LANE CHANGE EXPERIMENT THAT WAS AIMED AT REDUCING A TRAFFIC CONGESTION

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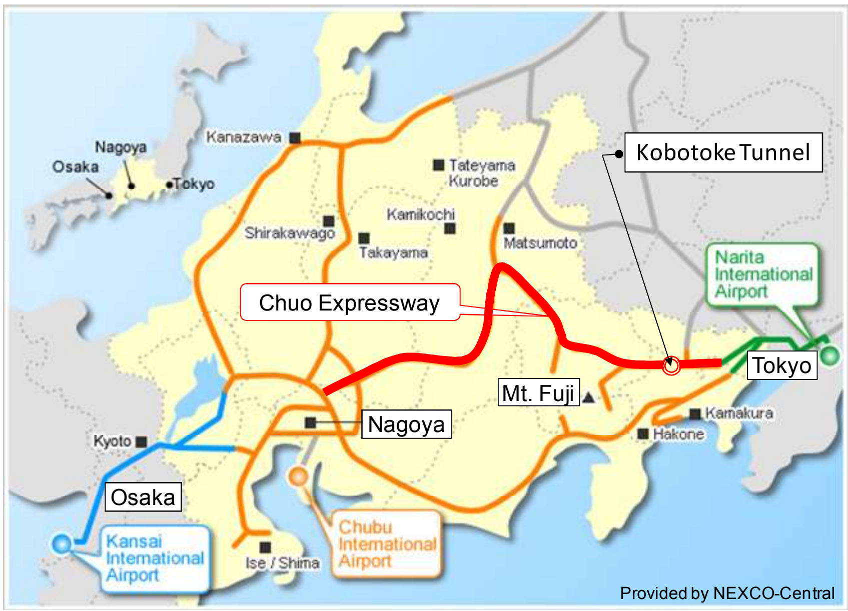
ABSTRACT

On an expressway which has two lanes running each way, there is a tendency for traffic to concentrate disproportionately in the inner lane when traffic volume reaches a high level just before actual congestion. When volume increases past this point, traffic in the inner lane begins to exceed that lane's capacity, resulting in congestion occurring in the inner lane which immediately spreads to all lanes. At this point, the outer lane has not yet reached its capacity. In other words, traffic congestion is occurring even though the capacity of the two lanes is not being fully utilized.
In order to sufficiently utilize the capacity of both lanes, it is desirable to correct the concentration of traffic volume in the inner lane during periods of high traffic volume by equalizing volume between to two lanes.
This experiment was aimed at equalizing lane usage. The chief characteristic of this experiment was to change lane operation in the section from two traffic lanes, with a climbing lane added to the left and then closed on the left; to adding one lane on the right to make three traffic lanes, and then closing the left lane at the end of the section.

1. INTRODUCTION

1.1. location

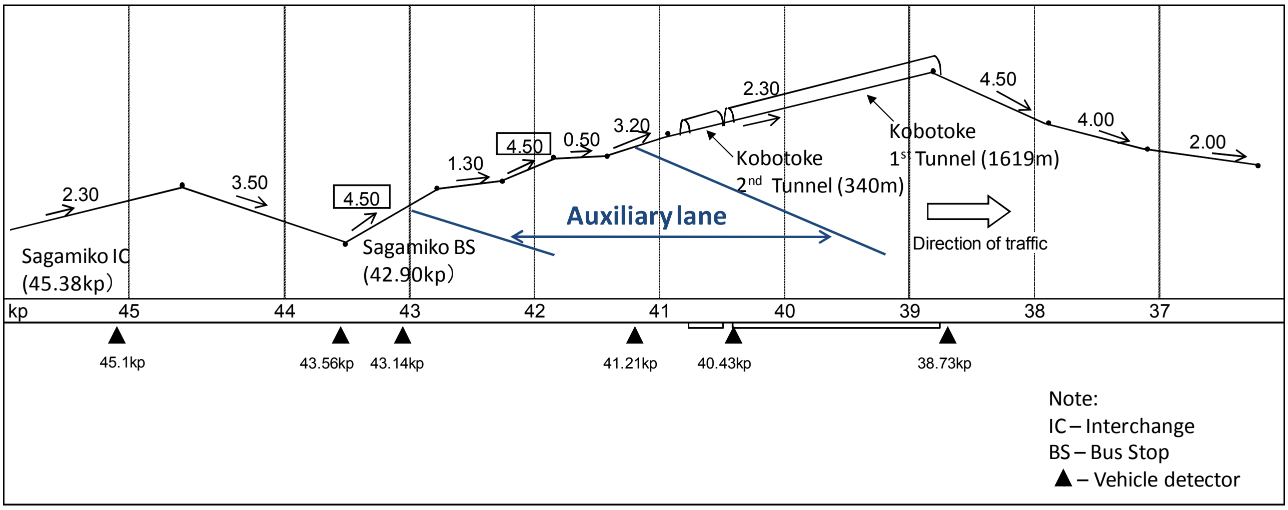
The Chuo Expressway links Tokyo, the capital of Japan, to major tourist spots such as Mt. Fuji (see Figuer1). One of congestion bottlenecks, the vicinity of the Kobotoke Tunnel on an inbound lane of the Expressway, is about 50 km away from Tokyo. This section has only two lanes in each direction.



"Figure 1 – Location of the Chuo Expressway and Kobotoke Tunnel"

1.2. Terrain

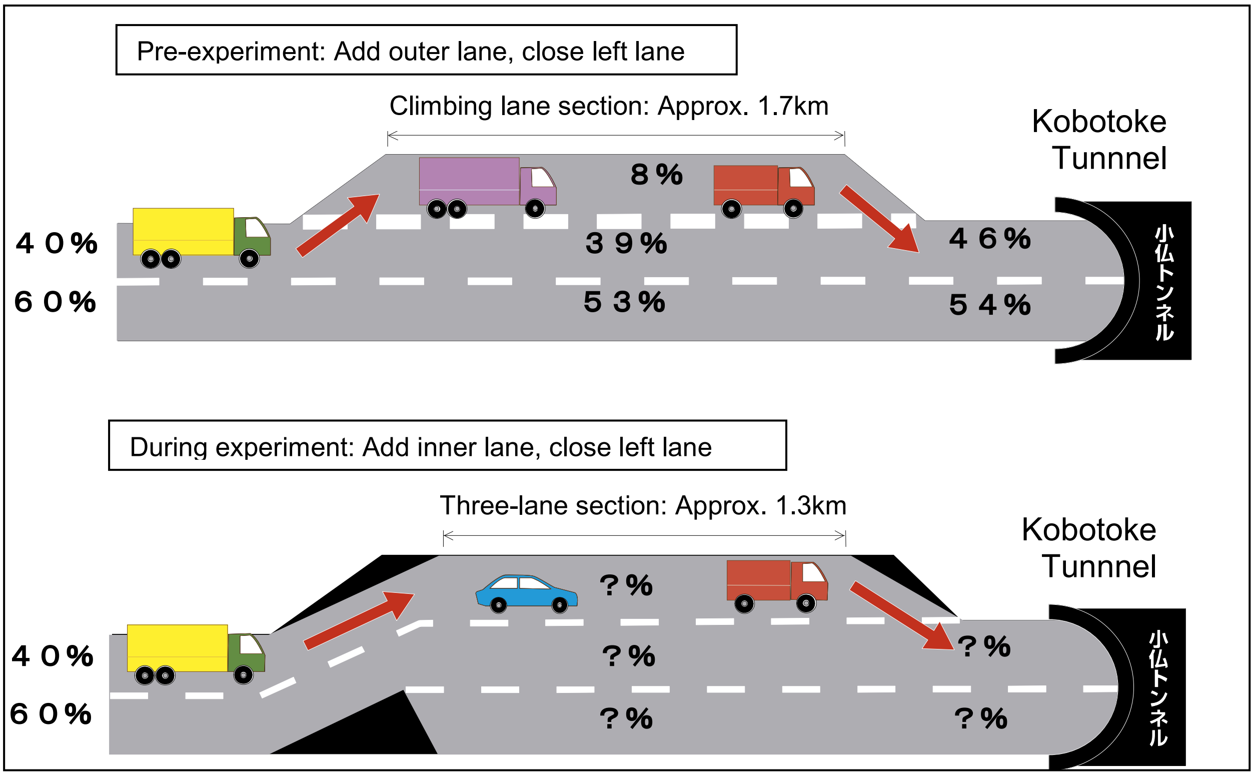
Figure2 is a vertical curve in the section. This section has a 4.7km continuous uphill slope with a maximum grade of 4.5%. A 1.8km section, downstream from a spot about 400m away from a sag, ensures a width of road that can place an auxiliary lane. A section with the width had been operated as a climbing lane for low-speed cars for a period between November 2007. There is the entrance of the Kobotoke Tunnel, about 400m downstream from the end of the climbing lane.
Subsequently, the uphill slope is changed to the downhill slope near the exit of the Tunnel of about 2km ahead.



"Figure 2 – Vertical curve in the section"

1.3. Experiment overview

Figure 3 shows the lane operation and lane usage rates for the 15 minutes directly prior to the congestion area, both before and during the experiment. The following is an overview, with details to be included later in the report.



"Figure 3 – Image of the Experiment"

Prior to the experiment, the usage rate was 60% in the inner lane section located upstream from the climbing lane, 53% in the climbing lane section, and 54% downstream from the climbing lane. Because of the climbing lane, inner lane usage decreased after the climbing lane, but lane usage nevertheless remained an unequal 54%. This is thought to have been caused by the low climbing lane usage rate of 8%, which led to ineffective utilization of the three lanes. Further, the plausible reasons for low climbing lane usage are as follows:

- Normal vehicles were hesitant to use the climbing lane because its purpose was to handle large or slow vehicles.
- Using the climbing lane was cumbersome because it required a total of two lane changes, at its beginning and end points.

As a solution to the problem, it was thought that by shifting the outer lane to flow directly into the climbing lane, usage rates for the climbing lane would increase while inner lane usage rates would decrease, resulting in a usage equalization effect that led to all lanes being sufficiently utilized.

As part of measures against congestion at the bottleneck, we started an experiment for the use of an existing climbing lane as a new lane on 28th january, 2010 (see Figure3)

This section generally forms an auxiliary lane that has the type for adding an inner lane and closing an outer lane. This type of the lane, the first operational type in multilane expressways of Japan, is intended to reduce the frequency of congestion by using the auxiliary lane.

- The part of the climbing lane is treated as one formal lane to form a three-lane section.
- One lane is added to an inner lane at the beginning.
- The outer lane is closed at the end.

2. THEORETICAL RESEARCH ON AUXILIARY LANE ARRANGEMENT

Before touching on the analysis results, here are the results of theoretical research related to the auxiliary lane arrangement. Generally, auxiliary lanes in Japan on multilane expressways are placed on the left and ended by closing the left lane. However, past research has indicated that the right-hand placement of the auxiliary lane followed by a left-lane closure, which was employed in the experiment, is much more effective than placing and ending on the left, as reported below.

2.1. Research performed using data from lane restriction during periods of construction

Lane utilization correction effects in a high-traffic-volume area were calculated by placing construction lane restrictions in two places on a three-lane highway and testing an "inner-add/outer-close" type, as well as the opposite arrangement. It became clear from the results that an "inner-add/outer-close" arrangement yields a higher lane utilization correction effect than does an "outer-add/outer-close" arrangement. (Oguchi et al[1)])

2.2. Research performed using traffic flow simulation

Analysis was performed using a traffic flow simulation with a variety of auxiliary lane configurations. Results made clear that compared to an "outer-add/outer-close" arrangement, the traffic volume point at which congestion occurs is higher (and therefore better) with an "inner-add/outer-close" arrangement. (Xing et al[2)])

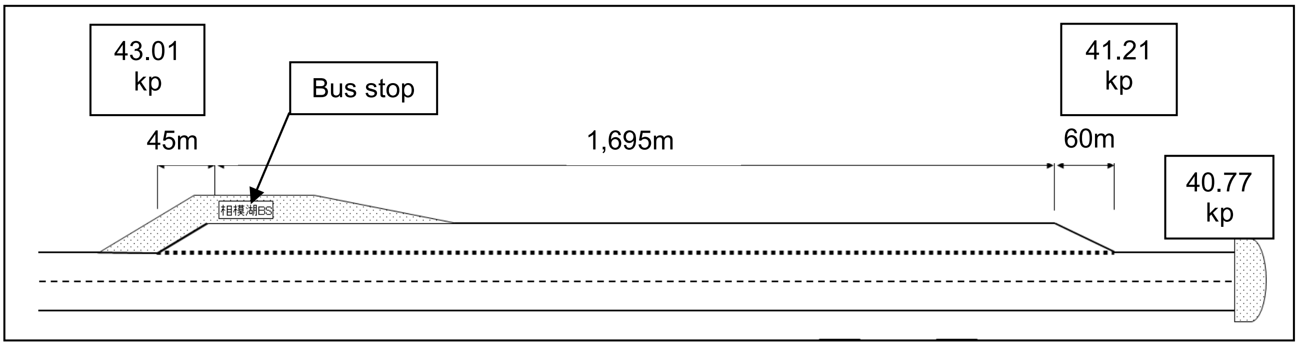
3. LANE OPERATION CONFIGURATION

3.1. Process

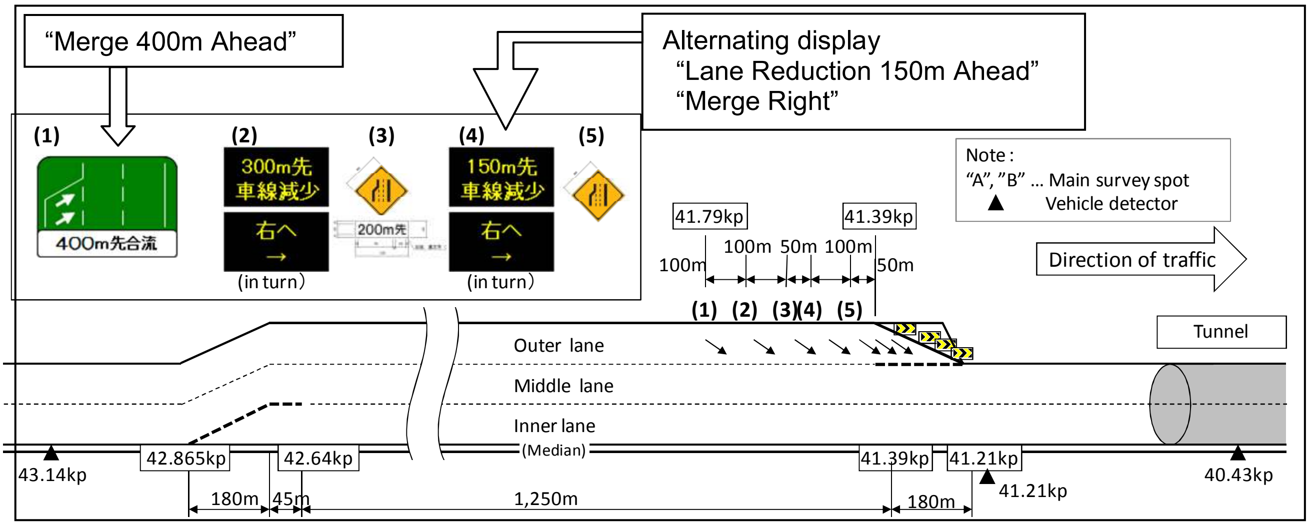
Two types of lane operation change experiments had been performed to confirm the behavior of vehicles at the starting point and differences in lane usage for the entire experimental section.

As a first step (see Figure 5), the road boundary along 180m of the outer lane shift section at the start of the climbing lane and the 45m of the right-hand buffer zone, a total of 225m, was given dot markings from January 28 to July 15, 2010.

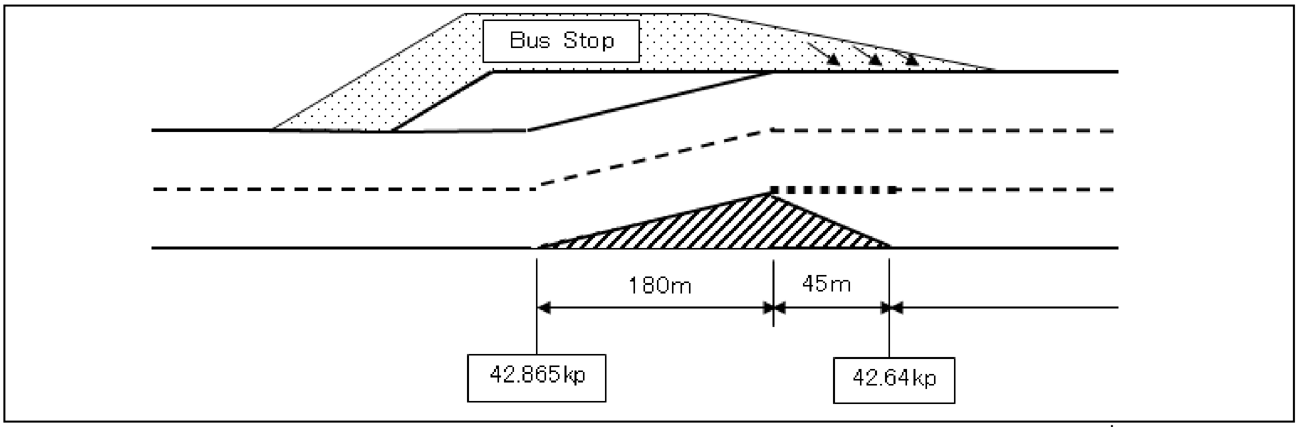
As a second step (see Figure 6), the 180m outer lane shift section right side was changed to zebra striping from July 16, 2010 to the present (February 1, 2011).



“Figure 4 – Pre-experiment climbing lane section”



“Figure 5 – Image of ‘Inner-add/outer-close type’ auxiliary lane (first step)”



"Figure 6 – Illustration of the 'inner-add/outer-close' type auxiliary lane (2nd step)"

3.2. Structure of beginning portion

In the beginning section of 180m, the outer lane and existing climbing lane were directly connected by shifting one lane. Figures 5 and 6 appear to depict a sudden shift, but the following factors allow the shift to be free of discomfort.

- The shift length 180m is kept within design standards based on AASHTO.
- The shift section is one in which a curve to the left eases into to a straightaway, making the curve radius constant.

In the first step, the roadway was structured so that the auxiliary lane was installed to the right of the outer lane shift section, making it possible for vehicles which had been travelling in the inner lane to travel along with the shift, or to travel alongside the central guardrail in the same manner as before the experiment.
This was the first experiment of its kind to be conducted in Japan, and took into consideration the safety of drivers who were not accustomed to a right-hand auxiliary lane.
In the second step, the outer lane shift was clearly indicated with zebra striping, after which the section where vehicles could begin to enter the right-hand auxiliary lane was placed 180m downstream. Because it was possible to change lanes at the beginning of a broad range of dot-marked sections in the first step, it is likely that travel trajectory is not stable. Changing dot-mark into zebra-mark may delay the timing by which vehicles entered the right-hand auxiliary lane, and might get stable travel trajectory at the beginning section, and might reduce traffic volume in the inner lane.

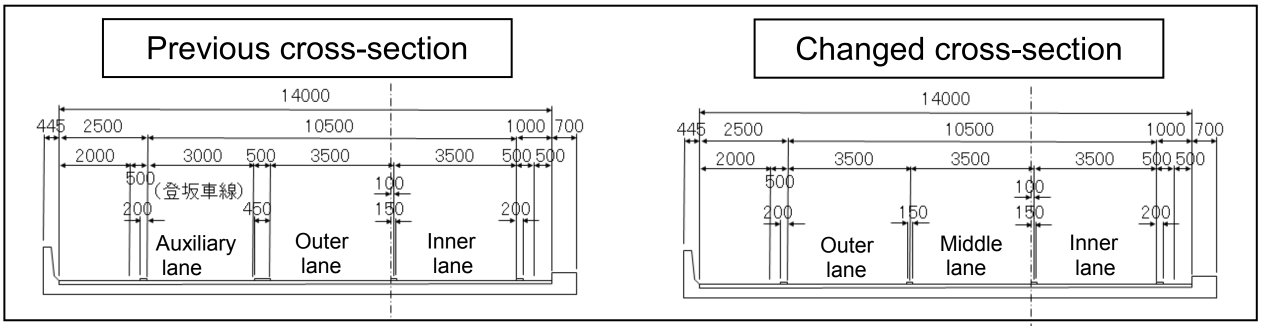
“Figure 7 – Before, first step, second step auxiliary lane starting points”

3.3. Three-lane section

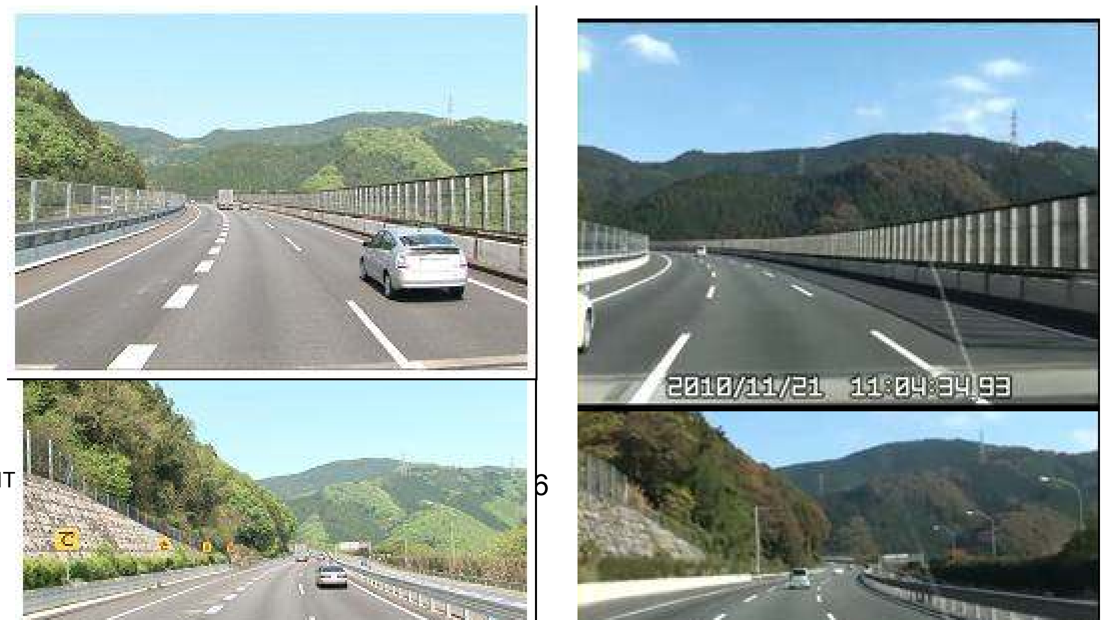
Upon consultation with related organizations, the following items were established regarding lane configuration in the lane operation change experiment:

- Lane composition must fulfill Road Construction Ordinance requirements for three-lane roads
- The experimental section will be treated as a three-lane road

Because the climbing lane in the experiment area had been constructed with the assumption that it would eventually become a three-lane road, the section already fulfilled conditions of the ordinance (Type 1 Level 3 standard requiring 3 lanes of 3.5m width and a left shoulder of 2.5m), the lane operation change experiment was able to begin without any widening construction.



“Figure 8 – Three-lane section lane composition before and during experiment”

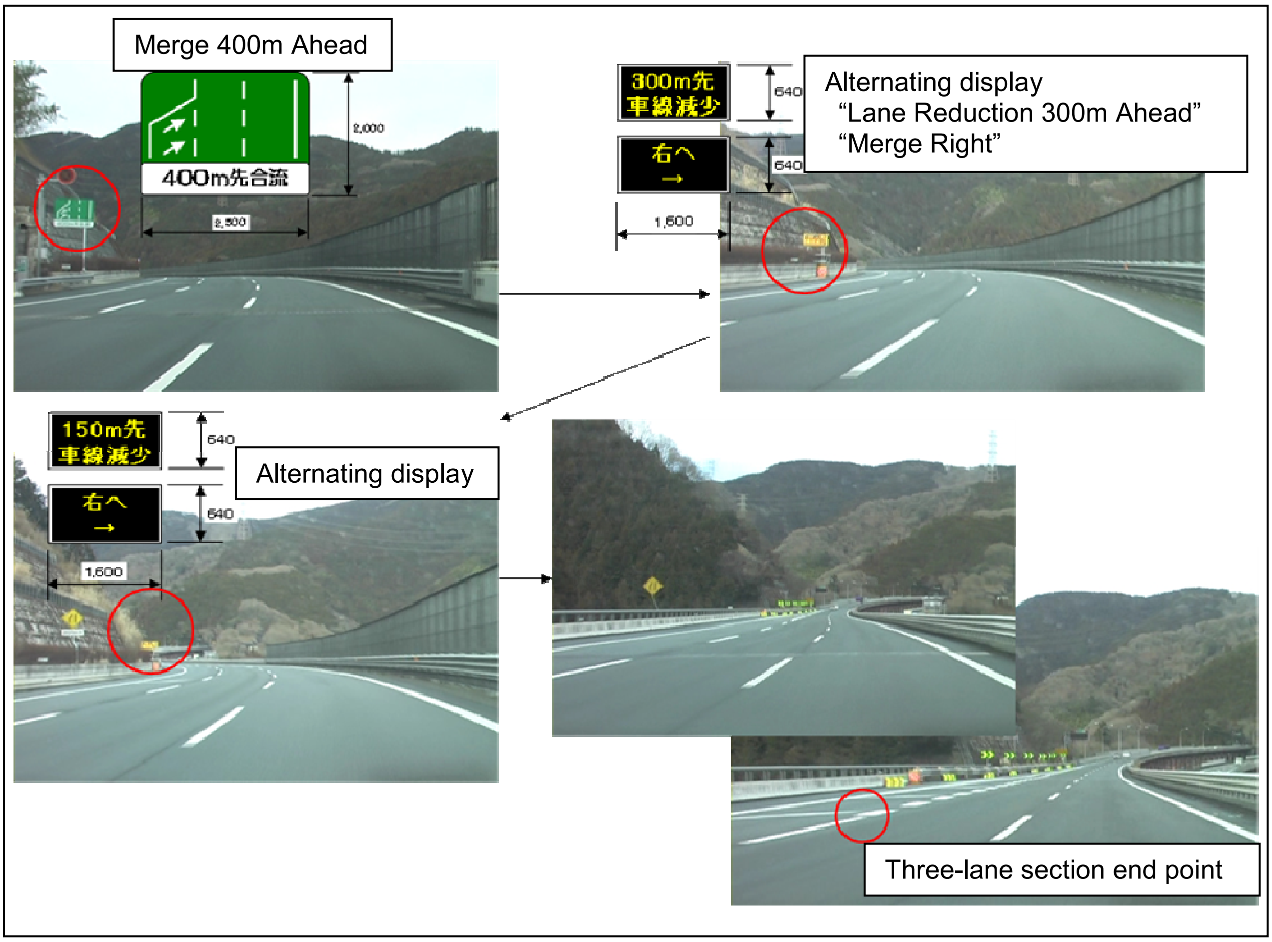


“Figure 9 – Photo of three-lane section during experiment”

3.4. End portion composition

The end portion of the section consists of closing the left lane, similarly to before the experiment. However, as previously stated, because during the experiment the left lane was treated as a outer lane as opposed to a climbing lane, the tapering length of the end closing section was changed from 60m before the experiment to 180m during, by using a temporary guard rail. The shift length 180m is kept within design standards based on AASHTO.

In addition, because the lane operation change experiment resulted in an increase in primary outer lane usage and more lane changes by vehicles than before the experiment, notice of the approaching lane reduction was placed earlier than usual as a safety consideration. First, a diagram sign was placed 400m before the reduction. Next, changeable LED signs were placed 300m and 150m before the reduction, and further, arrows painted on the road surface were place at 100m intervals beginning 400m before the reduction.



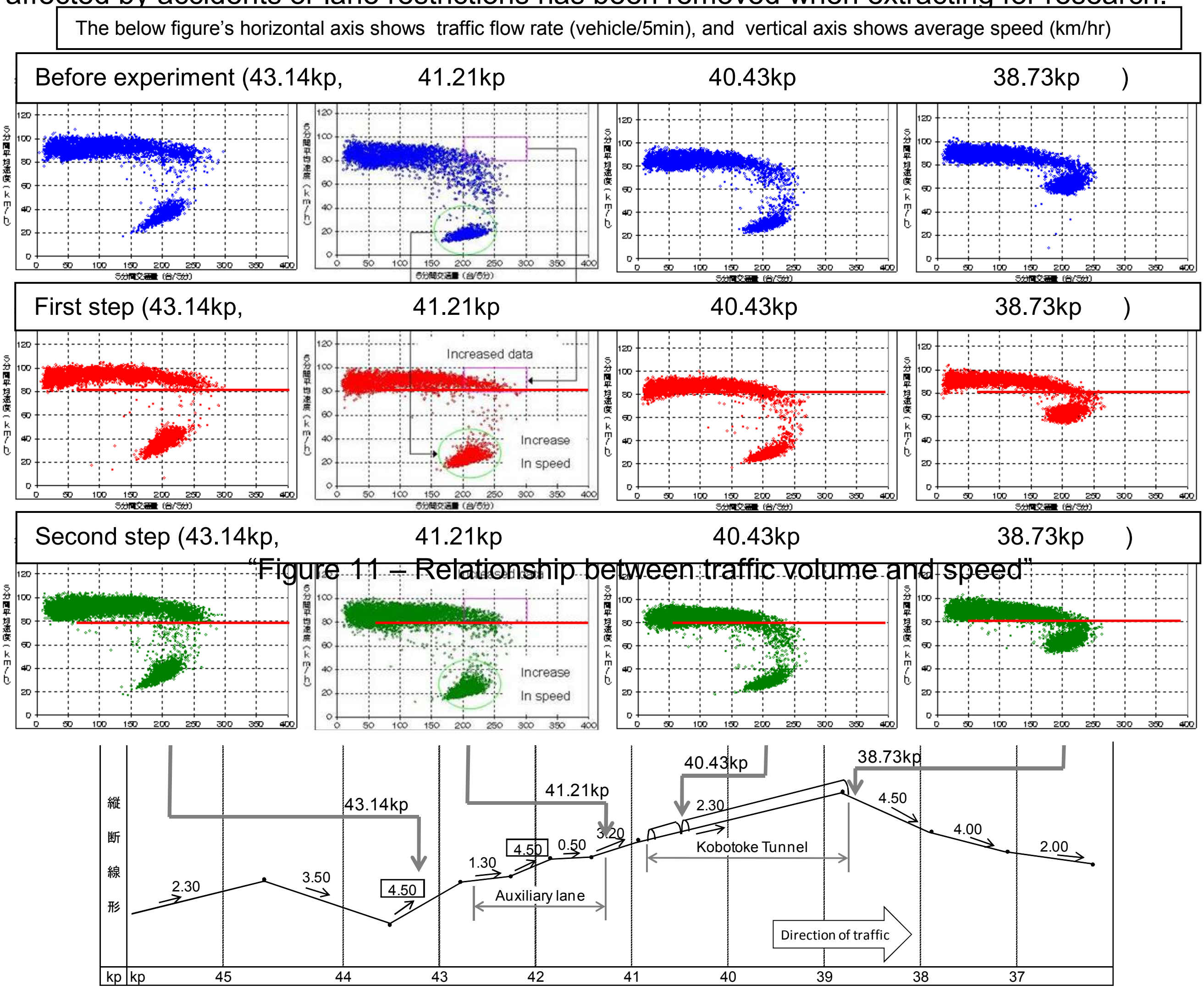
“Figure 10 – Photos of the end section area during”

4. ANALYSIS RESULTS

This section describes the overall traffic situation, the traffic situation when volume is high, and the situation when congestion occurs.

4.1. Relationship between traffic volume and average speed

Figure 11 illustrates the relationship between traffic volume and speed upstream and downstream from the experiment section through data totaled over five minute periods as produced by vehicle detectors and gathered on days when congestion occurred. Data affected by accidents or lane restrictions has been removed when extracting for research.



"Figure 11 – Relationship between traffic volume and speed"

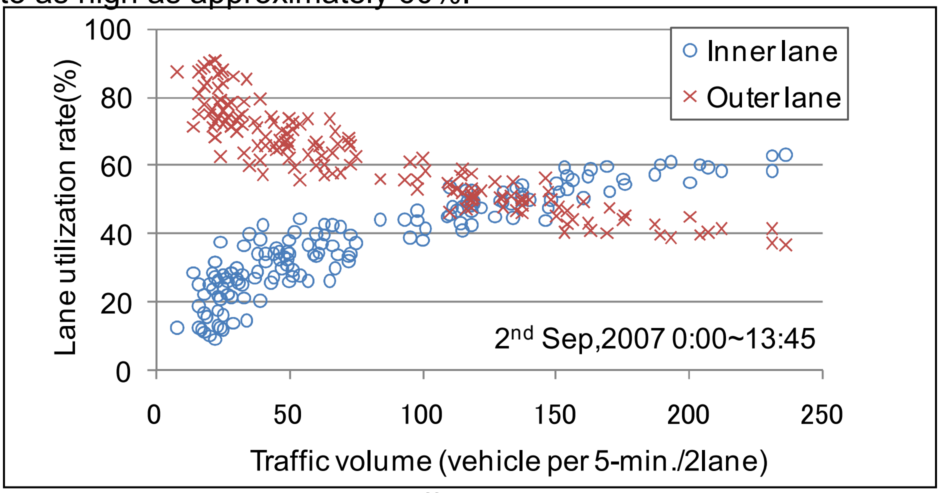
Looking at separate locations, little difference appears at the experiment section starting point (43.14kp), the bottleneck (40.43kp), or downstream from the bottleneck (38.73kp) before or after the experiment. However, at the experiment section end portion (41.21kp), the characteristics listed below were observed, showing that during both non-congested and congested periods, traffic flow was smoother.

- At non-congested times (when the speed is 40km/h or higher), and for the range of speeds of 80km/h or higher and 200 vehicles or more per five minutes, the data dispersion is low before the experiment and increases during the experiment.

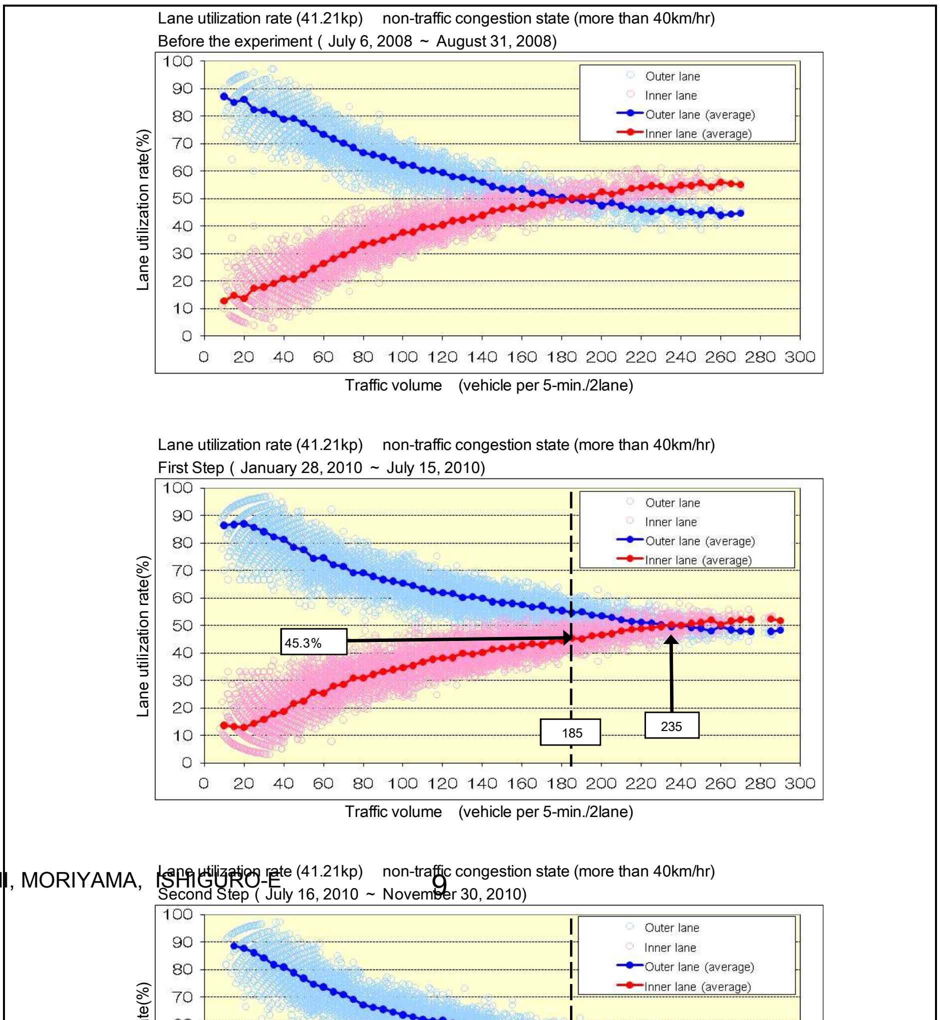
- At congested times (when the speed is 40km/h or less), the data dispersion range centers around 10 to 30km/h before the experiment, while it centers around 15 to 40km/h during the experiment, showing an increase in speed.
- Vague velocity of about 60 km/h level, data dispersion is observed before the experiment, but during the experiment such data dispersion is mostly nonexistent.

4.2. Relationship between traffic volume and lane utilization rates

On an expressway with two lanes in each direction, there is a tendency for traffic to disproportionately concentrate in the inner lane directly before times of congestion. Figure 12 shows the relationship between the five-minute traffic volume intervals and lane utilization during times of non-congestion on the bottleneck located near the Kobotoke Tunnel (40.43kp). The data show that as traffic volume levels increase, rates of inner lane utilization rise to as high as approximately 60%.



"Figure 12 – Relationship between traffic volume and inner lane utilization rate (40.43kp; September 2, 2007)"



"Figure 13 – Illustration of traffic volume and lane utilization rate (before experiment, during first step, and during second step)"

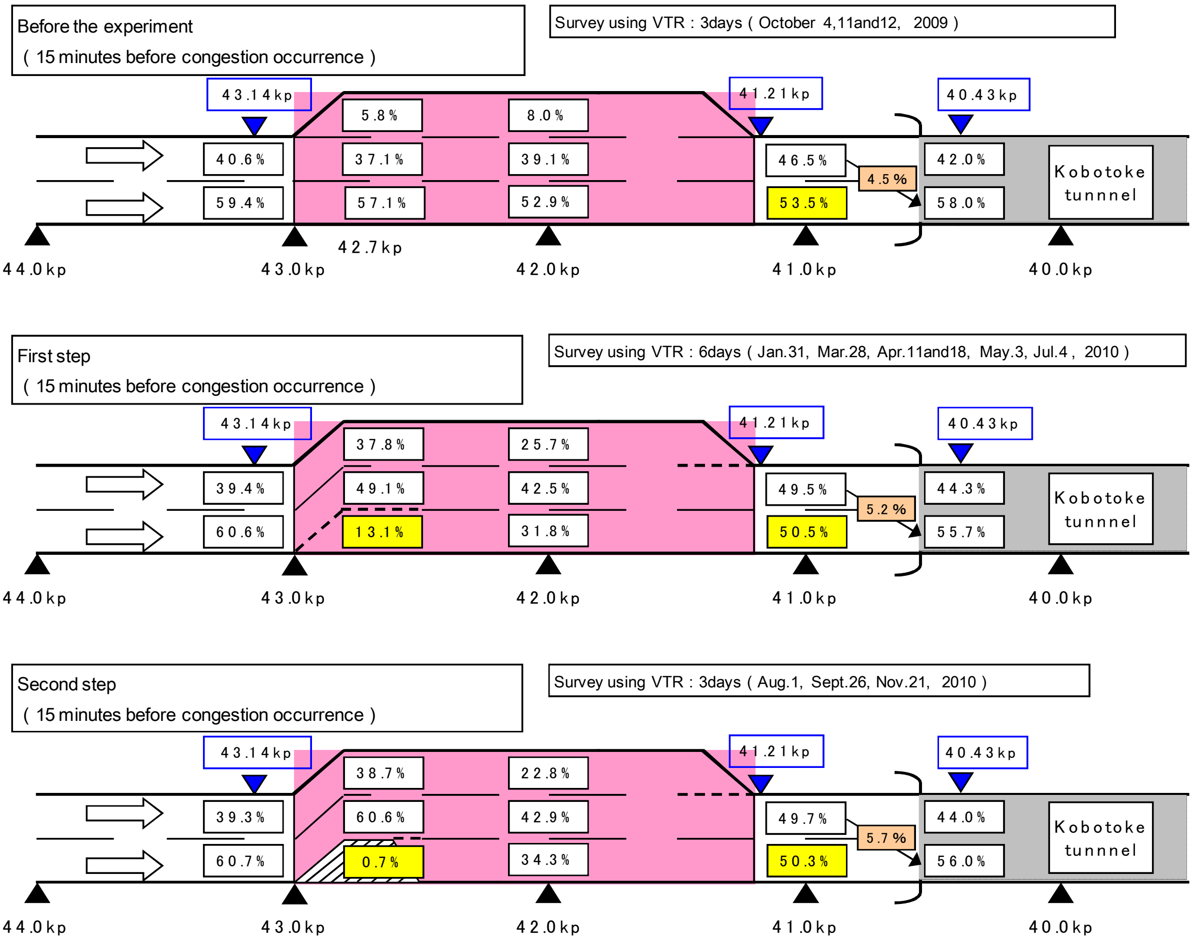
Figure 13 further shows the relationship between the five-minute traffic volume intervals and lane utilization during times of non-congestion downstream from the experiment section end point, or in other words, the two-lane section following the three-lane section (41.21kp).

Prior to the experiment, when traffic volume exceeded 185 vehicles per five minutes, the inner lane utilization rate exceeded 50%, making it a disproportionate percentage. However, during the experiment, periods with the same traffic volume showed lower inner lane utilization rates of 45.3% during the first step and 46.6% during the second step. In addition, the traffic volume during which the inner lane utilization rate exceeded 50% was 235 vehicles per five minutes during the first step, and 225 vehicles per five minutes during the second step. This means that during the experiment, the fundamentally desirable traffic scenario of "keep left" (or "keep right" in right-hand outer countries), or using the outer lane, continued well into high traffic volume periods. Further, the inner lane utilization rate during the highest traffic volume periods was approximately 55%, which represents a more than 50% reduction.

4.3. Lane utilization rate for separate points at times just before congestion occurrence

The Figure 14 shows the lane utilization rates for separate points during the 15 minutes before congestion occurrence.

That information indicates that upstream from the experiment section the inner lane utilization rate was a disproportionate 60%, while it had been equalized to approximately 50% directly after inner through the experiment section. This confirms that the "inner-add/outer-close" method used in this experiment had an equalizing effect.



"Figure 14 – Lane utilization rates
(before experiment, during first step, and during second step)"

Upstream from the starting point of the experiment section (43.1kp), the inner lane utilization rate is approximately 60% for both before and during the experiment. That percentage means that 1.5 times more traffic is in the inner lane than in the outer lane (approx. 40%).

In the three-lane section, before the experiment, the climbing lane utilization rate was a low 7.9%, in contrast to the 53% utilization seen in the inner lane, demonstrating a situation of disproportionate traffic volume between lanes. During the experiment, first outer lane utilization was 25.7% during the first step and 22.9% during the second step, while inner lane utilization was 31.8% during the first step and 34.8% during the second step, meaning that the three lanes were being utilized more or less equally.

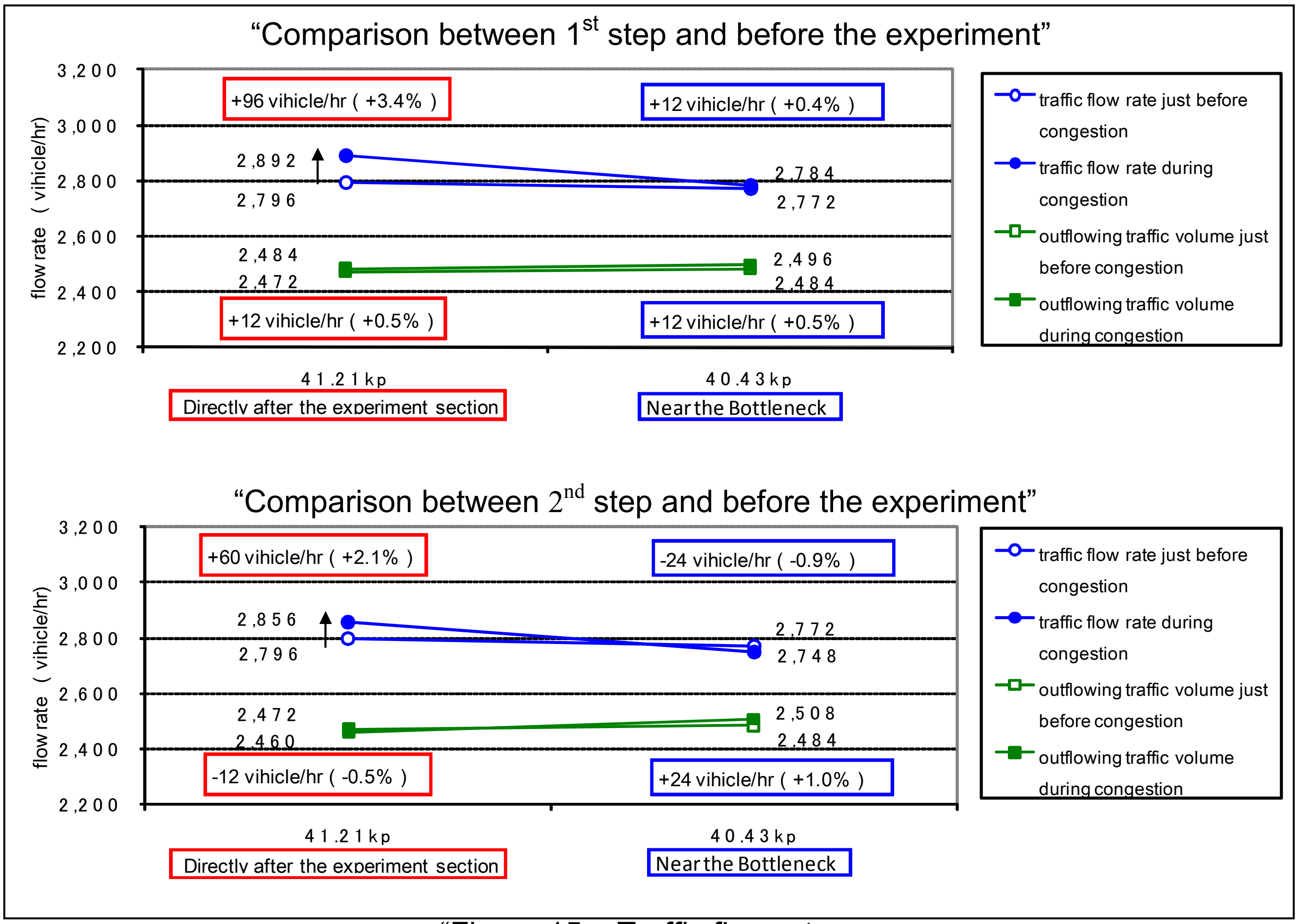
At the end portion of the experiment section (41.21kp), inner lane utilization was 53.5% before the experiment. That rate fell to 50.4% during the first step and 50.2% during the second step of the experiment for an equal lane utilization rate.

4.4. Traffic flow rates

The Figure 15 shows change in traffic flow rates directly after the experiment section (41.21kp) and at the bottleneck (40.43kp). In this paragraph, the traffic flow rate for the 15 minutes just before congestion and the outflowing traffic volume during congestion is converted to unit of time.

At the location just after the experiment section (41.21kp), traffic capacity increased; in the first step it was 3.4%, and in the second step it was 2.1%, exhibiting an effect of increasing traffic capacity.

However, at the bottleneck location (40.43kp), the increase in traffic capacity was small; 0.4% during the first step and 0.9% during the second step.



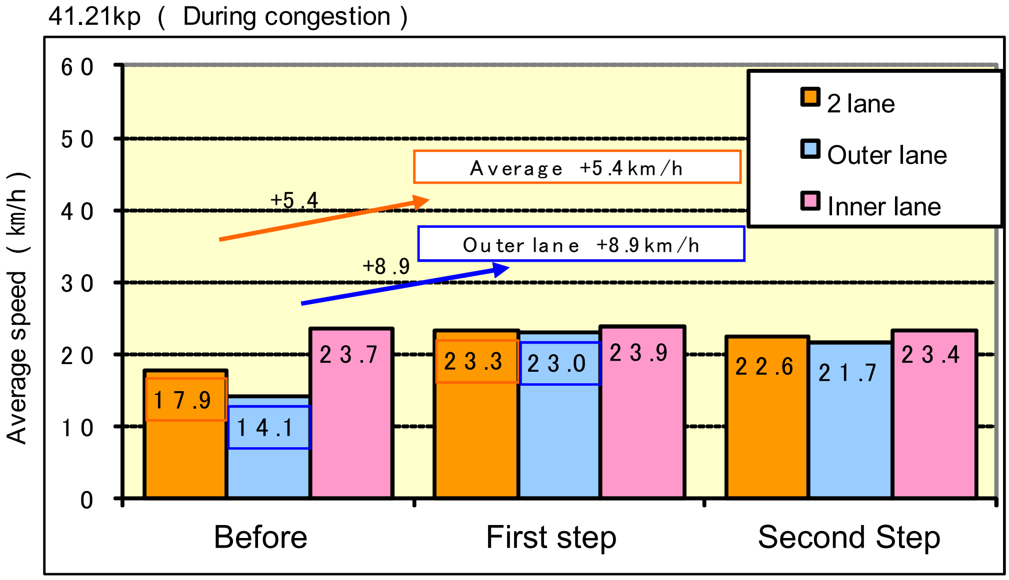
"Figure 15 – Traffic flow rate
(before experiment, during first step, and during second step)"

A possible reason for this is the inner lane utilization rate described in the last section. The downstream of the end of experiment section (41.21kp), the inner lane utilization rate has been equalized to 50%. However, at the bottleneck (40.43kp), the rate is approximately 56% and utilization id skewed toward the inner lane, dampening the traffic capacity increase effect. Conversely, if lane utilization equalization could be continued from the end of the experiment section to the bottleneck, an even greater increase in traffic capacity could be expected.

4.5. Traffic situation during congestion

The Figure 16 shows the traffic situation at the two-lane location (41.21kp) just after the end of the experiment section during congestion.

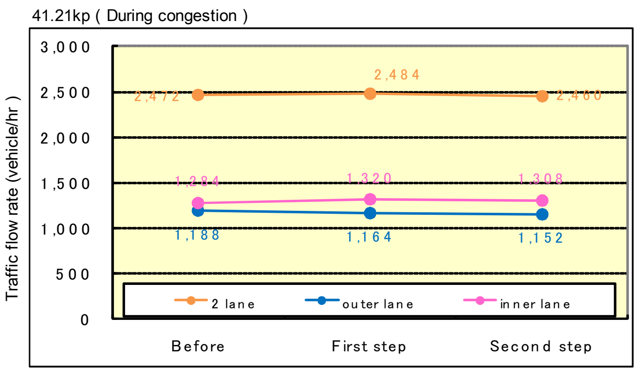
The average speed during congestion before the experiment was 14.1km/h in the outer lane and 23.7km/h in the inner lane, or a difference of 9.6km. During the experiment, congestion speeds improved to between 21.7km/h and 23km/h in the outer lane, making the difference between it and the inner lane just 0.9km/h to 1.7km/h, or very little difference at all. As a result, the average speed has increased all lanes.



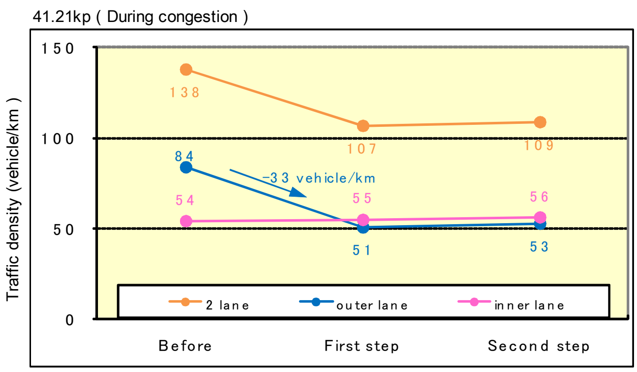
"Figure 16 – Congestion speed (41.21kp)"

The traffic flow rate during congestion remained unchanged at approximately.
Especially at the outer lane, vehicle concentration during congestion Improved as lower.

- Before: Outer lane concentration = 84 vehicles/km (11.9m between vehicles)
- First step Outer lane concentration = 51 vehicles/km (19.6m between vehicles)
- Second step Outer lane concentration = 53 vehicles/km (18.9m between vehicles)



"Figure 17 – Traffic flow rate during congestion (41.21kp)"



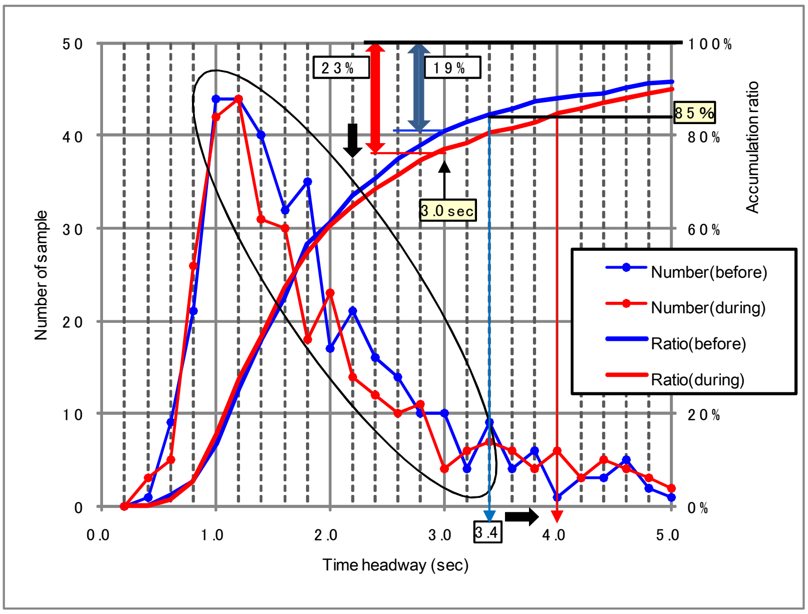
"Figure 18 – Traffic concentration during congestion (41.21kp)"

4.6. Vehicle time spacing distribution

The figure below contains organized pulse data from vehicle detection equipment measuring the average space distribution for each vehicle. Comparison is made between a 15-minute period directly prior to congestion on November 22, 2009 before the experiment and a selected 15-minute continuous period prior to congestion during the experiment on January 31, 2010 which had the same sample number (2800 vehicles/hour) in the pre-experiment cross-section.
Table 1 shows time distance between vehicles in both the outer and inner lanes for average, standard deviation, and each percentile.
From this information, the distribution status for samples measured at 0.2 second units in the inner lane for each vehicle's time spacing is shown in Figure 19.

"Table 1 – Vehicle time spacing distribution (41.21kp)"

	Inner lane		Outer lane	
	before the experiment	during the experiment	before the experiment	during the experiment
Number of sample	384	354	316	346
Standard deviation (sec)	2.27	2.65	2.13	1.77
Average (sec)	2.34	2.53	2.85	2.59
85th persentile (sec)	3.40	4.00	4.30	4.10
50th persentile (sec)	1.70	1.60	2.30	2.00
15th persentile (sec)	1.00	0.90	1.33	1.30
headway less than 3 sec (%)	0.81	0.77	0.67	0.74
headway more than 3 sec (%)	0.19	0.23	0.33	0.26



"Figure 19 – Vehicle time spacing distribution (41.21kp inner lane)"

- The figures in the 85th percentile have increased to 0.6 seconds in the inner lane, while they have decreased to 0.2 seconds in the outer lane, meaning there is little difference in vehicle time spacing between the outer and inner lanes.
- When organized according to vehicle time spacing, the number of vehicles (sample) decreased in the 1.4 top 1.8 second spacing range, which is the range that forms the main group of vehicles
- The percentage in which there is minimal effect on groups of vehicles, 3.0 seconds of time spacing or more, increased from 19% before the experiment to 23% during the experiment.

5. SUMMARY

When comparing the traffic phenomena from before and after the experiment using the "inner-add/outer-close" lane operation, the following items were confirmed:

- At the downstream of the end of experiment section, the utilization of the inner lane decreased at each traffic level. This shows that the traffic condition continues to keep left between low traffic levels to high traffic level.
  In particular, 15 minutes immediately before the occurrence of the congestion, the utilization of the inner lane decreased to about 50%, the most efficient use of two-lane.

At the same time, the traffic flow rate increased in “2.1% to 3.4%” comparing to before the experiment. Also, it decreased from 81% to 77% the percentage of headway of less than 3 seconds that was forming vehicle group. In other words, it improved in traffic conditions such reduce occurrence of congestion.

・During the congestion at the downstream of the end of auxiliary lane, the speed increased from 17.9km/hr to 23.3km/hr, and the headway stretched from about 12m to about 19m, but rate of traffic flow did not increase.

・At the end of experiment section (41.21kp),the traffic quantitiy of two lanes is equalized, however it disproportionately concentrate again in the inner lane at the bottleneck (40.43kp).

Analysis of this experiment confirmed with demonstrable data that the end portion of the “inner-add/outer-close” lane operation had alleviation effects on traffic, including an equalizing effect on lane utilization and an easing effect on vehicle group formation.
However, because there was distance from the experiment section to the bottleneck, a disproportionate utilization of the inner lane had reappeared by the time traffic flow reached the bottleneck, after utilization raters having been equalized in the experiment section. This reduced the traffic flow improvement effect.
In order to sufficiently take advantage of the equalization effect achieved by an “inner-add/outer-close” lane operation section in the future, there need to be more proposals and implementations such as restriction of lane changes in the section between the auxiliary lane end portion and the bottleneck.

In addition, this report is one portion of the results of the “Chuo Expressway Congestion Measures Study Group,” (Chairman: Masahiko Katakura, Honorary Professor at Tokyo Metropolitan University) which was held by the NEXCO Hachioji Office. Many valuable opinions were provided by those who attended the study group. We express our heartfelt gratitude for their contributions.

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