# Quantifying Effects of Acceleration Lane Lengths and Traffic Conditions on Merging Maneuvers at Urban Expressway Entrances

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**Abstract**: Quantifying effects of geometry and traffic conditions on merging maneuvers is an important concern for providing a rational design of acceleration lane. This study aims at gaining insights into this issue based on the data collected at two urban expressway entrances in Nagoya City, Japan (left-hand traffic). In this study, the traffic conditions were divided into four levels A, B, C and F to analyze their effects. It was found that merging speeds decrease as traffic conditions become more congested. The comparison of initial speed and merging speed showed that, merging vehicles use the acceleration lane not only for acceleration purpose but also for deceleration purpose. Furthermore, it was also found that the longer acceleration length results not only in further merging positions but also in more variations of merging positions under congested conditions.

*Keywords*: urban expressway, merging maneuver, traffic conditions, geometric design

## 1. INTRODUCTION

Entrances on expressways are designed to allow vehicles coming from a ramp to smoothly merge into the mainline. The operational efficiency of these sections has been regarded as an important concern. It has been identified that driver behavior at entrances affects traffic operations. For instance, breakdown events are found to be associated with the interactions between the two competing traffic streams. Thus, understanding merging maneuver is very important for the design of the acceleration lane in order to provide a smooth merging process and meanwhile minimize the impacts of merging vehicles on mainline vehicles.

In reality, merging maneuvers vary depending on geometry of entrances and traffic conditions. Unfortunately, existing guidelines such as AASHTO (2011) and the Japan Road Association (2004) are based on the design speeds of the ramp and mainline in addition to assuming a simplified constant acceleration rate for the estimation of minimum acceleration lane length without considering any interaction between merging and mainline traffic. Hence, it is necessary to investigate the effects of geometry and traffic conditions on merging maneuvers.

Accordingly, the objective of this paper is to analyze effects of these influencing factors on merging maneuvers, namely initial speed, merging speed and merging position by using video data. The video data were collected during three periods at two urban expressway entrances in Nagoya City, Japan (left-hand traffic), covering both uncongested and congested regimes of mainline traffic. The acceleration lanes at these sites were extended in 2011 as a measure to relieve congestion. Note that, during the extension of these sections, the acceleration lanes were slightly shortened due to construction work. Therefore, the video data taken during three periods with different acceleration lane lengths provide a good basis for this study.

The remainder of this paper is organized as follows. After the literature review, the methodology is explained in detail. This is followed by study sites description, data collection and data processing procedure. Then, comprehensive discussions about the effects of acceleration lane lengths and traffic conditions on merging maneuver are presented. Finally, the paper ends up with conclusions and future works.

## 2. LITTERATURE REVIEW

Several studies have investigated the merging maneuvers on acceleration lanes by using observed data or by using driving simulators.

Polus *et al.* (1985) analyzed merging position of merging vehicle based on video data collected at four acceleration lanes in Israel. The comparison was given for tapered and parallel acceleration lane. However, the effects of traffic conditions and acceleration lane lengths on merging position were not concerned. Ahammed (2008) modeled merging maneuvers including merging speed and merging position based on field data observed in Ottawa City, Cananda. The models showed that merging speeds and merging positions increase as the acceleration lane length becomes longer. However, the effects of the mainline traffic conditions were not considered since the field observation was conducted during the off-speak hours only.

Most recently, Calvi and Blastis (2011) studied the driver behavior on acceleration lane by using a driving simulator. Six configurations were used to test the participants in the simulator including acceleration lanes of different lengths under low (1000 veh/h/2-lane), medium (1500 veh/h/2-lane) and high traffic conditions (3000 veh/h/2-lane). The findings demonstrated that traffic volumes on the mainline significantly affect merging maneuvers. Initial speed, merging speed, merging positions and acceleration oscillations increase as traffic volumes become higher. In addition, the length of the acceleration lane was found not to affect merging position except under high traffic volume. Although they considered both mainline traffic conditions and acceleration lane lengths, it is unrealistic to assume a fixed mainline speed of 120 [km/h] for all of six configurations in the driving simulator. In reality, the speeds of mainline vehicles are quite dependent on the mainline traffic conditions and cannot be constant under different traffic conditions. That might be the reason why they concluded that initial and merging speeds of merging vehicles increase as traffic volumes become higher.

In summary, effects of geometry of entrances and traffic conditions on merging maneuvers have not been thoroughly studied yet. In addition, previous studies did not focus on urban expressways although they have special features. In metropolitan areas in Japan, due to lack of space, urban expressways are built as viaducts and the entrances sometimes are positioned in the middle of the two expressway carriageways. In this case, it is common to have entrances located on the right-side (left-hand traffic) even left-side entrances are preferable as suggested by design guidelines. This study tends to cover these gaps by taking into account both of these influencing factors using video data collected under various traffic conditions and acceleration lane lengths at urban expressway entrances in Nagoya City, Japan.

## 3. METHODOLOGY

### 3.1 Definitions

As aforementioned, it is often the case to have entrances located on the right-side in metropolitan areas in Japan (left-hand traffic). In this study, merging maneuvers of vehicles, which merging from right-side, including initial speed $v_1$, merging speed $v_2$ and merging position $x_M$ are analyzed. Figure 1 illustrates the definitions of these maneuvers which are explained below.

- Initial speed ($v_1$): The speed of merging vehicle at the position of physical nose [km/h]. The physical nose is defined as the connection point between median separator and tapered chevron marking.
- Merging speed ($v_2$): The speed at the moment of merging completion [km/h]. Merging completion is defined at the moment when the right-rear side of merging vehicle touches the dashed marking line.
- Merging position ($x_M$): The distance from physical nose to the front bumper of merging vehicle at the moment of merging completion [m].

Moreover, the geometric parameters of entrance using in this study are also represented in Figure 1. They include:

- $x_{PN\text{-}SN}$: the distance from physical nose to soft nose [m]. The soft nose is defined as the end point of the tapered chevron marking between on-ramp and expressway.
- $L$: the length of acceleration lane [m]. It is defined as the distance from physical nose to the end of the taper.

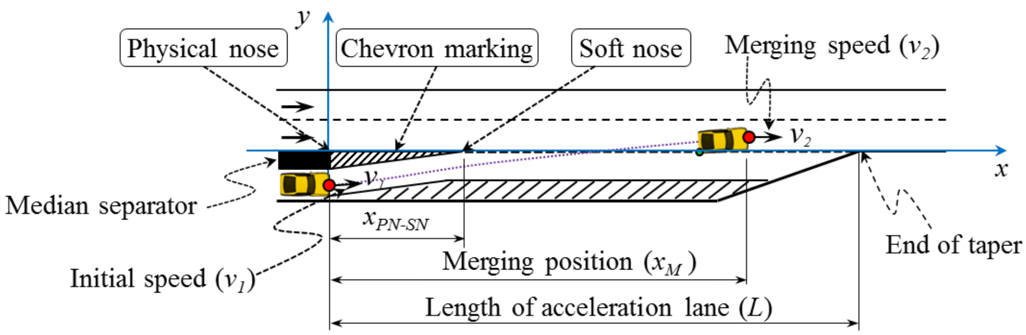
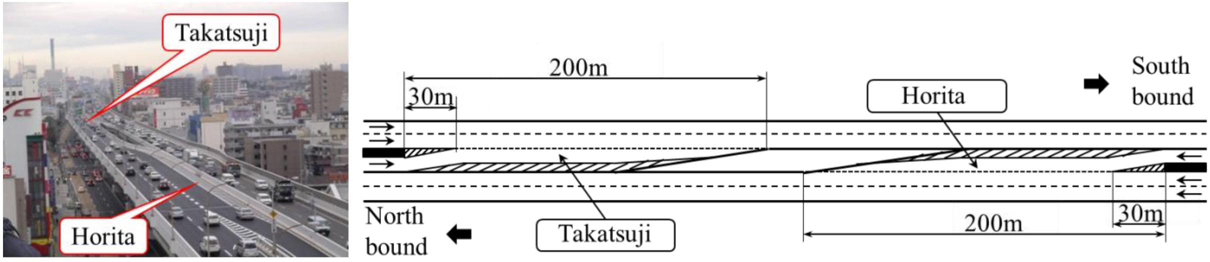


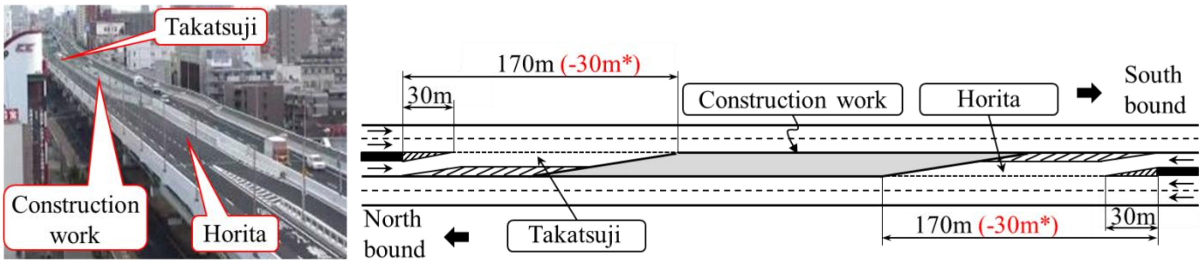

Figure 1. Definitions of merging maneuvers and geometric parameters

### 3.2 Study sites

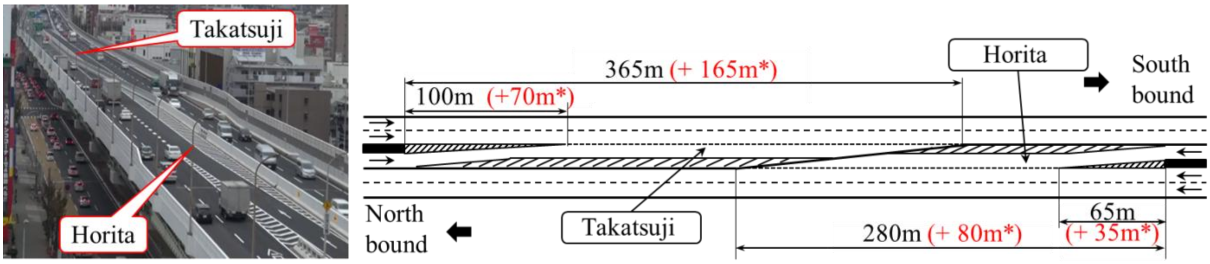
Two entrances, named Horita and Takatsuji are chosen for this study. Both of these entrances are located on Route No. 3 of Nagoya Urban Expressway, Nagoya City, Japan. At the study sites, both of the entrances are located on the right side. The design speeds of the mainline and ramp are 60 [km/h] and 40 [km/h], respectively. In addition, at these sites acceleration lanes were extended in October 2011 as a measure to relieve congestion. Furthermore, after the extension of acceleration lane, the distances from physical nose to soft nose $x_{PN\_SN}$ were also extended to 65 [m] at Horita entrance and to 100 [m] Takasuji entrance. What to be noted is that, in the process of extending the sections the acceleration lanes were slightly shortened due to construction work. In this study, the situations of before, during and after the extension of acceleration lanes are denoted as “before”, “during” and “after”, respectively. Their geometric characteristics are presented in Figure 2.




a) Before the extension of acceleration lanes




b) During the extension of acceleration lanes




c) After the extension of acceleration lanes

Note: (*) compared to before the extension of acceleration lane

Figure 2. Geometry of acceleration lane at Horita and Takatsuji entrances

### 3.3 Data collection

Video data were collected for both Horita and Takatsuji entrances, covering the periods of not only "before" and "after" but also "during" the extension of the acceleration lanes in various durations of the day and days of the week. It enabled to observe various mainline traffic conditions, which ranges from uncongested to congested regimes. In order to reduce errors while extracting trajectory data of vehicles, cameras were positioned on the top of the buildings located near the sections with wide shooting angles. Note that, weather conditions during all observation periods were fine with no rain. The observation dates, duration of the survey and mainline traffic situation are summarized in Table 1.

It is important to mention about the special characteristics of the sites, that is, the different lengths of acceleration lane could be realized at the same location. It was expected that the characteristics of drivers such as driver's population, percentage of aggressive drivers, etc. are the same for "before", "during" and "after" the extension of acceleration length. Moreover, because of the opening of Meinikan Expressway in March 2011 which goes parallel to the observed sites, a significant demand has moved to the new route. Traffic conditions of "during" and "after" situations become less congested compared to "before" situation.

Table 1. Video survey periods and mainline traffic conditions

| Merging section | Situation | Survey date | Day | Survey time | 5-min mainline flow rate [veh/h/2-lane] (min-max) |
|---|---|---|---|---|---|
| Horita Entrance | Before | 09/16/2005 | Friday | 14:00 - 17:00 | 1,735 – 3,158 |
| | During | 07/26/2011 | Tuesday | 06:00 - 10:50 | 588 – 3,240 |
| | | | | 15:14 - 18:00 | 2,484 – 3,444 |
| | | 07/30/2011 | Saturday | 05:45 - 09:00 | 432 – 2,232 |
| | After | 11/10/2011 | Thursday | 14:00 - 18:00 | 2,064 – 3,348 |
| | | 11/13/2011 | Sunday | 07:30 - 10:00 | 1,008 – 2,580 |
| Takatsuji Entrance | Before | 01/18/2005 | Tuesday | 08:00 - 09:00 | 2,650 – 3,325 |
| | During | 08/02/2011 | Tuesday | 09:00 - 11:00 | 2,400 – 3,072 |
| | | | | 15:00 - 18:00 | 1,800 – 2,652 |
| | | 08/06/2011 | Saturday | 12:00 - 15:00 | 1,500 – 2,316 |
| | After | 01/10/2011 | Thursday | 14:00 - 18:00 | 1,800 – 2,820 |
| | | 01/13/2012 | Friday | 06:45 - 09:30 | 2,154 – 3,242 |
| | | 01/21/2012 | Saturday | 08:00 - 12:15 | 1,584 – 2,496 |

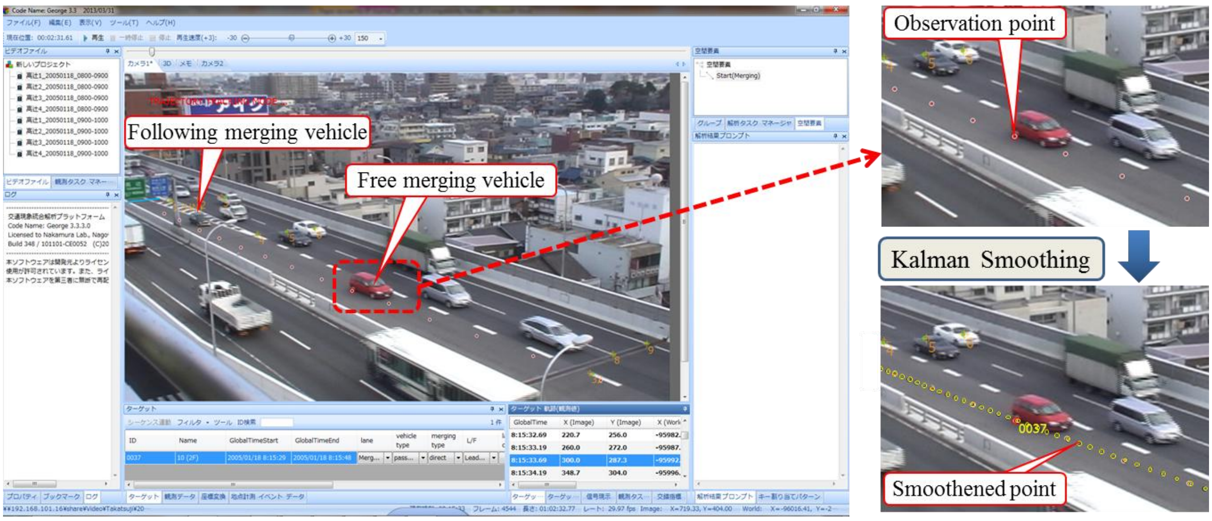



Figure 3. Vehicle trajectory extraction from video data using *TrafficAnalyzer*

### 3.4 Data processing

Trajectories of free merging vehicles were extracted from video data by using the image processing system *TrafficAnalyzer* (Suzuki and Nakamura, 2006). A free merging vehicle is defined as the vehicle that does not face any other merging vehicles ahead in the acceleration lane when passing the position of the physical nose. As illustrated in Figure 3, the position and timing of each vehicle were extracted every 1.0 second and then, by using the Kalman Smoothing function vehicle trajectories were estimated for every 0.1 seconds. The point where the right-rear wheel is touching the ground is defined as the reference observation point for all vehicles. By considering the dimension of each vehicle, the observed trajectories based on the right-rear wheel were transformed to the trajectories which correspond to the center of the vehicles. Then, for each merging vehicle, its speed and position at any moment can be extracted from the trajectory data.

### 3.5 Classification of traffic conditions

To investigate the effects of mainline traffic conditions on merging maneuvers, 5-minute detector data at Horita entrance from 6/6 to 6/10/2007 were analyzed as shown in Figure 4. The mainline traffic conditions are firstly classified into uncongested and congested regimes by assuming a critical speed of 60 [km/h]. Then, the uncongested condition is further divided into three levels A, B, and C with the thresholds of 5-min 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. The average mainline speed in each condition A, B, C and F is 85.2, 78.0, 72.6 and 38.5 [km/h], respectively.

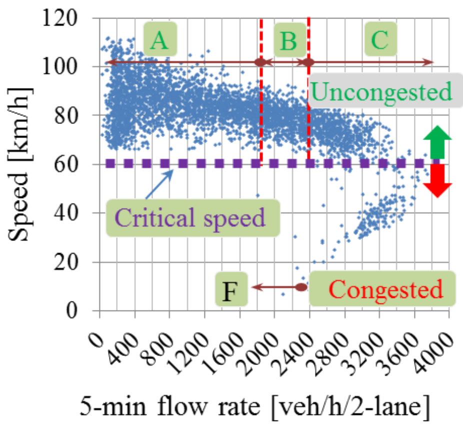



Figure 4. Classification of mainline traffic conditions

Table 2 shows the observed number of merging vehicles under different mainline traffic conditions at Horita and Takatsuji entrances covering all situations of "before", "during" and "after". It is important to note that all traffic conditions A, B, C and F can only be observed at the situations of "during" at both study sites and "after" at Horita entrance.

## 4. ANALYSIS ON MERGING MANEUVERS

### 4.1. Effects of mainline traffic conditions on merging speed $v_2$

Figure 5 gives comparisons of merging speed distributions at Horita and Takatsuji entrances for "during" ($L$ = 170 [m]), "before" ($L$ = 200 [m]) and "after" ($L$ = 280 [m] at Horita and $L$ = 365 [m] at Takatsuji), respectively. It is clearly shown that the merging speeds decrease as mainline traffic conditions change from A to F. The statistical test results for the difference of mean merging speed by traffic conditions shown in Table 3 also suggest that traffic conditions significantly affect the merging speed. This result implies that when the density in the mainline becomes higher, the speeds of the mainline vehicles become lower and merging vehicles have to reduce their speed to merge into the mainline.

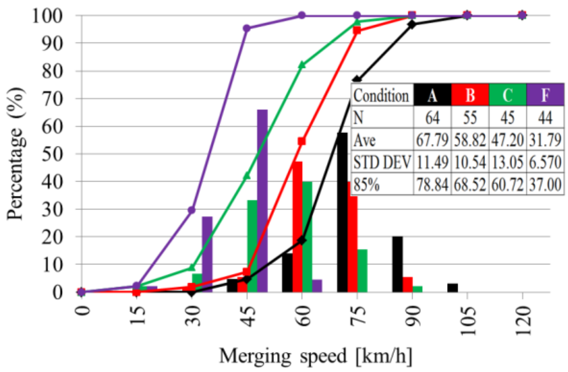
Table 2. Observed number of merging vehicles in different mainline traffic conditions at Horita and Takatsuji entrances

| Horita Entrance | | | Condition | Takatsuji Entrance | | | Condition |
|---|---|---|---|---|---|---|---|
| Survey date | Processed duration (minute) | N | | Survey date | Processed duration (minute) | N | |
| Before: L = 200 [m] $x_{PN\text{-}SN}$ = 30 [m] | | | | Before: L = 200 [m] $x_{PN\text{-}SN}$ = 30 [m] | | | |
| 16/09/2005 (Friday) | 15 *(14:00:14:15)* | 48 | A | 18/01/2005 (Tuesday) | 30 *(08:10-08:40)* | 81 | F |
| | 15 *(15:15-15:30)* | 46 | C | | | | |
| | 35 *(16:00-16:35)* | 96 | F | | | | |
| During: L = 170 [m] $x_{PN\text{-}SN}$ = 30 [m] | | | | During: L = 170 [m] $x_{PN\text{-}SN}$ = 30 [m] | | | |
| 26/07/2011 (Tuesday) | 30 *(06:02-06:32)* | 64 | A | 02/08/2011 (Tuesday) | 25 *(16:35-1700)* | 51 | B |
| | 25 *(08:58-09:23)* | 55 | B | | 10 *(10:30-10:40)* | 23 | C |
| | 20 *(16:05-16:26)* | 45 | C | | 34 *(09:06-09:40)* | 82 | F |
| | 15 *(17:15-17:30)* | 44 | F | 06/08/2011 (Saturday) | 28 *(12:10-12:38)* | 78 | A |
| After: L = 280 [m] $x_{PN\text{-}SN}$ = 65 [m] | | | | After: L = 365 [m] $x_{PN\text{-}SN}$ = 100 [m] | | | |
| 10/11/2011 (Thursday) | 25 *(14:05-14:30)* | 34 | B | 10/11/2011 (Thursday) | 20 *(14:10-14:30)* | 41 | B |
| | 32 *(15:50-16:22)* | 58 | C | | | | |
| | 20 *(17:00-17:20)* | 38 | F | 13/01/2012 (Friday) | 45 *(07:10-08:05)* | 90 | C |
| 13/11/2011 (Sunday) | 22 *(07:33-07:55)* | 49 | A | 21/01/2012 (Saturday) | 30 *(11:30-12:00)* | 81 | A |

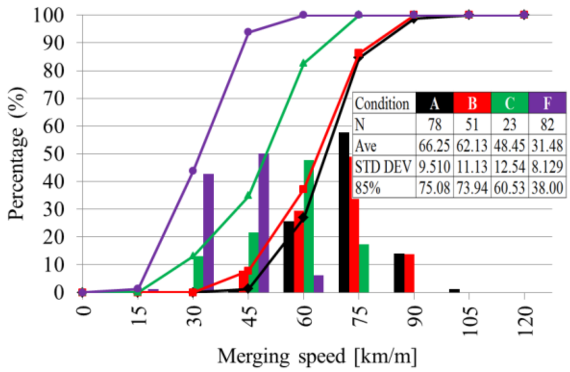
Note: N is the number of samples

### 4.2. Relationship between initial speed $v_1$ and merging speed $v_2$

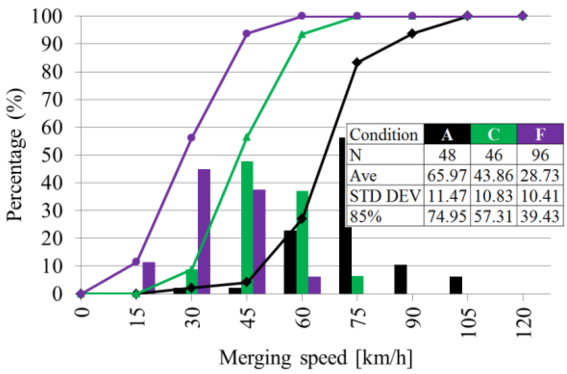
An important aspect in the design of acceleration lane length when discussing initial and merging speeds is whether merging vehicles accelerate or decelerate. It is dependent on initial speed and traffic conditions of the mainline. Figures 6a) and 6b) show the relationship between initial and merging speeds under different traffic conditions for Horita and Takatsuji entrances, respectively. It is found that under traffic condition A, merging vehicles pass the physical nose with lower initial speeds than merging speeds. In such a case, they need to accelerate before merging. In contrast, under condition F, merging vehicles come to the acceleration lane with higher initial speeds compared to merging speeds, and they are expected to decelerate. In addition, under traffic conditions B and C, merging vehicles come with either higher or lower initial speeds than merging speeds. It implies that the design of acceleration lane length should be provided not only for the purpose of acceleration but also for the purpose of deceleration. Although authorities do not assume congested conditions at the planning design stage, it does not guarantee that traffic congestion will not occur. In reality, congested conditions can occur due to driver behavior, unexpected increase in traffic demand and so on. Therefore, in practice, the length of acceleration lane should be designed for both of these purposes so that it can satisfy driver behavior under various operational conditions of mainline traffic.



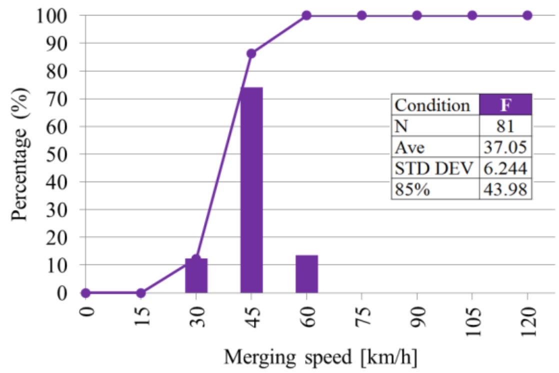

a) Horita entrance, “during” L = 170 [m]



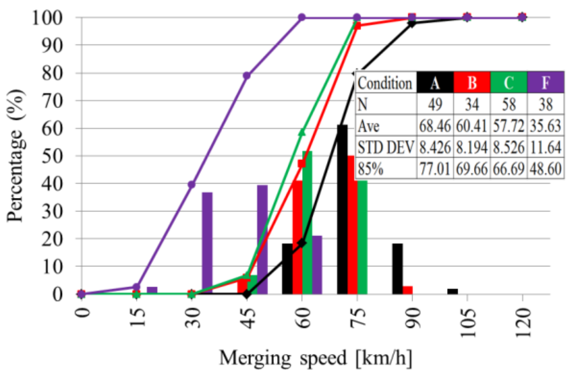

b) Takatsuji entrance, “during” L = 170 [m]



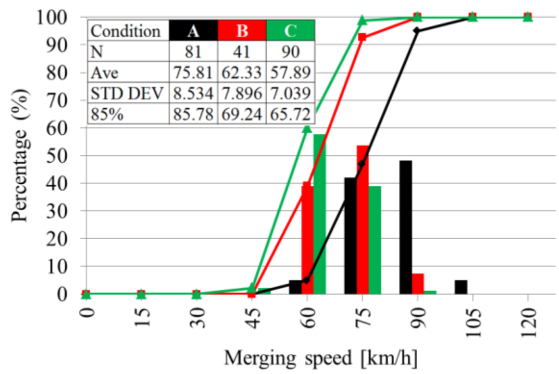

c) Horita entrance, “before” L = 200 [m]




d) Takatsuji entrance, “before” L = 200 [m]




e) Horita entrance, “after” L = 280 [m]



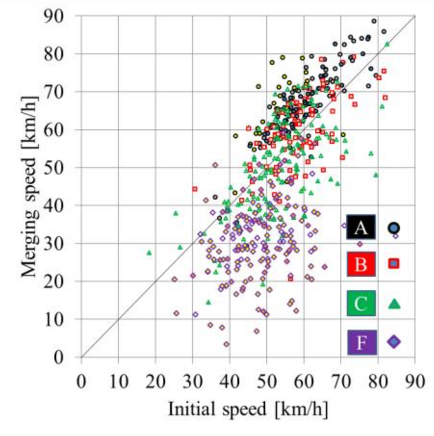

f) Takatsuji entrance, “after” L = 365 [m]

Figure 5. Comparisons of merging speed distributions by traffic condition

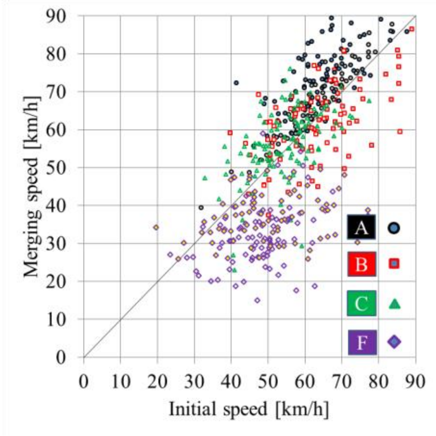
Table 3. Statistical test for the difference of mean merging speed distributions by traffic condition (t-value)

| Entrance | Traffic conditions | A vs. B | A vs. C | A vs. F | B vs. C | B vs. F | C vs. F |
|---|---|---|---|---|---|---|---|
| Horita Entrance | During | 4.413** | 8.713** | 18.77** | 4.929** | 14.85** | 7.011** |
| | Before | - | 9.601** | 19.55** | - | - | 7.998** |
| | After | 4.330** | 6.527** | 15.26** | 2.113** | 10.33** | 10.72** |
| Takatsuji Entrance | During | 2.244** | 7.308** | 24.89** | 4.702** | 18.31** | 7.778** |
| | Before | - | - | - | - | - | - |
| | After | 4.763** | 7.929** | - | 2.105** | - | - |

Note: - Not available; ** Significant at the 95% confidence level; * Significant at the 90% confidence level




a) Horita entrance (all lengths)




b) Takatsuji entrance (all lengths)

Figure 6. Relationship between initial and merging speeds by traffic condition

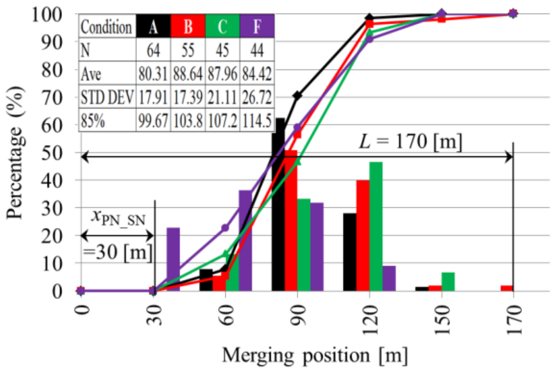
### 4.3. Merging position $x_M$

#### 4.3.1 Effects of mainline traffic conditions

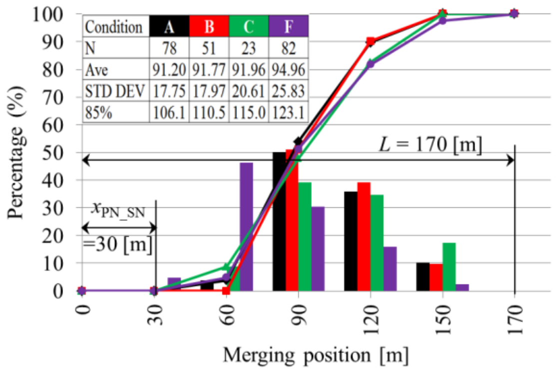
Comparisons of merging position distributions under different traffic conditions are presented in Figure 7. It shows that the curves of merging position distribution are shifted to the right side when traffic conditions change from A to C. It means that merging vehicles have to go further from physical nose to finish merging. The statistical test in Table 4 indicates that, in most cases, the traffic conditions do not significantly affect on the mean merging positions. However, as shown in Figure 7, the shape of merging position distributions under congested condition F are different from other conditions. Furthermore, the standard deviations under traffic condition F are larger than those of other conditions. It means the variations of merging positions under traffic conditions A, B and C are not significant compared to that under congested conditions. It is understandable because, due to high density under congested conditions, the gaps among mainline vehicles are sometimes too small to be accepted. In addition, under these conditions, as shown in previous discussion, it is common for merging vehicles to have higher speeds compared to that of mainline vehicles. As a result, some merging vehicles tend to go to the latter half of the acceleration lane to merge. In contrast, due to low mainline speed, some merging vehicles try to utilize available gaps for them immediately after passing physical node. That explains why some vehicles merge into the mainline around the position of soft nose as can be seen in Figures 7a) and 7e).

#### 4.3.2 Effects of acceleration lengths

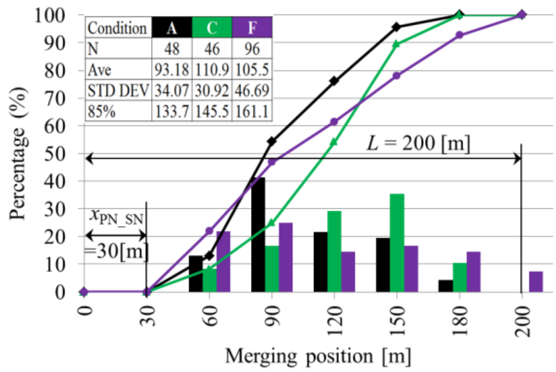
Figure 8 shows comparisons of merging position distributions by acceleration lane length. And Table 5 summarizes results of the statistical test for the difference of mean merging position (95% confidence level). It is obvious that merging positions significantly move downstream as acceleration lane length increases. In addition, by comparing the 15$^{th}$ and 85$^{th}$ percentile values, it is found that the variations in merging positions of the "during" case with the shortest acceleration length (L=170 [m]) are less significant compared to "before" and "after" situations, especially under congested conditions. It implies that given the shorter acceleration lane length, the fewer opportunities are provided for merging vehicles to merge into the mainline.



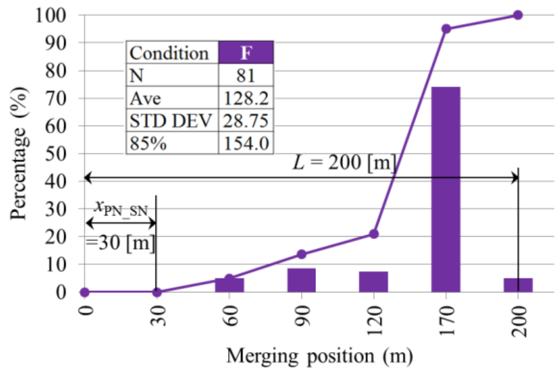

a) Horita entrance, “during” L = 170 [m]



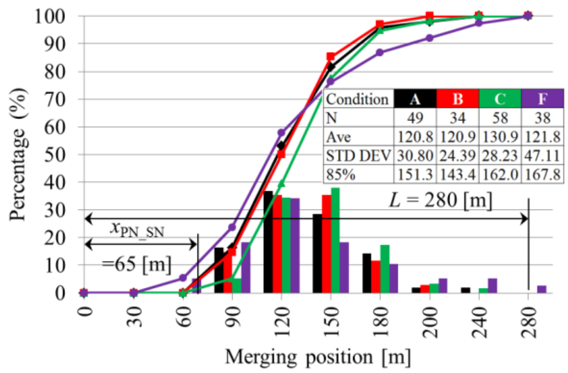

b) Takatsuji entrance, “during” L = 170 [m]



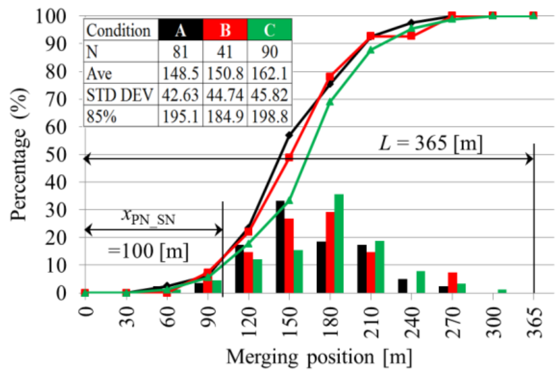

c) Horita entrance, “before” L = 200 [m]




d) Takatsuji entrance, “before” L = 200 [m]




e) Horita entrance, “after” L = 280 [m]



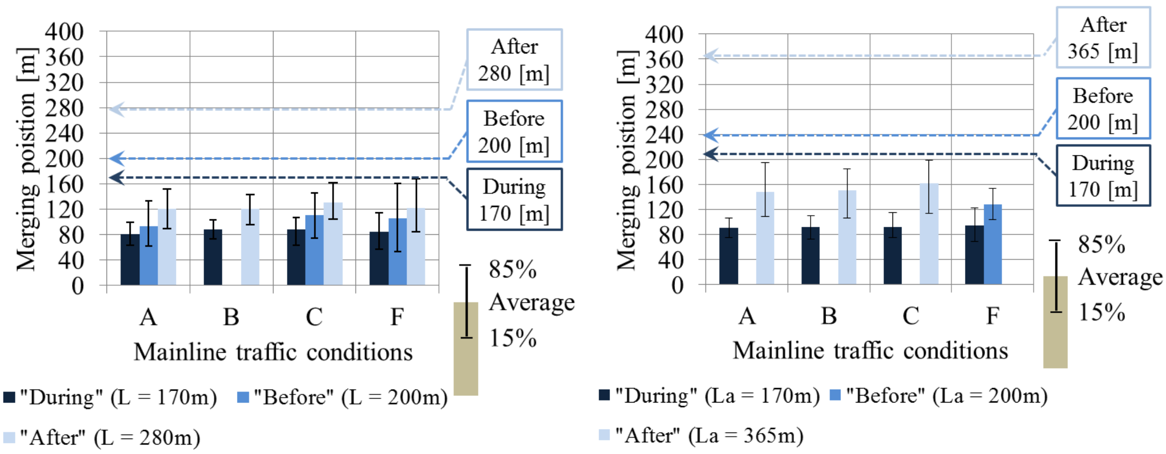

f) Takatsuji entrance, “after” L = 365 [m]

Figure 7. Comparisons of merging position distributions by traffic condition

Table 4. Statistical test for the difference of mean merging position distributions by traffic condition (t-value)

| Entrance | Traffic conditions | A vs. B | A vs. C | A vs. F | B vs. C | B vs. F | C vs. F |
|---|---|---|---|---|---|---|---|
| Horita Entrance | During | -2.564** | -2.038** | -0.956 | 0.177 | 0.498 | 0.695 |
| | Before | - | 2.645 | 0.726 | - | - | -1.598 |
| | After | -0.070 | -1.753 | -0.120 | -1.717 | -0.107 | 1.172 |
| Takatsuji Entrance | During | -0.178 | -0.176 | -1.069 | -0.041 | -0.773 | -0.512 |
| | Before | - | - | - | - | - | - |
| | After | -0.281 | -2.008** | - | -1.318 | - | - |

Note: - Not available; ** Significant at the 95% confidence level; * Significant at the 90% confidence level




a) Horita entrance b) Takatsuji entrance

Figure 8. Comparison of merging positions by acceleration lane length and traffic condition

Table 5. Statistical test for the difference of mean merging position distributions by acceleration lane length (t-value)

| Entrance | Horita Entrance | | | Takatsuji Entrance | | |
|---|---|---|---|---|---|---|
| Traffic conditions | “during” vs. “before” | “before” vs. “after” | “after” vs. “during” | “during” vs. “before” | “before” vs. “after” | “after” vs. “during” |
| A | -6.586** | -2.012** | 8.772** | - | - | 10.98** |
| B | - | - | 7.270** | - | - | 8.614** |
| C | -2.376** | -6.167** | 8.508** | - | - | 7.145** |
| F | -2.791** | -2.023** | 4.500** | -7.766** | - | - |

Note: - Not available; ** Significant at the 95% confidence level; * Significant at the 90% confidence level

### 4.3.3 Effects of length between physical nose and soft nose $x_{PN\_SN}$

It should be mentioned that, both lengths between physical nose and soft nose at Horita and Takatsuji entrances for “before” and “during” situation were 30 [m]. However, they were extended to 65 [m] (Horita entrance) and 100 [m] (Takatsuji entrance), respectively. From Figure 7, it is found that after extending the length, the percentages of vehicles which merge from 30 to 65 [m] (Horita entrance) and from 30 to 100 [m] (Takatsuji entrance) are significantly reduced by comparing “after” situation with “before” and “during” situations. These results are summarized in Table 6. It can be inferred that the reduction is due to the effects of tapered chevron markings on merging drivers. Basically, the purpose of tapered chevron marking is to guide traffic flow and merging vehicles should not cut it to merge into the mainline. However, some of aggressive drivers do not comply this guidance and still cut the tapered chevron marking to merge.

By comparing the percentage of vehicles which merge within 30 to 65 [m] (Horita entrance) with that of vehicles which merge within 30 to 100 [m] (Takatsuji entrance) “after” situation, it can be seen that the percentage at Takatsuji entrance is relatively higher. One possible reason is that the distance between physical nose and soft nose at Takatsuji entrance is longer compared to that of Horita entrance.

Table 6. Impact of length between physical nose and soft nose on merging position

| Traffic conditions | | Percentage of vehicles merging within | | | | | | | | Corresponding number of sample | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 ~ 30 m | | | | 30 ~ 65 m | | | | | | | |
| | | A | B | C | F | A | B | C | F | A | B | C | F |
| Horita Entrance | During | 0 | 0 | 0 | 0 | 21.9 | 5.45 | 17.7 | 27.3 | 64 | 55 | 45 | 44 |
| | Before | 0 | - | 0 | 0 | 10.4 | - | 19.6 | 27.1 | 48 | - | 46 | 96 |
| | After | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.26 | 49 | 34 | 58 | 38 |
| Traffic conditions | | Percentage of vehicles merging within | | | | | | | | Corresponding number of sample | | | |
| | | 0 ~ 30 m | | | | 30 ~ 100 m | | | | | | | |
| | | A | B | C | F | A | B | C | F | A | B | C | F |
| Takatsuji Entrance | During | 0 | 0 | 0 | 0 | 73.1 | 70.6 | 78.8 | 63.4 | 78 | 51 | 23 | 82 |
| | Before | - | - | - | 0 | - | - | - | 13.6 | - | - | - | 81 |
| | After | 0 | 0 | 0 | - | 12.3 | 12.2 | 8.88 | 0 | 81 | 41 | 90 | - |

Note: - Not available

## 5. CONCLUSIONS AND FUTURE WORKS

This paper examined effects of of mainline acceleration lane lengths and traffic conditions on merging speed and merging position.

It is concluded that mainline traffic conditions significantly affect merging speeds. Merging speed decreases as traffic conditions become more congested. The relationship between initial and merging speeds showed that, merging vehicles use the acceleration lane not only for acceleration purpose but also for deceleration purpose.

Comparisons of merging position distributions showed that the longer acceleration lane length results in further merging positions. Furthermore, the traffic conditions do not significantly affect on the means of merging positions but their variations. The variations of merging positions become significant when mainline traffic is congested. The similar tendency can be observed if acceleration lane length becomes longer. From these results, it can be implied that a longer acceleration lane may not always provide a benefit in terms of efficiency. Under near-congested or congested conditions, the variation of merging positions when the longer acceleration lane is provided can cause more negative impacts on mainline traffic.

Note that in this study, only free merging vehicles were considered. However, it is also necessary to analyze following merging vehicles. On Nagoya Urban Expressway, the Electronic Toll Collection (ETC) are installed upstream of on-ramps. Recently, the utilization rate of ETC has reached almost 90%. As a result, the merging vehicles can enter the acceleration lane within a platoon and might cause greater impacts on mainline traffic. Thus, quantifying the effects of vehicles coming as a platoon on merging maneuvers needs to be further investigated. In addition, future works should be carried out for to the analysis of the acceleration/deceleration rate, which is important for the estimation of minimum acceleration lane length.

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