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AN EXPERIMENTAL STUDY ON MITIGATION OF EXPRESSWAY TRAFFIC CONGESTION WITH LED INFORMATION BOARD

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Abstract: Provision of traffic information to drivers around bottleneck by Light Emitting Diode (LED) information board has been expected as a new congestion antidote which will mitigate congestions in the normal sections of expressways with considerably low costs. It has already been reported that LED sign car may increase congested flow rate as the result of guiding drivers to accelerate their speeds during congestion. The study aims to verify the effect of LED information board to increase the bottleneck capacity during congestion as well as the maximum flow rate before congestion. As the result of the survey, it is shown that through provision of dynamic traffic information of congestion via LED information board will increase the congested flow rate at the bottleneck. However, it is difficult to show a clear increase of the maximum flow rate before congestion.

Key Words: traffic congestion on interurban expressway, LED information board, congested flow rate, maximum flow rate before congestion, bottleneck capacity

1.INTRODUCTION

Traffic congestion has been an important social issue not only in Japan but also in all over the Asian countries. Economic losses caused by the waste of time and environment deterioration around the roadside area by the exhaust gases during congestion are serious negative impacts. In Japan, chronic congestions occur frequently in metropolitan areas and recreational congestions on interurban expressways on weekends and holidays. The widening of road to

mitigate the congestion is the main solution, but it is often very difficult to implement due to limited budget on road construction and operations.

Most of congestions occur in the uninterrupted sections of interurban expressways not in the merging or lane drop sections (Koshi, 1986, Iwasaki, 1985, *et al*). The triggers for the congestion on the normal sections have been explained by speed reduction of the vehicular platoons at the sag or upgrade sections, the so-called shock wave theory. It is, however, well known that not every sag would become bottleneck in capacity. A sag of larger upgrade does not necessarily become bottleneck. Therefore, it is too difficult to accurately forecast what kind of geometric structure of road would lead to a bottleneck, and the antidote is not found except for the widening of road.

Provision of traffic information to drivers around bottleneck has been expected as a new congestion antidote which will mitigate congestions in the normal sections of expressways with considerably low costs. The information instrument, Light Emitting Diode (LED) sign car and information board as shown in Photos 1-2, is set around the bottleneck here to display dynamic traffic information of congestion and bottleneck location so as to stimulate the drivers to hike their speeds downstream of the bottleneck, thus to increase the flow rate from the congested queue behind the bottleneck, which is also the capacity of the bottleneck during congestion.

It has already been reported that LED sign car and LED information board may increase flow rate as the result of guiding drivers to accelerate their speeds during congestion (Yamada, 2003, Okada, 2002). This experimental study aims to thoroughly verify the effect of LED information board of the same sort to increase the bottleneck capacity during congestion as well as the maximum flow rate before congestion.

Photo 1. LED Sign Car

Photo 2. LED Information Board

2.OUTLINE OF THE SURVEY

2.1 Location of the Survey

The survey is conducted at a bottleneck of sag, about 1km downstream of the Yaita Interchange southbound direction of the Tohoku Expressway, which is a major arterial expressway connecting Tokyo and the northeast part of Japan. It is located about 120km north of Tokyo. The sag is one of the most famous bottlenecks of the Expressway, where the congestion occurs over 30 times a year caused by the sag. Figures 1 & 2 show the location of the survey and geometrical alignment of the survey section.

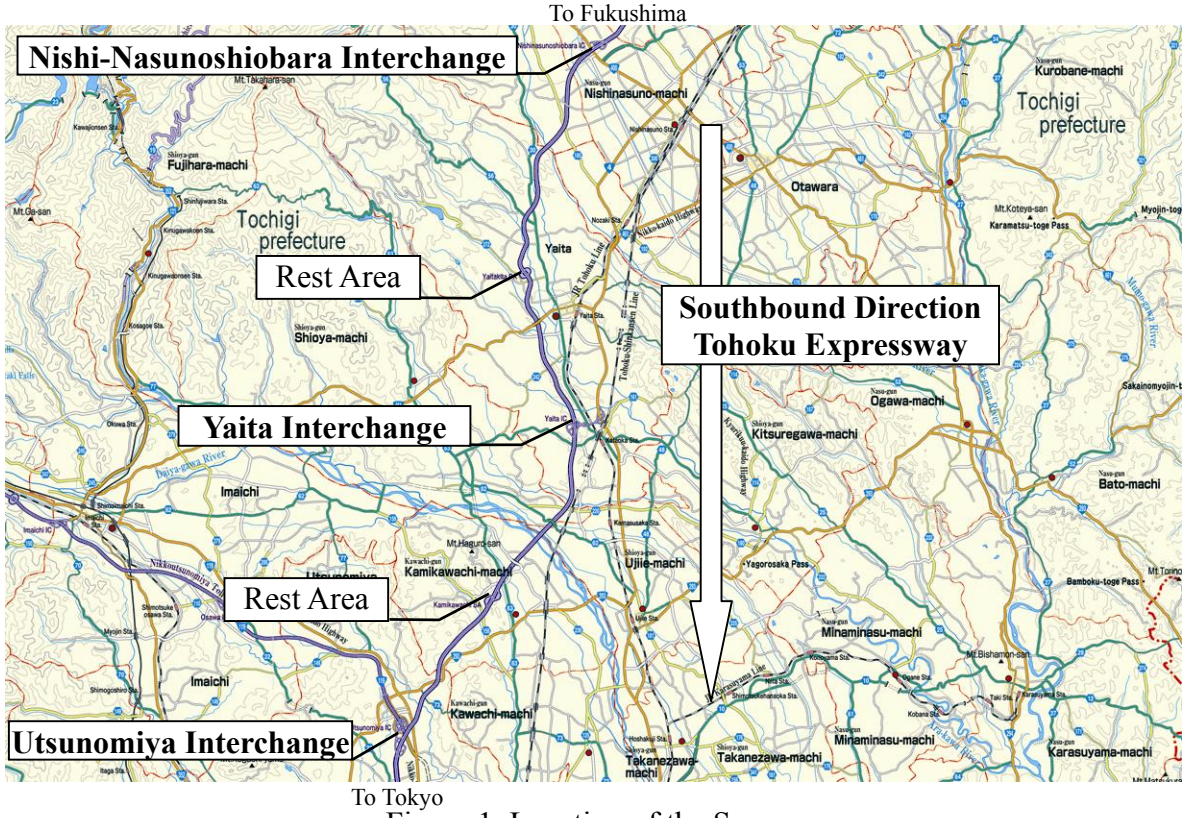


Figure 1. Location of the Survey

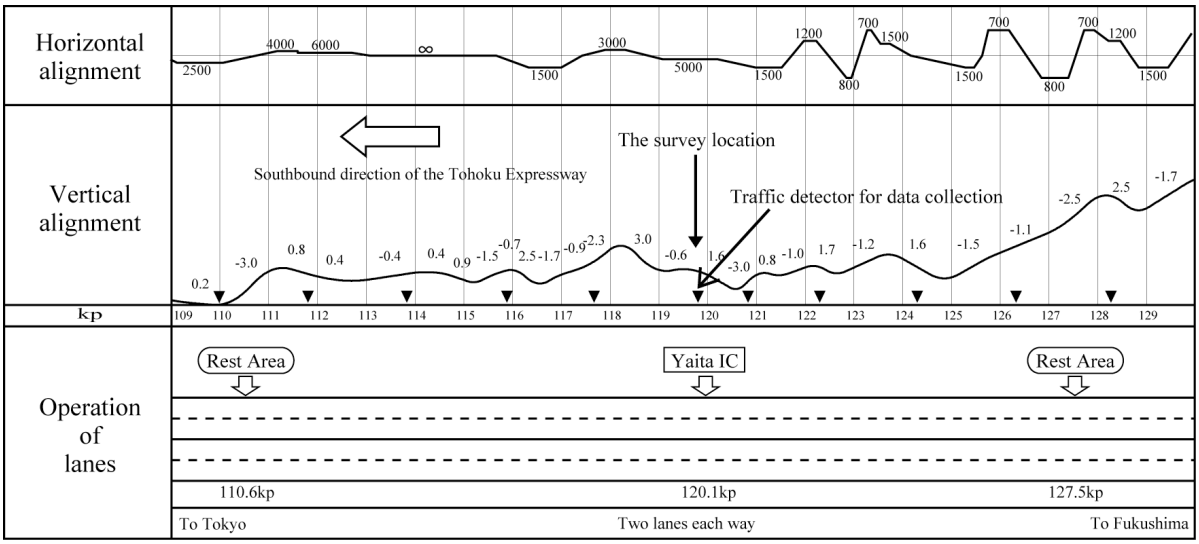


Figure 2. Geometrical Alignment of the Survey Section

2.2 Date of the Survey

The survey is conducted 5 days in May, August, October and November of 2004 (Table 1). The congestion occurs more frequently because May and August are long holiday season, October and November are tourist season, when most of the expressway users behave on the same traffic O-D pattern for recreational activities.

Table 1. Date of the Survey

Season type	Date of the survey	Remarks
Long holiday season	May 4 (Tuesday), 2004	
	August 15 (Sunday), 2004	
	August 16 (Monday), 2004	
Tourist season	October 24 (Sunday), 2004	2 LED information boards
	November 7 (Sunday), 2004	

2.3 Display of the LED Information Board

The display of the LED information board includes 2 main patterns. One provides vehicles in uncongested flow before congestion with static information on the existence of sag or upgrade of the expressway to make them accelerate so as to avoid speed reduction. And the other displays dynamic traffic information of congestion to alert drivers to accelerate their speeds in downstream section of the bottleneck. Table 2 shows the details of the survey and the display messages of the LED information board.

Table 2. Display of the LED Information Board

Flow type	The number of the LED information boards		Display message
Uncongested flow before congestion	1 or 2 (500m apart)		Upgrade Ahead! <---> Speed up!
Congested flow during congestion	1		End of congested queue <---> Speed up!
	2 (500m apart)	Down-stream	End of congested queue <---> Speed up!
		Up-stream	Congested queue ends 500m ahead!

<--->: Alternate display

2.4 Method of the Survey

In this study, two kinds of flow rates, i.e. maximum flow rate just before congestion and congested flow rate during congestion, are compared with and without LED information board. The two flow rates with LED are observed in this survey, while those without LED are obtained from vehicle detector data of 1999-2002 (Table 3). The vehicle detector data are collected in each 5 minutes. The maximum flow rate is defined as the 15-minute traffic flow rate right before congestion in vehicle per hour (veh/h). The congested flow rate is determined by the average traffic flow rate during congestion in vehicle per hour. Since it is known from the previous studies that the both flow rates differ in value depending on weather (fine/rain) and period of time (daytime/dusk/night), the flow rates are discriminately calculated by weather and period of time for comparison. When the speed falls below 40km/h, it is considered that congestion happens as shown in Figure 3 as an example.

From Table 3, we can know that the both flow rates before and during congestion do differ in value depending on weather (fine/rain) and period of time (daytime/dusk/night). The both flow rates are highest in daytime, followed by those in dusk period, and lowest in the night. As for the weather conditions, fine days yield higher values than the rainy days for the both flow rates. Even for the same period of time and weather condition, the both flow rates vary in value within a certain range, showing different distributions to be described in Section 3.

Table 3. Maximum Flow Rate just before Congestion and Congested Flow Rate during Congestion

Period of time	Maximum flow rate just before congestion (Veh/h)				Congested flow rate during congestion (Veh/h)			
	Fine		Rain		Fine		Rain	
	Average	Range	Average	Range	Average	Range	Average	Range
Daytime	3082 (31)	2000-3500	2725 (18)	2096-3428	2748 (35)	2195-3115	2470 (18)	2085-2777
Dusk	2901 (19)	2344-3416	2694 (5)	2300-3084	2455 (67)	2038-3192	2272 (19)	1991-2554
Night	-	-	-	-	2350 (43)	2053-2612	2261 (13)	1880-2552
Average	3013 (50)	2000-3500	2718 (23)	2096-3428	2495 (145)	2038-3192	2340 (50)	1880-2777

Note: 1. Bottleneck location: the sag around 119kp;
2. Location of the vehicle detector for data collection: 119.7kp;
3. Time period for data analysis: 1999-2002.

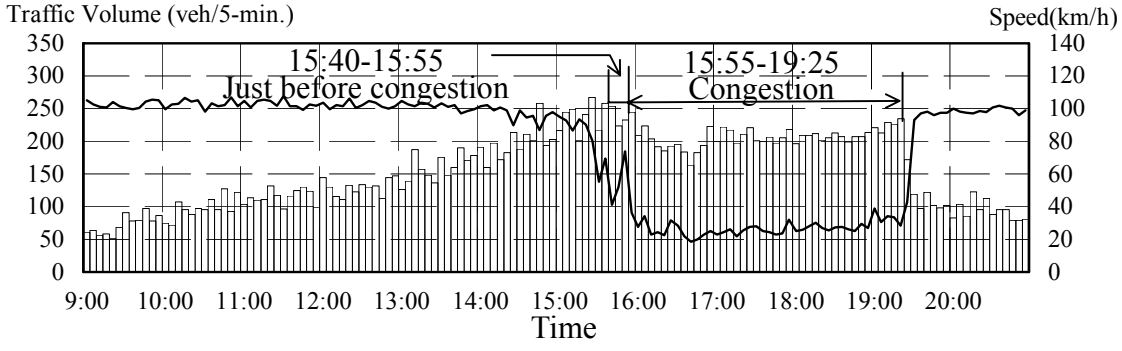


Figure 3. Definition of the Maximum Flow Rate before Congestion and Congested Flow Rate (Ex. Tohoku Expressway 119.7kp(around the Yaita Interchange) November 7 (Sunday), 2004)

3.RESULT OF SURVEY

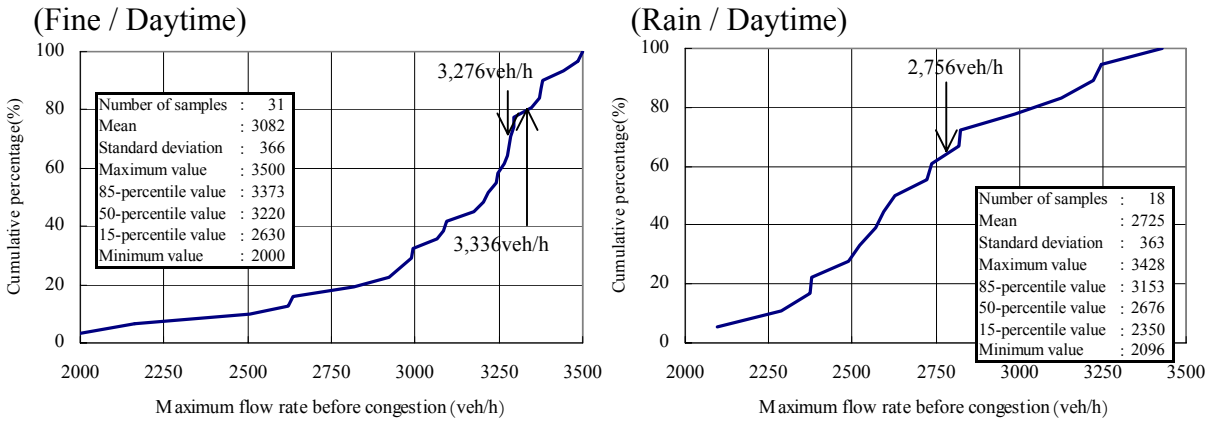
3.1 Maximum Flow Rate before Congestion

Table 4 and Figure 4 show the observed maximum flow rates with LED before congestion during the survey and their comparison with the cumulative distribution function of the maximum flow rate of non-LED. The solid line in the figure shows the cumulative distribution function of the maximum flow rate before congestion without LED display, and the arrow shows the observed maximum flow rate with LED display for comparison. A high flow rate of 3,788veh/h was observed on May 4 (Tuesday), 2004, exceeding all the maximum flow rates with non-LED in 1999-2002. The bottleneck shifted from the frequently observed sag (119.0kp) to another downstream sag (115.7kp) on that day. Nevertheless, it is still difficult to say that the LED information board will always increase the maximum flow rate because the observed maximum flow rates with LED are within 60-80 percentile value of those with non-LED. It is partly because not all the vehicles will react to the static information of road structure and instruction of speed increase, which is commonly installed on the roadside sign of bottleneck of sags. The message on the LED information board is "Upgrade Ahead!" and "Speed up!" displayed alternately before congestion occurs.

Table 4. Maximum Flow Rate before Congestion with LED Information Board

Date	Time (Weather / Period of time)	Maximum flow rate (%-tile value of the maximum flow rate with non-LED)
May 4 (Tuesday), 2004	10:40 - 10:55 (Fine / Daytime)	3,788 veh/h (Maximum value)
August 15 (Sunday), 2004	9:55 - 10:10 (Rain / Daytime)	2,756 veh/h (61 - 67% tile)
August 16 (Monday), 2004	11:00 - 11:15 (Fine / Daytime)	3,336 veh/h (77 - 81% tile)
* October 24 (Sunday), 2004	15:20 - 15:35 (Fine / Daytime)	3,276 veh/h (65% tile)

* Two LED information boards are set at 500m interval.



Note: Solid line: the cumulative distribution function of the maximum flow rate without LED display;
Arrow: the observed maximum flow rate with LED display.

Figure 4. Maximum Flow Rate before Congestion with Non-LED

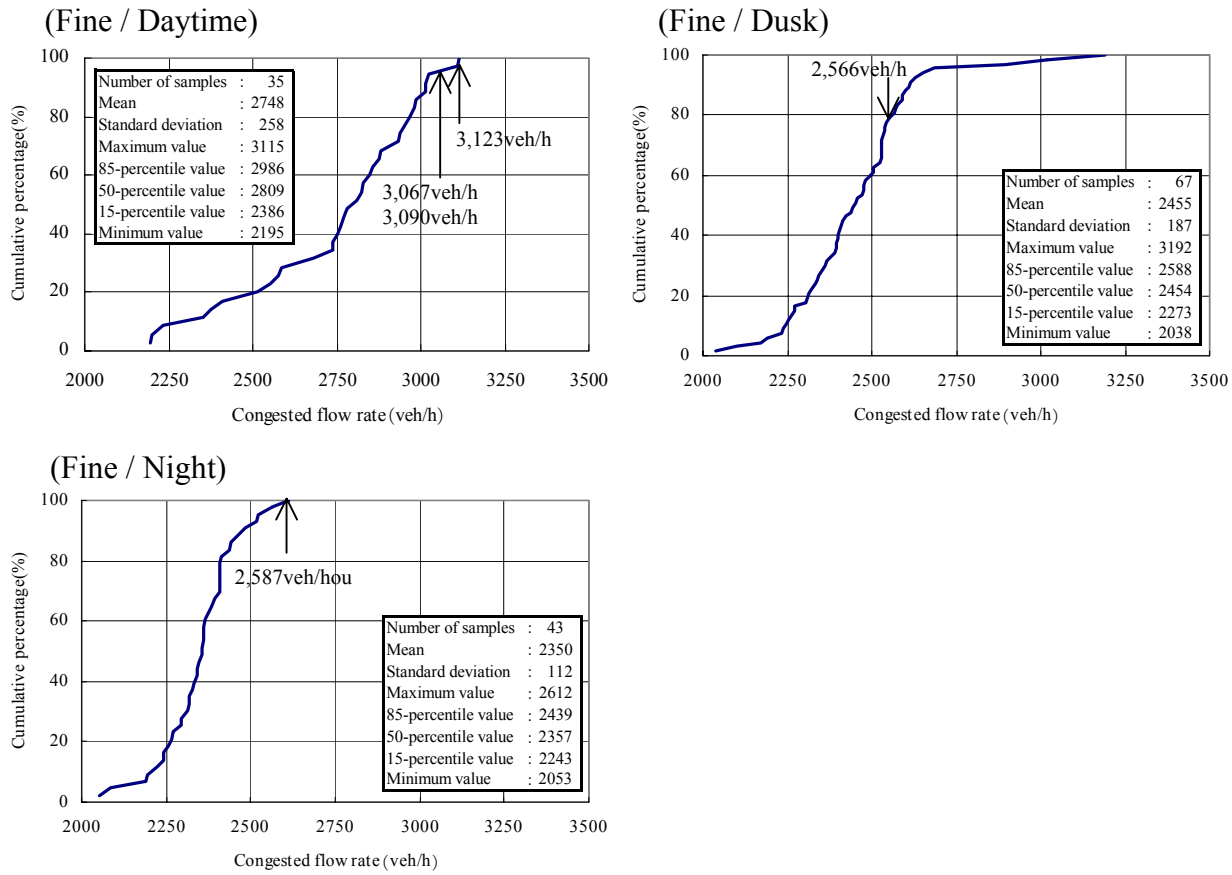
3.2 Congested Flow Rate

Table 5 and Figure 5 show the observed congested flow rates with LED during the survey and their comparison with the cumulative distribution function of the congested flow rate of non-LED. The solid line in the figure shows the cumulative distribution function of the congested flow rate without LED display, and the arrow shows the observed congested flow rate with LED display for comparison. The messages on the LED information board are alternate display in case of one board and separate display in case of 2 boards of "End of congested queue ahead" and "Speed up" after congestion occurs. It can be seen from the table that LED information board increases congested flow rate almost in the all cases as a result of stimulating drivers to accelerate the speed in the downstream section of the bottleneck. The most of observed congested flow rates with LED are over 90-percentile value of those with non-LED including maximum value. It suggests from the increase of the congested flow rate that drivers tend to react more easily to the dynamic traffic information of congestion than to the static information, which is displayed before congestion.

Table 5. Congested Flow Rate with LED Information Board

Date	Time (Weather / Period of time)	Congested flow rate (%-tile value of the congested flow rate with non-LED)
August 15 (Sunday), 2004	10:40 - 12:35 (Fine / Daytime)	3,067 veh/h (94 – 97%)
August 16 (Monday), 2004	11:30 - 12:00 (Fine / Daytime)	3,090 veh/h (94 - 97%)
* October 24 (Sunday), 2004	15:50 - 16:10 (Fine / Daytime)	3,123 veh/h (Maximum value)
* October 24 (Sunday), 2004	16:50 - 17:20 (Fine / Dusk)	2,566 veh/h (79 - 81%)
November 7 (Sunday), 2004	18:30 - 19:25 (Fine / Night)	2,587 veh/h (98 - 100%)

* Two LED information boards are set at 500m interval.



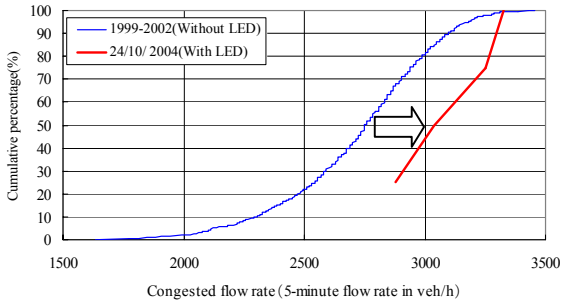
Note: Solid line: the cumulative distribution function of the congested flow rate without LED display;
Arrow: the observed congested flow rate with LED display.

Figure 5. Congested Flow Rate with Non-LED

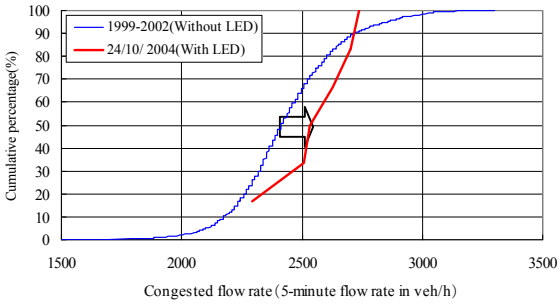
Figure 6 demonstrates a comparison of the distribution of the observed congested flow rates with and without LED from the 5-minute flow rate data for different time of period of congestion in fine days. The data of Figure 6 are used to test whether the observed congested flow rates with and without LED have statistically significant difference through t-test, and the result is shown in Table 6. It indicates that the 5 minutes congested flow rates with and without LED in daytime and night of fine weather condition have statistically significant difference at 5% significance level. The difference for the 5 minutes flow rate at dusk, however, doesn't seem to be statistically significant. Therefore, it is clear that LED information board increases the congested flow rate at the bottleneck, thus having an effect of reducing congestion time and congested queue length with limited investment.

In the same way, the 5-minute congested flow rates in daytime of fine days are compared with one and two LED information boards by using the data of Aug. 15, 16 (one board) and on Oct. 24 (two boards) as shown in the top three lines of Table 5. The result of t-test is shown in Table 7. It indicates that the 5 minutes flow rates with one and two boards do not have statistically significant difference at 5% significance level partially due to the limited available data of two LED boards.

(Fine / Daytime)



(Fine / Dusk)



(Fine / Night)

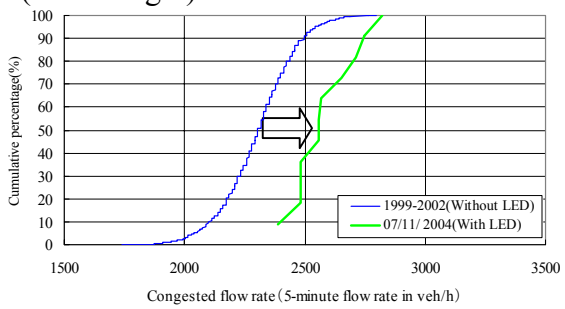


Figure 6. Comparison of the Distribution of Congested Flow Rates with and without LED

Table 6. T-test Results of Congested Flow Rate with and without LED Information Board

(Weather / Period of time)	Statistical value	With LED information board	Without LED information board
(Fine / Daytime)	Sample size	703	4
	Mean (veh/h)	2723.7	3123.0
	Standard deviation (veh/h)	310.3	203.0
	Statistic t-value	2.57	
	Critical t-value (5%)	1.96	
(Fine / Dusk)	Sample size	1395	6
	Mean (veh/h)	2435.0	2566.0
	Standard deviation (veh/h)	223.7	161.4
	Statistic t-value	1.43	
	Critical t-value (5%)	1.96	
(Fine / Night)	Sample size	1016	11
	Mean (veh/h)	2303.0	2586.5
	Standard deviation (veh/h)	152.4	131.8
	Statistic t-value	6.14	
	Critical t-value (5%)	1.96	

Note: Equal variances were confirmed for all the cases by f-test before t-test, and therefore, t-test with equal variances was used for the tests.

Table 7. T-test Results of Congested Flow Rate with One and Two LED Information Boards

Statistical value	One LED information board	Two LED information boards
Sample size	29	4
Mean (veh/h)	3071.6	3123.0
Standard deviation (veh/h)	137.1	203.0
Statistic t-value	0.49	
Critical t-value (5%)	3.18	

Note: Variances were confirmed to be statistically different by f-test before t-test, and therefore, t-test with unequal variances was used for the test.

4.CONCLUSION

It can be concluded from this experimental study that provision of dynamic traffic information of congestion via LED information board will increase the congested flow rate at the bottleneck. The effect is tested through statistical t-tests and it is found that the difference of congested flow rates are statistically significant in daytime and night of fine days and the difference between one and two boards, however, is not statistically significant. Besides, the bottleneck capacities before and during congestion vary depending on the weather condition and time of period of the congestion, and each of the both capacities shows a different statistical distribution even for the same weather condition and time of period of congestion. The statistical distributions of the bottleneck capacity imply that the capacity is also affected by the characteristics of traffic flow, e.g. different driver behavior and different vehicular platooning, etc. as well as the road structure of the bottleneck, weather and time of day of congestion. Therefore it is possible to reduce congestion time and congested queue length and to mitigate congestion on expressways. However, it is difficult to show a clear increase of the maximum flow rate before congestion, partly because the information provided by LED information board is not dynamic but static one, i.e. information about the geometrical characteristics of the road structures and instruction of speed increase.

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