each merging case. Each case was extracted from when the ego-vehicle passed a hardnose to when it passed end of merging lane. See Figure 2 as an example. In this case, ego-vehicle merged from right to left while 4 other vehicles were driving on the traffic lanes (Figure 2a). Red points in Figure 2b shows the trajectory of the lidar points. Then these points were extended to longitudinal and lateral direction to obtain the edge of the other vehicles (Figure 2c). The obtained white area is the area where the ego-vehicle's driver didn't allow the other vehicles to enter in this case. As a second step, a heatmap of other vehicles' existence possibility was obtained by superimposing each case and dividing it by the number of merging cases (Figure 3). Note that each case is flipped horizontally because there was no significant difference between cases of merging to left and to right. Figure 3a shows the result with lateral position and longitudinal position axis, and Figure 3b shows the result with lateral position and THW axis. Note that negative THW means that to the following vehicle, and there is no THW in the side area of ego-vehicle. The area surrounded by red line is the area where the other vehicles never entered. This is the target performance of AM as "restricted area for other vehicles to enter." In addition, we also conducted a study with the same method in Michigan. The result is also shown in Figure 3 as the areas surrounded by white dotted lines. Here we can see the difference between two regions. This shows that suitable target performances would be different among regions or countries.



[a] Overview *[b] Trajectory* *[c]Edge extraction*

Figure 2. Analysis method of restricted area (1 case example)



[a] Distance-based *[b] THW-based*

Figure 3. Restricted area for other vehicles

1-2. T/P example 2: "Which space to merge"

<u>*Concept & Data collection*</u>

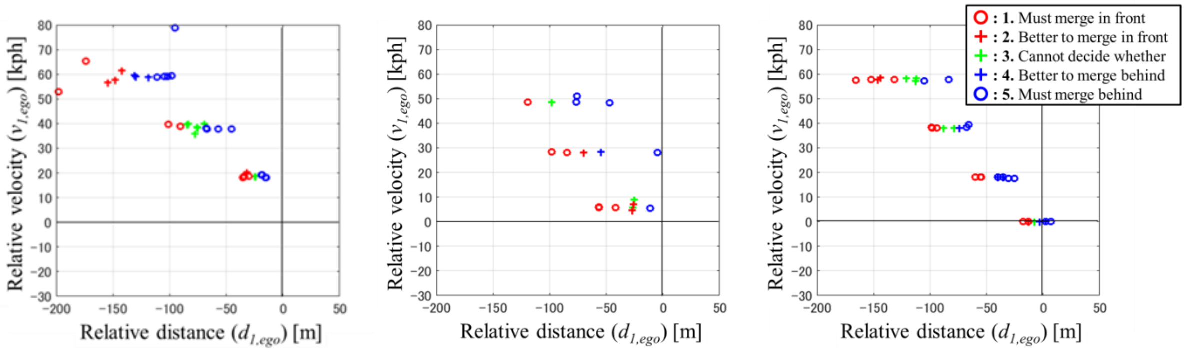
This target performance provides "which space should the ego-vehicle merge, in front or behind of a vehicle on 1st lane" when driver recognizes the vehicle on 1st lane at H/N position. The purpose is to avoid uneasy or strange feeling caused by AM's judgment different from drivers' own. Then skillful drivers' behaviors were studied with controlled conditions of one other vehicle. The test was conducted on a test track for test efficiently. Tests were conducted with varied conditions as shown in Table 3. The test track was modeled as a typical merging lane of interurban highway in Japan. Initial v_{ego}, v_1 and $d_{1,ego}$ means those of when the ego-vehicle passes H/N. As for velocity, in this paper, we focused on the condition that the ego-vehicle's velocity is lower than or equal to the other vehicle's because it is the most common situation in Japan. Then the drivers scored from 1 to 5 in each test case to describe their judgment as defined in Table 4. For example, the driver scored "1" when he/she judged that ego-vehicle must merge in front of the other vehicle. All of the drivers' scoring are shown in Figure 4.

Table 3. Test conditions for the study

Length of merging lane (x_{END})[m]	Speed limit assumption of 1st lane [kph]	Initial v_{ego} [kph]	Initial v_1 [kph]	Initial $d_{1,ego}$ [m]	Total number of test cases
220	100	40 to 60	60 to 120	-180 to 10	92

Table 4. Definition of scoring

Evaluation score	Definition
1	Must merge in front
2	Better to merge in front
3	Cannot decide whether
4	Better to merge behind
5	Must merge behind



[a] v_{ego} = 40kph *[b] v_{ego} = 50kph* *[c] v_{ego} = 60kph*

Figure 4. Judgment of skillful drivers

<u>Analysis & Result</u>

We set the target performance as "ego-vehicle must merge in front/behind if the skillful drivers judge it as must." Here, the target performance based on driver's judgment models is proposed as below.

(i) <u>Must merge behind</u> if Equation 1 is satisfied. (*Merge behind model*)

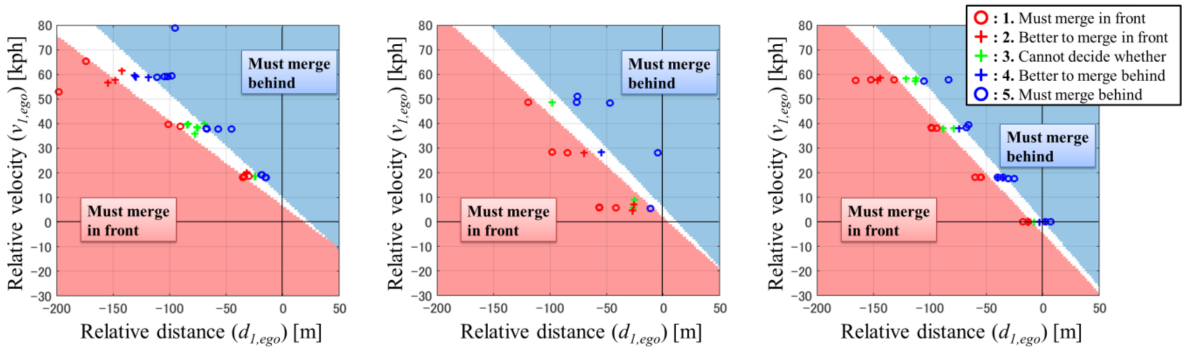
$$F_b = w_{b1}d_{1,ego} + w_{b2}v_{1,ego} + w_{b3}v_{ego} + w_{b4}x_{END}\frac{v_{1,ego}}{v_{ego}} + C_b > 0 \quad \text{[Equation 1]}$$

(ii) <u>Must merge in front</u> if Equation 2 is satisfied. (*Merge in front model*)

$$F_f = w_{f1}d_{1,ego} + w_{f2}v_{1,ego} + w_{f3}v_{ego} + w_{f4}x_{END}\frac{v_{1,ego}}{v_{ego}} + C_f < 0 \quad \text{[Equation 2]}$$

(iii) <u>No requirement</u> if neither of them is satisfied.

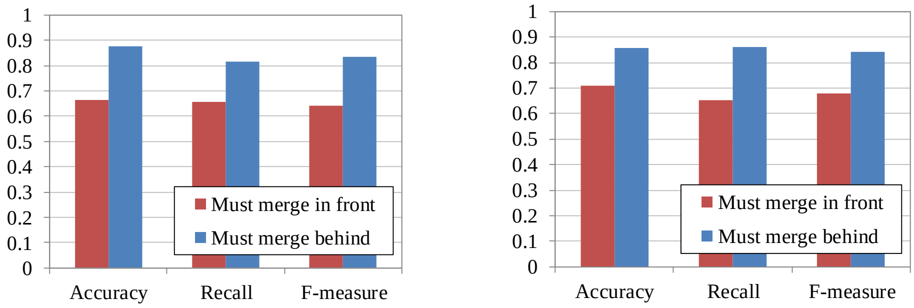
Here, $d_{1,ego}$, $v_{1,ego}$, v_{ego}, x_{END} are the variables defined in Table 1, and w_* is the weight of each variables. To identify the parameters of each model, Support Vector Machine (SVM) [4] is adopted. Parameters of *Merge in front model* are identified by dividing the score "1" from "2, 3, 4, 5" and those of *Merge behind model* are identified by dividing the score "5" from "1, 2, 3, 4" respectively. Then the suitable parameters for each model were obtained. Figure 5 shows the fitting result of the each model. The blue-colored area means "must merge behind", the red-colored area means "must merge in front", and the non-colored area means "no requirement."



[a] v_{ego} = 40kph *[b] v_{ego} = 50kph* *[c] v_{ego} = 60kph*

Figure 5. Fitting result of each model

To evaluate the accuracy of the obtained model, three accuracy indexes: precision, recall, and F-measure are calculated. These values of *Merge in front model* and *Merge behind model* are shown in Figure 6a. The model accuracy is high considering that human judgment is sometimes inconsistent even under the same condition. Additionally, these values of *Merge in front model* are lower than those of *Merge behind model*. It implies that it is more difficult for human to judge consistently as “merge in front” than as “merge behind” because the 1st lane vehicle is further away.
The same methodology was also applied to urban-highway-modeled merging test which has a shorter length of merging lane (140m). Then the similar fitting result was obtained, and the fitting accuracy was as high as that of interurban-highway-modeled merging test (Figure 6b).



[a] Interurban model ***[b] Urban model***

Figure 6. Fitting accuracy of each model

2. Test condition setting by studying 1st lane traffic flow

The conditions of 1st lane vehicles play a key role in AM evaluation. For example, it is obviously more difficult to merge when there are the other vehicles on 1st lane with close distance than when there is no other vehicle. Then reasonable and rather difficult test conditions should be set for effective evaluation of AM. In this chapter, we aim to set suitable ones by studying 1st lane traffic flow of real environment.
First of all, we have to consider what difficult conditions are. There would be two types of traffic situation: traffic jam and non-traffic jam. In this paper, we focus on the difficulty of non-traffic jam situation. Then, we assume that it would be difficult for drivers to merge in the conditions below:

- *(C1)* There is a 1st lane vehicle in a position where the ego-vehicle driver cannot judge which space to merge immediately. (Then the driver would have to drive long distance to merge.)
- *(C2)* There is another vehicle near the vehicle described in *C1*.

Figure 7 shows an image of these conditions.

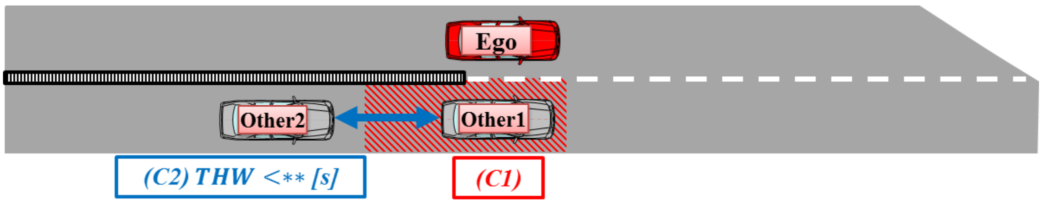


Figure 7. Difficult conditions for merging

With this assumption, a possibility to encounter such a difficult situation can be calculated. We call it "difficult possibility (P_{dif})." It is calculated by following equation.

$$P_{dif} = P(C1 \cap C2) \qquad \text{[Equation 3]}$$

As for the condition *C1*, it can be modeled as no requirement area of "which space to merge" (described as white areas in Figure 5) because drivers within this area have to drive further. Furthermore, it would be also difficult for AM because it should switch its judgment within this area. Then, it is important to clarify how often these conditions (*C1* and *C2*) appear in the real highway. Then traffic camera data was analyzed for this purpose because it allows us to obtain the traffic flow on 1st lane quite directly without losing statistical information. Two interchanges (Higashi-Ikebukuro and Kasugai) are chosen to study the traffic flow of urban and interurban highway (Figure 8). Table 5 and Figure 9 show the overview of traffic camera data. Note that the traffic jam situation (1st lane velocity < 30kph) was excluded in this paper.

[a] Higashi-Ikebukuro (urban) ***[b] Kasugai (interurban)***

Figure 8. Traffic camera image

Table 5. Traffic camera data overview

No.	Interchange	Highway	Speed limit on 1st lane [kph]	Shooting time [hour]	Number of vehicles on 1st lane	Average number of vehicles [Num. / hour]
1	Higashi-Ikebukuro	Shutoko (urban)	60	10.4	7758	746.0
2	Kasugai	Tomei (interurban)	100	11.1	5375	484.2

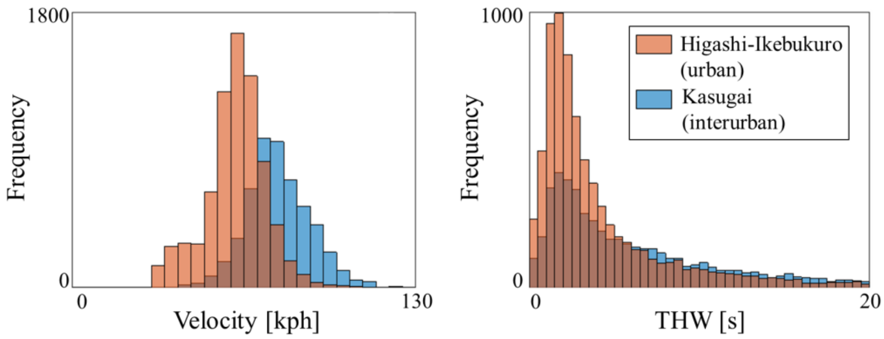
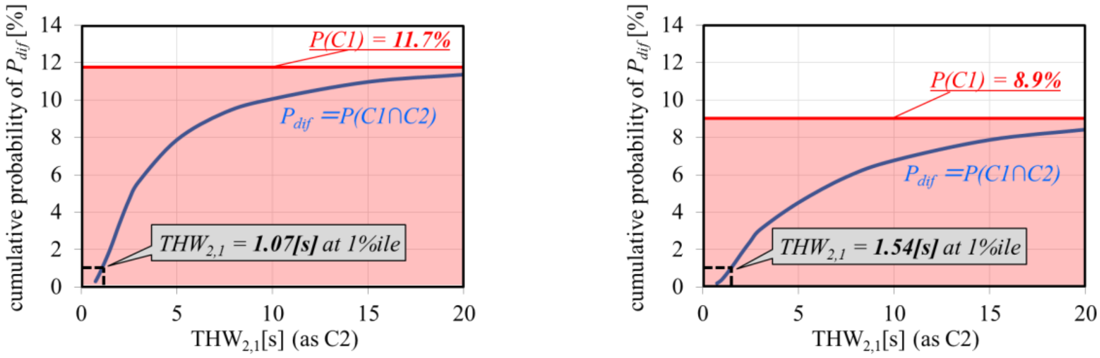


Figure 9. Traffic camera data overview

With these data, P_{dif} can be calculated by following equation with the assumption that the data distribution of sampled period is equal to that of the population.

$$P_{dif} = \frac{t(C1 \cap C2)}{t_{total\_cam}} \qquad \text{[Equation 4]}$$

Here, $t(C^*)$ is the accumulated time when the condition C^* is satisfied, and t_{total_cam} is the total time of traffic camera data. To calculate $t(C1 \cap C2)$ with Equation 1 and 2, it is assumed that ego-vehicles appear at every moment at the hardnose with initial velocity. The initial velocity should be set as AM's setting considering that the purpose is to set reasonable test conditions. Here, it is supposed that AM's initial velocity is 50kph at Higashi-Ikebukuro and 60kph at Kasugai, for example. Figure 10 shows the result of P_{dif} calculation. The horizontal red line shows $P(C1)$. The blue line shows the cumulative distribution *of* P_{dif} as a function of $THW_{2,1}$ (as *C2*). With this result, reasonable AM test conditions can be set by setting reasonable value of P_{dif}. For example, if we assume that AM test condition should be set as difficult as “P_{dif} =*1%*” of real environment, corresponding $THW_{2,1}$ is 1.07[s] for Higashi-Ikebukuro (urban highway), and 1.54[s] for Kasugai (interurban highway). The set $THW_{2,1}$ is shorter at Higashi-Ikebukuro than at Kasugai even with the same P_{dif} because the 1st lane traffic is heavier in Higashi-Ikebukuro than in Kasugai. (In other words, it is more frequent to encounter a difficult situation in Higashi-Ikebukuro than in Kasugai.)



[a] Higashi-Ikebukuro (urban) ***[b] Kasugai (interurban)***

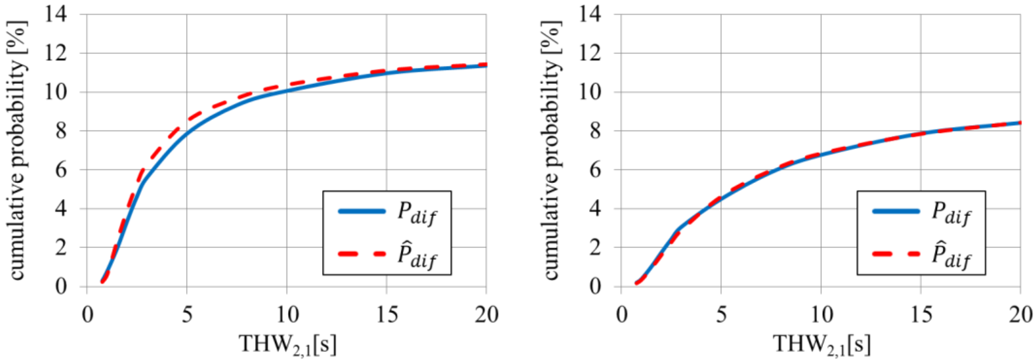
Figure 10. Result of difficult possibility calculation

With this method, it would be possible to make reasonable test conditions corresponding to every merging lane of real environment. However, it is unfeasible to collect traffic data of every merging lane by methods such as traffic camera. Then we kept studying to seek an alternative method as following.

$\hat{P}_{dif}$ is defined by the following equation.

$$\hat{P}_{dif} = P(C1) * P(C2) \qquad \text{[Equation 5]}$$

Figure 11 shows the comparison between P_{dif} and $\hat{P}_{dif}$ of each interchange. Their values match well, which means it is possible to suppose that conditions *C1* and *C2* are almost independent of each other when velocity is higher than 30kph.



[a] Higashi-Ikebukuro (urban) ***[b] Kasugai (interurban)***

Figure 11. Comparison of P_{dif} and $\hat{P}_{dif}$

The following equation is obtained from this result.

$$P_{dif} \cong \hat{P}_{dif} \qquad \text{[Equation 6]}$$

Then, we assume a data sampling method that some of vehicles can send v_{ego} and *THW* to data cloud (Figure 12). Note that, unlike traffic camera data analysis, it is impossible to obtain the data of all vehicles on 1st lane through the sampled period.

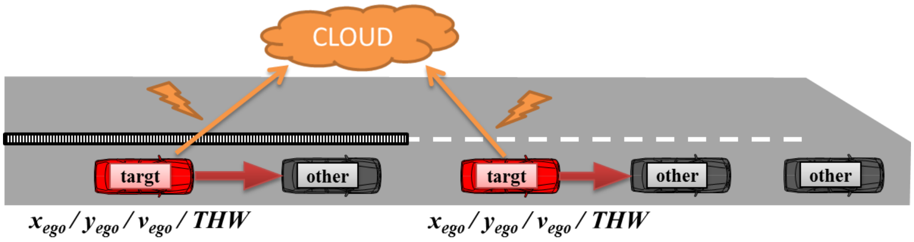


Figure 12. Data collection by cloud

With this kind of method, *P(C1)* and *P(C2)* can be also calculated as following equations with assumption that v_{ego} and *THW* distributions of sampled vehicles are equal to those of the population.

$$P(C1) = \frac{t_{sample}(C1)}{t_{total\_sample}} * \frac{N_{AVE\_population}}{N_{AVE\_sample}} \qquad \text{[Equation 7]}$$

$$P(C2) = \frac{t_{sample}(C2)}{t_{total\_sample}} \qquad \text{[Equation 8]}$$

Here, $t_{sample}(C*)$ is accumulated time when the condition $C*$ is satisfied by sampled vehicles, t_{total_sample} is total time of data-sampled period, $N_{AVE\_population}$ is number per unit time of vehicles of the population, and N_{AVE_sample} is that of sampled vehicles. Note that $N_{AVE\_population}$ can be obtained from public database of each region or country. For example, those data of major road junctions in Japan are open to public by MLIT of Japan [5]. Finally, it is possible to calculate P_{dif} of each merging lane of real environment by Equations 5-8 with this kind of data collection method.

CONCLUSION

New methodologies are proposed to determine "target performances" and "test conditions" for Automatic Merging (AM). As for target performances, skillful drivers' merging behaviors were studied and modeled as what AM should follow. It was found that one of the target performances is different between in Japan and in Michigan. As for test conditions, a new method is proposed to calculate the possibility that a merging vehicle encounters a difficult situation by analyzing traffic camera and cloud data, which allows us to set reasonable test conditions as "X%ile difficulty" of real environment. In addition, another analysis method using cloud data is also proposed as a substitute for traffic camera analysis. These methodologies proposed in this paper would help us to set suitable target performances and test conditions for each country or region.

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