AN ANALYSIS OF MERGING SPEEDS AT URBAN EXPRESSWAY MERGING SECTIONS

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1. INTRODUCTION

Among urban expressway facilities, merging section is one of the most important parts where traffic congestion and accident are likely to occur. This is because at merging sections, merging traffic and mainline traffic have to compete for the same space. Therefore, it is important to develop design standard that considers merging maneuvers for a smooth and safe merging process. Although the merging maneuvers may be significantly affected by the mainline traffic conditions (MTCs) and acceleration lane length (ALL), the existing guidelines for the design of minimum ALL such as AASHTO (2011) and Japanese guideline (2004), are based on the design speed of the mainline and on-ramp and constant acceleration rate without considering actual situation. Thus, this paper aims to investigate the impacts of MTCs and ALL on merging speeds by using video data.

2. DATA COLLECTION AND PROCESSING

Two merging sections named Horita and Takatsuji in Nagoya Expressway were chosen for the analysis of this study. The design speeds of Nagoya Expressway and on-ramp are 60 and 40 [km/h], respectively. At both of the sites, acceleration lanes were extended in October 2011, as a countermeasure against congestion. The video data was collected in different time period of the day and day of the week for both Horita and Takatsuji to observe various MTCs, covering both periods of “before” and “after” the extension of the acceleration lanes. The observation dates, the duration of survey and the mainline traffic situation are summarized in **Table 1.** Note that, during extending the length, the ALL was temporarily shortened for the construction work. This case is called “during”. The geometric characteristics of these two merging sections are presented in **Fig. 1.**

Table 1 Video survey period and mainline traffic situation

Merging section	Situation	Survey date	Day of the week	Survey time	Mainline flow rate (veh/h/2-lane) (Min-Max)
Horita	Before	16/09/2005	Friday	14:00 – 17:00	1735 - 3158
	During	26/07/2011	Tuesday	06:00 - 10:50	0588 - 3240
				15:14 - 18:00	2484 - 3444
		30/07/2011	Saturday	05:45 - 09:00	0432 - 2232
	After	10/11/2011	Thursday	14:00 - 18:00	2064 - 3348
		13/11/2011	Sunday	07:30 - 10:00	1008 - 2580
Takatsuji	Before	18/01/2005	Tuesday	08:00 - 10:00	2650 - 3325
	During	02/08/2011	Tuesday	09:00 - 11:00	2400 - 3072
				15:00 - 18:00	1800 - 2652
		06/08/2011	Saturday	12:00 - 15:00	1500 - 2316
	After	10/11/2011	Thursday	14:00 - 18:00	1800 - 2820
		13/01/2012	Friday	06:45 - 09:30	2154 - 3242
		21/01/2012	Saturday	08:00 - 12:15	1584 - 2496

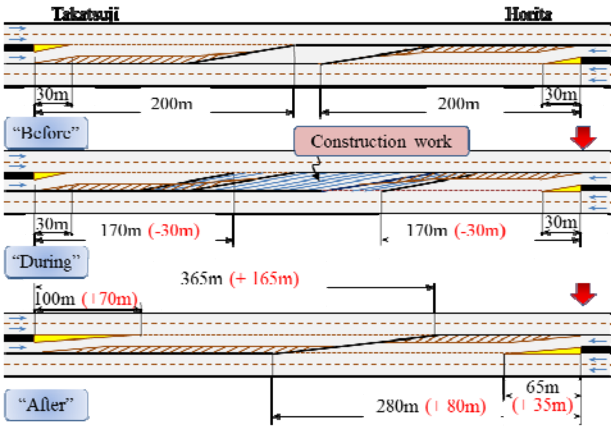

Fig. 1 Geometry of Horita and Takatsuji

To investigate impacts of the MTCs, MTCs are classified into uncongested and congested regimes by assuming the critical speed is 60 [km/h]. Then, the uncongested condition is divided into three levels A, B, C with the threshold of flow rate Q [veh/h/2-lane] as follows: A (Q < 1800), B (Q = 1800~2400) and C (Q > 2400). Moreover, the congested condition is denoted F as shown in **Fig. 2.** The average mainline speeds for condition A, B, C and F are 85.2, 78.0, 72.6 and 38.5 [km/h] respectively.

The trajectory of each vehicle was extracted every 1.0 seconds by using the image processing system “TrafficAnalyzer” developed by Suzuki and Nakamura (2006). The reference observation point of each vehicle is right-rear wheel. Then, by using Kalman smoothing function, vehicle trajectories were extracted into 0.1 sec. It is important to note here that merging position is defined as the distance from the right-rear wheel of merging vehicle to the end of the hard nose when it touches the dashed line and merging speed is the speed of merging vehicle at the merging moment. Approach speed is defined as the instantaneous speed of merging vehicle at the end of hard nose. In order to analyze the relationship between merging position and merging speed, the acceleration lane is divided into two parts. The speeds of merging vehicles which merge within the first and second half are denoted V_{m1} and V_{m2}, respectively.

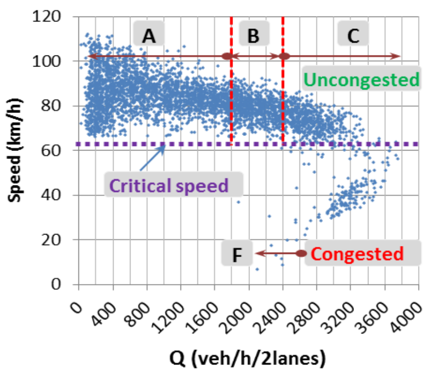

Fig. 2 Classification of MTCs

Keywords: Merging section, vehicle behavior, geometry, traffic conditions
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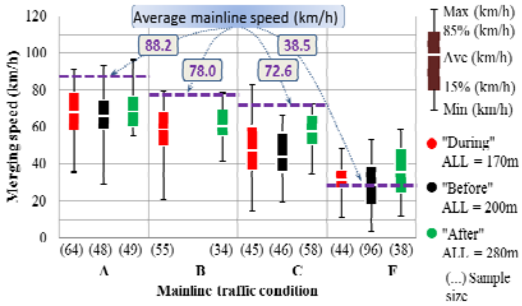
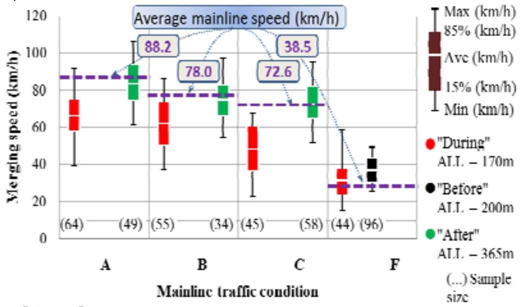
3. RESULTS AND DISSCUSSION

The comparisons of merging speeds at Horita and Takstsuji are presented in **Fig. 3** a) and b), respectively. By comparing the “during” and “before” with the “after” case, it is found that the merging speed of “after” case is significantly higher (at 95% significance level) than those of “during” and “before” cases except the condition A and B at Horita. Also, it is obvious that the average merging speed of “after” case at Takatsuji almost reached the average speed of mainline. This can be referred to the longest ALL at Takatsuji “after” case compared to the others. It means for longer ALL, merging vehicles will have enough time to adjust the mainline speed; therefore, they can more smoothly merge into the mainline. However, by comparing the “during” and “before” case, it is found that the merging speed of “before” case is smaller than that of “during” case at Horita while the tendency was opposite at Takatsuji. The reason might be that the difference of ALL for “before” and “during” case is not large (200m and 170m). Regarding the traffic condition, it is clear that the merging speed is significantly smaller (at 95% significance level) as the MTCs changes from A to F. It is logical because when mainline traffic becomes higher, the average mainline speeds are also reduced and then merging vehicles have to decrease their speed to merge into the mainline.



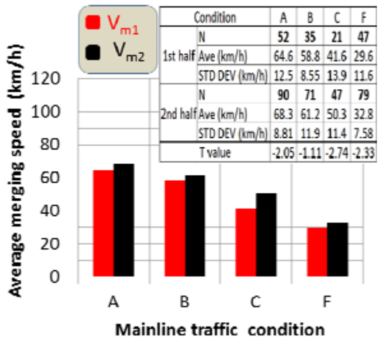
a) Horita



b) Takatsuji

Fig. 3 Comparison of merging speed

Fig. 4 shows the comparison of V_{m1} and V_{m2} for the ALL of 170m. Generally speaking, the second half merging speed is significantly higher than the first half merging speed (at 95% significance level). The same trend can be found for the ALL of 200, 280 and 365m. This trend is understandable because the farther merging position is, the higher speed merging vehicles can reach. Also, V_{m1} and V_{m2} tend to reduce as the MTCs change from A to F. This tendency is consistent with the results of merging speed analysis as discussed above.



Condition		A	B	C	F
1st half	N	**52**	**35**	**21**	**47**
	Ave (km/h)	64.6	58.8	41.6	29.6
	STD DEV (km/h)	12.5	8.55	13.9	11.6
2nd half	N	**90**	**71**	**47**	**79**
	Ave (km/h)	68.3	61.2	50.3	32.8
	STD DEV (km/h)	8.81	11.9	11.4	7.58
T value		-2.05	-1.11	-2.74	-2.33

Fig. 4 Relationship between merging speed and merging position (ALL = 170m)

Fig. 5 illustrates the comparison of approach speed at Horita. It is obvious that the approach speed significantly decreases (at 95% significance level) if the vehicles in the mainline become denser. The reason might be that merging vehicles can see the MTCs from upstream and slightly reduce speed to merge more smoothly into the mainline especially under condition F. For the ALL, the analysis does not show any significant impacts of ALL on approach speed except approach speed between “during” and “before” cases at condition A.

The existing guidelines assume that merging vehicles enter in design speed of on-ramp and constantly accelerate till the speed of the mainline. Although the ALL of all cases satisfies the requirement of minimum ALL given by guidelines, the results showed that approach speeds and merging speed are quite different from design speed of expressway and on-ramp. Furthermore, vehicles in shorter ALL do not accelerate as expected in the guidelines. It means, merging vehicles with shorter ALL prefer to merge into the mainline rather than accelerate to reduce the gap between merging speed and mainline speed. However, merging vehicles with longer ALL have enough space to accelerate for adjusting to mainline speed, which reduces the impacts of merging vehicles on mainline vehicle maneuver and may achieve safer condition. Although the existing guideline only provides the minimum ALL, it was shown that the longer ALL than the minimum requirement has positive impact for the improvement of level of service in terms of safety and efficiency.

4. CONCLUSIONS

In this paper, merging speed, approach speed and relationship between merging speed and merging position were analyzed and compared considering the effects of MTCs and ALL. The results showed that not only the merging speed but also the approach speed reduces as the traffic demand becomes higher. Merging speed increases and becomes more adjacent to mainline speed as ALL is longer. It implied that extending ALL may improve efficiency and safety.

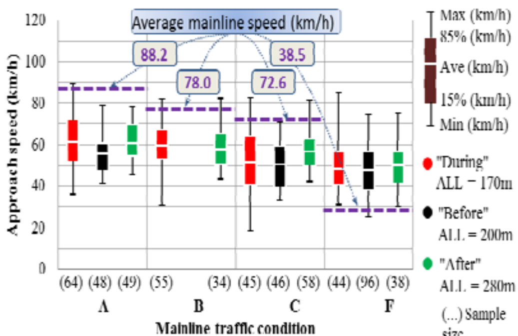


Fig. 5 Approach speed at Horita

5. ACKNOWLEGEMENTS

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