

AN APPROACH TO REDUCE TIE-UPS BY SPEED ADAPTATION AT SAG/TUNNEL SECTIONS ON EXPRESSWAYS

Kobayashi Hiroshi (Senior Researcher)

Mizuguchi Satoshi (Researcher)

Otsuka Shingo (Research Engineer)

Ichikawa Hirokazu (Guest Research Engineer)

Intelligent Transport Systems Division

National Institute for Land and Infrastructure Management

Ministry of Land, Infrastructure and Transport, Japan

1 Asahi, Tsukuba City, Ibaraki-ken 305-0804 Japan

Tel (+81)29-864-4496 Fax (+81)29-864-0565

E-mail: kobayashi-h92qs@nilim.go.jp

mizuguchi-s22aa@nilim.go.jp

otsuka-s8310@nilim.go.jp

ichikawa-h924a@nilim.go.jp

ABSTRACT

About 50% of the traffic tie-ups in Japan form at the sag/tunnel sections of expressways. The study introduced in this paper has put forward an approach of vehicle speed control as a suitable measure to negotiate sag/tunnel sections. This prevents irregular traffic flow from forming tie-ups and keeps traffic movement uninterrupted (unbiased lane use) on expressways. A prime example of the conditions that create tie-up formation at sag/tunnel sections is Kobotoke tunnel on the Chuo-Expressway. This is exemplary data to use for the traffic simulator, SIPA (Smart Infrastructure Performance Analyzer). A review using simulation by SIPA on impacts of speed control for tie-up conditions has explicitly proved the validity of the speed control approach.

FORWARD

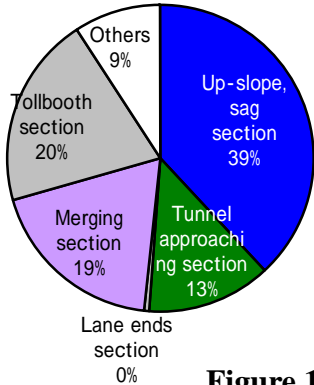
The economic loss ascribed to tie-ups on Japanese inter-urban expressways amounts to around 230 billion yen annually and more than half of the loss is caused by tie-ups at sag/tunnel sections (Figure 1)(1). For this reason, construction works have been conducted to provide another adjacent tunnel or an alternative ascending route, as well as a visibility

enhancement system installation along tunnels. Responding to tie-ups, a hardware solution has often encountered both topographic and structural barriers, and significant cost and time have been invested.

A causal factor that clearly explains the tie-ups at sag/tunnel section is vehicle deceleration due to inherent structures. The high density of vehicles operating as a platoon due to the biased lane use (vehicles converging in an overtaking lane) further aggravates the situation.

In that event, the unbiased use of lanes for vehicles in operation resists the formation of tie-ups, and further catalyzes the early recovery from tie-ups when they do form. The study focused on the impact of balanced lane use and its impact on the dispersal of tie-ups. A traffic simulator, SIPA (Smart Infrastructure Performance Analyzer) was used to calculate the impact, and the outcome is reported in this paper.

This study is conducted on the hypothesis that speed adaptation control decelerates vehicle operation and creates a disincentive to changing lanes from an overtaking lane to a main lane. Eventually, balanced use is achieved over all lanes. For simulations by SIPA, improvements for modeling are carried out to calculate the impacts precisely.



- The subject sections have experienced either prime bottlenecks more than 5 times annually, maximum tie-up length averaging 2 km or more, or more than 30 instances of congestion annually.
- Congestion definition
Vehicle operational speed is less than 40km/h, or repetitive stop-and-go operations over an excessive distance, traveling more than 1 km and during more than 15 minutes.

Figure 1: Tie-up forming section of inter-urban highways

TIE-UP FORMING MECHANISM AT SAG/TUNNEL SECTION AND DISPERSING MECHANISM BY SPEED ADAPTATION

A generic mechanism of tie-up at sag/tunnel sections is explained as a synergistic effect (2). The structurally inherent features of sag/tunnel sections add to the impact of biased lane use to an overtaking lane in a section where neither inflow nor outflow traffic exists (vehicles are converging on the overtaking lane). The elimination of either of these causal factors will bring about a dispersal effect. A biased use of overtaking lane is often identified as the cause for a bottleneck forming not only at sag/tunnel sections but also in other sections, particularly a section with no inflow/outflow traffic. The approach to achieve balanced use over individual

lanes will be powerfully effective on tie-ups in general.

An exemplary model of this approach is the test referred to as ‘Controlled Motorway’ that has been carried out on M25 of England since 1995. The Controlled Motorway senses operational vehicle speed and traffic volume to discern potential tie-ups, and then controls the speed limit to prevent the anticipated formation of tie-ups. The Controlled Motorway keeps the use of road unbiased to maintain smooth and safe traffic flow. The synergistic relation of the impact from applied speed control and achieved condition of a lane use has been proven. The explanation for this is that an incentive to use an overtaking lane wanes when a vehicle speed decelerates to a certain level.

The data from the test on M25 proves the effectiveness:

- Ratio of lane use has increased by 15% and traffic flows smoothly
- Traffic accidents have declined by about 30%
- Air pollution and noise have decreased
- Reliability in travel time has been enhanced
- Driver’s irritation has been removed

The system is favorably evaluated by 90% of drivers and 70% of them expect the service to be available on other expressways (3)(4). In view of this result, implementing suitable vehicle operational speed control creates a positive effect on biased use of an overtaking lane and consequently, the expressway resists tie-up formation. Moreover, even if a tie-up forms, it starts later and begins to disperse earlier.

SAG SECTION

A driver who starts to negotiate a sag section is sometimes unaware of the topographical change from descending to ascending, leading to deceleration. This results in a closing distance with the vehicle ahead, and subsequently the driver brakes to keep an appropriate space. This impact ripples over the following vehicles, and eventually tie-ups form.

In sections with no traffic flow interruptions, a prominent trend has been generally observed where vehicles operate in the overtaking lane while avoiding the main lane as the traffic volume increases (5). Consequently, vehicles concentrating in the overtaking lane form a highly dense traffic operation, or platoon, causing congestion in this section.

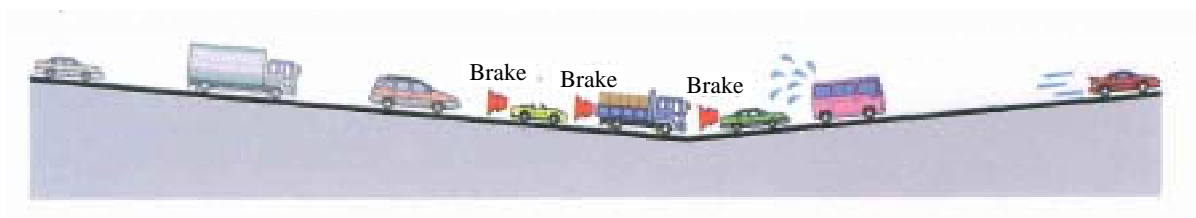


Figure 2: Tie-up mechanism at sag section

TUNNEL SECTION

A vehicle driver approaching a tunnel section sometimes decelerates in response to a feeling of depression by the darker entrance of the tunnel entry. The following drivers also brake to keep an appropriate space from the leading vehicle, and tie-ups form. The mechanism of tie-up formation here is almost the same as in a sag section. The vehicles converging in an overtaking lane aggravate tie-ups.

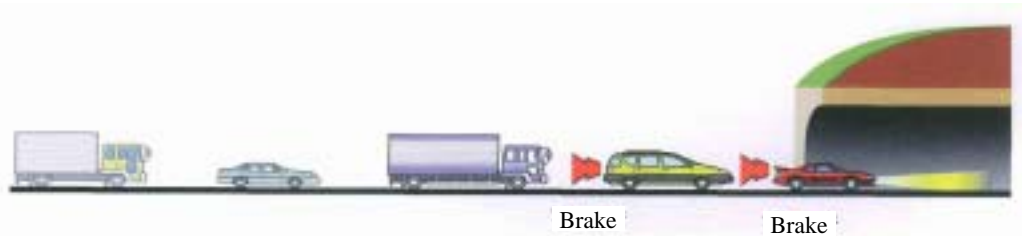


Figure 3: Tie-up mechanism at tunnel approaching section

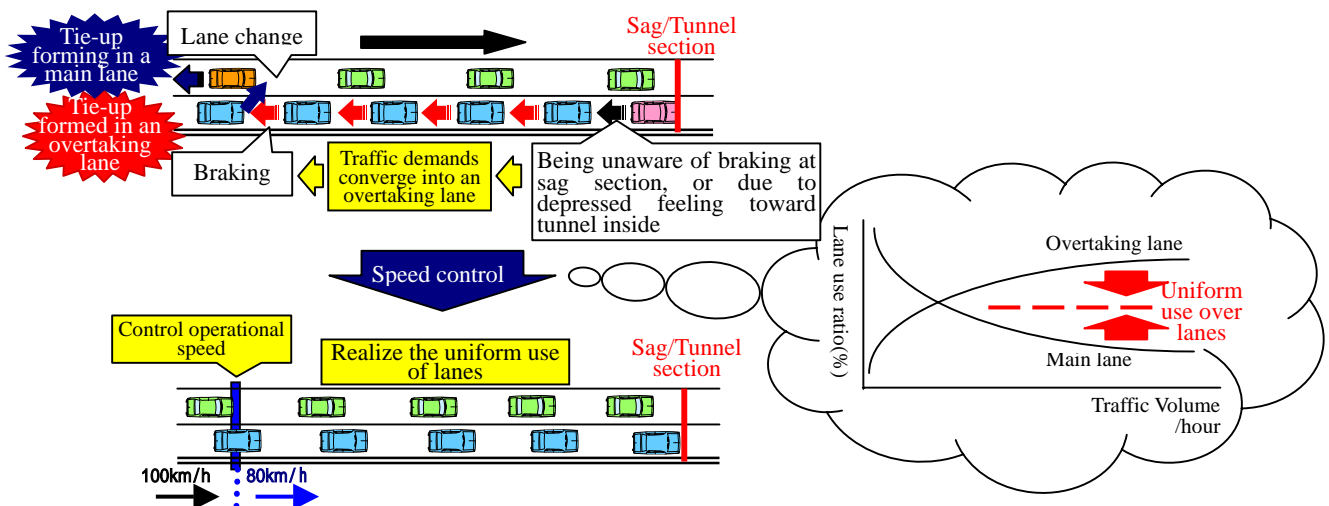


Figure 4: Conceptual image of tie up dispersion through the speed control at sag/tunnel sections

DESCRIPTION OF SPEED CONTROL IN SIMULATION

Since the driver's behavior for deceleration or lane-changing with speed control has not been analyzed in the traffic engineering study, a hypothesis is provided to improve modeling for traffic simulation by SIPA (6) of NILIM (National Institute for Land and Infrastructure Management). A verification using the hypothesis data was evaluated. The result produced nearly the same values as expected (Figure 5 shows part of the verification results).

DECELERATION BY SPEED CONTROL

In simulation, each vehicle operates at a set speed in the speed control sections. However, lane changes rarely occur when operational speed is higher than the specified value, and those

operational speeds converge, which is unrealistic. On this score, a fluctuation range is provided for the target speed by operational speed control.

The grace range is + 10km/h at set value.

LANE CHANGE BY SPEED CONTROL

The speed gap between the main lane and the overtaking lane becomes closer in the speed control section. The almost converged operational speed reverses vehicles from an overtaking lane to a main lane, resulting in balanced ratios of vehicles in both lanes. This is explained in the case where the gap between vehicles in the main lane induces a vehicle at a lower set speed to cross to the adjacent main lane. Also, a gap observed in the overtaking lane allows a vehicle at higher set speed to change into the overtaking lane.

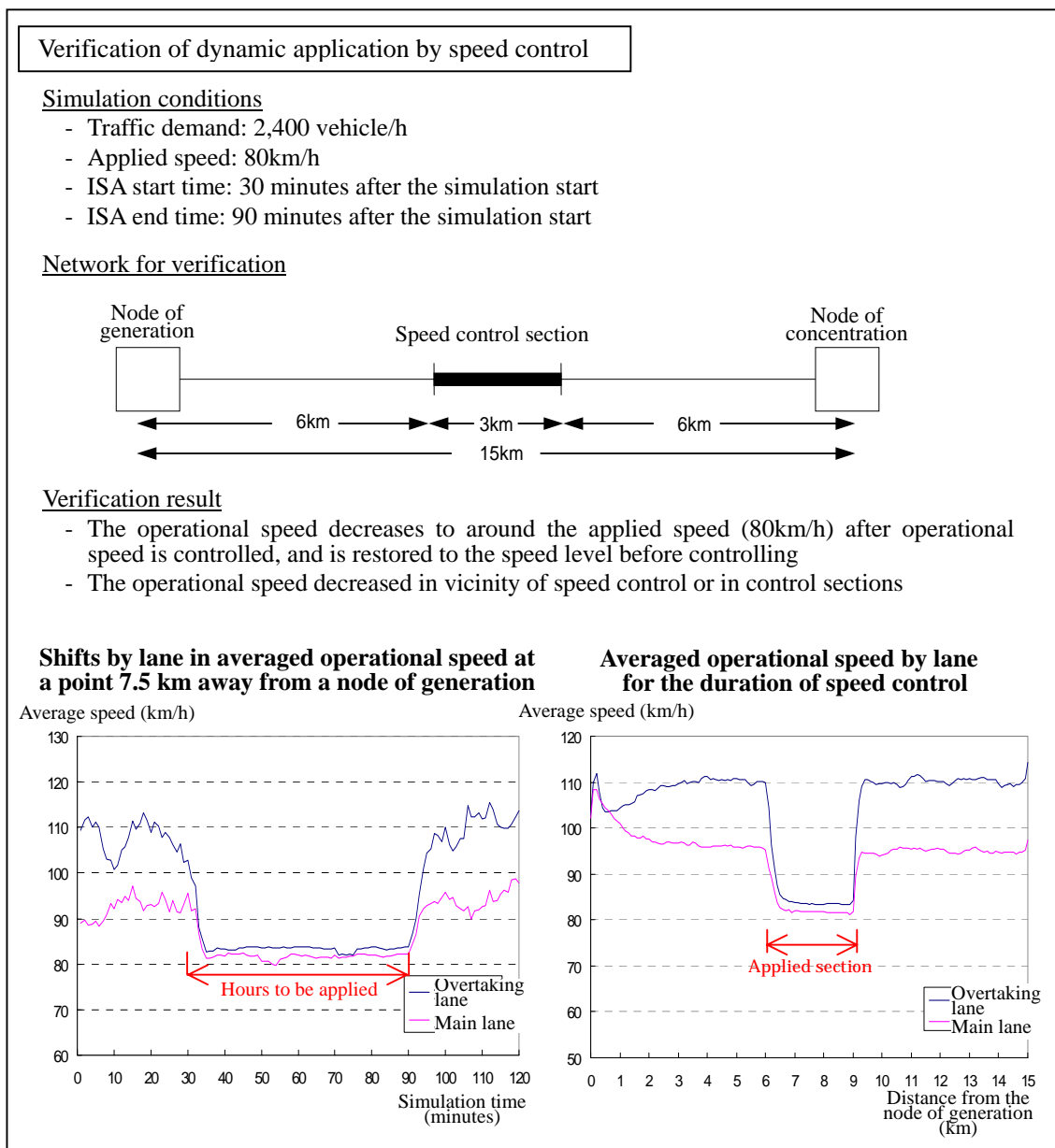


Figure 5: Example of verification results

SIMULATION STUDY ON IMPACT OF SPEED CONTROL ON DISPERSION

SUBJECT FIELD

The frequently congested inbound sag/tunnel sections between Otsuki and Hachioji along Chuo Expressways are subject to study. Chuo-Expressway offers four to six lanes and links Tokyo and Nagoya. About 51,000 vehicles/day were observed in this section. Based on vehicle detection data from 2002, the Kobotoke tunnel as a bottleneck point was selected for the reasons below. The 30 km extension around the tunnel was used to study the impact of tie-up dispersion (Figure 6).

(1) The section between Otsuki and Hachioji, where bottlenecks were often identified in 2002, is listed in Table 1. The Kobotoke tunnel section recorded the highest number of tie-ups at 75.

(2) The traffic capacity in the upstream section of Kobotoke tunnel, where a bottleneck point exists, exceeds 3500 vehicles/h, while the capacity of Kobotoke tunnel itself is smaller, at 3200 vehicles/h.

(3) A section between Otsuki and Hachioji with bottleneck points other than Kobotoke tunnel is Nakanohashi and Saruhashi BS. On the upstream side of the Uenohara interchange, at the site where critical bottlenecks often formed, tie-ups have been eliminated since lane doubling to six serviceable lanes was completed in March 2003.

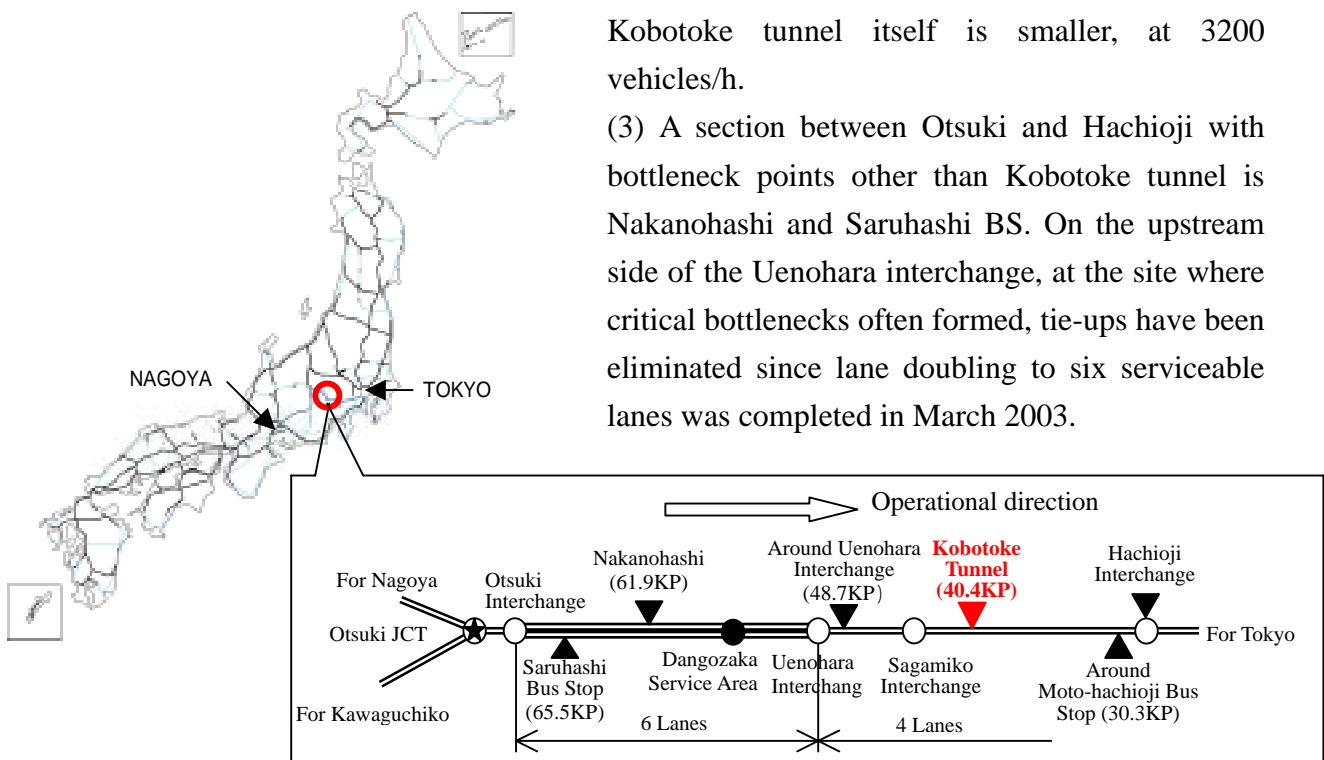


Figure 6: Subject field

Table 1: Number of tie-ups on the inbound of Chuo-Expressways

Bottleneck location	Original point KP	No. of tie-ups
Hachioji Tool Barrier	25.8	15
Moto-hachioji Bus Stop	30.3	7
Kobotoke Tunnel	40.4	75
Uenohara Interchange	48.7	7
Nakanohashi	61.9	37
Saruhashi Bus Stop	65.5	27
Iwadono Tunnel	67.7	9

} The lane-doubling to the extended 6 service lanes has dispersed tie-ups

RATIONALE OF SIMULATION

TIME AND DAY IN SIMULATION

Tie-ups formed 75 times in 2002 at the inbound Kobotoke tunnel section of Chuo-Expressway. Of these, 65 cases were caused by accidents or excess volume of traffic on the upstream tunnel section. Except for these 65 cases, the remaining ten cases are subject to study. The study focused on two particular cases and executed simulations. The first case was a tie-up on May 2nd, 2002 (maximum tie-up length: 4.6 km, lasting 2 hours and 30 minutes), which represents the average condition of the other 10 cases above. The second case, and the largest of the tie-ups, was on July 27th, 2002 (maximum length 9.4 km; 3 hours and 40 minutes).

SIMULATION CONDITIONS

A timing to control speed: Based on Q-V in the section around Kobotoke tunnel shown in Figure 7, speed control is implemented in a transitional area from free flow to a tie-up flow. The target is 2400 vehicles/h to ensure safety and 80 km/h taking account of a speed restriction in the subject section. The control was lifted 15 minutes after tie-up dispersion. When no tie-ups are observed, the control is lifted after the maximum number of vehicles (traffic volume) is sensed at the specified point.

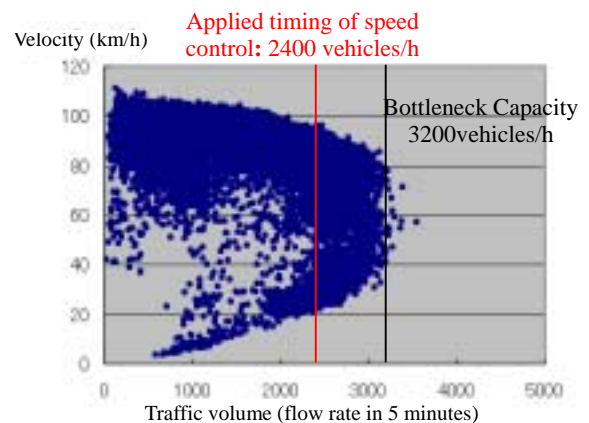


Figure 7: A timing of speed control

A speed control application range: The operational speed stabilized after about 1 km from the start, as Figure 5 shows. Theoretically, the ratio of unbiased use over lanes increases when the length of the applied distance is extended. The evaluation is conducted on 2 km, 5 km and 10 km extensions.

OD TABLE

A five-minute-OD table is created using traffic volume data (over 5 minutes) of vehicle sensors and toll booth. The sensors that provide traffic data are located at 59.65 KP (20 km upstream from Kobotoke tunnel) and at 35.33 KP in the downstream side of the tunnel, where the impact of tie-ups due to the tunnel is small. The traffic volume data at Uenohara interchange and Sagamihara interchange is replaced by an hour traffic volume at each tollbooth (Figure 8).

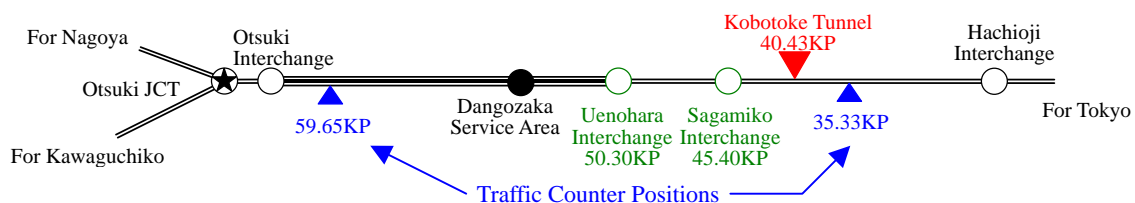
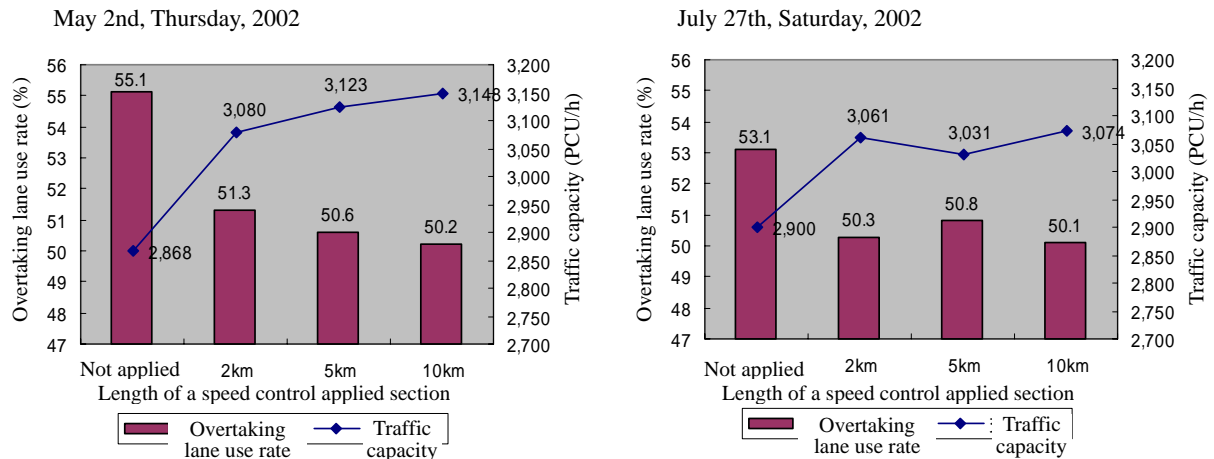


Figure 8: Data collecting positions for OD table

IMPACT OF SPEED CONTROL ON DISPERSION SHIFT OF LANE USE AND TRAFFIC CAPACITY

Figure 9 shows a lane-use-ratio that allows a maximum number of vehicles to operate under bottleneck conditions. The graph indicates that vehicles change lanes between the overtaking and the main lanes and are uniformly spread over each individual lane, though only provided with a 2 km speed control section. This 2 km control section proves the potential to increase traffic capacity by 5% to 7%.



Note: Lane use rate on PCU basis, where the maximum traffic volume is achieved (16:10 to 16:25) at a timing of a bottleneck forming immediately before congestion conditions.
For PCU conversion, coefficient of a passenger vehicle supposed to be 2.0

Figure 9: Lane use rate and traffic volume shifts when a maximum number of vehicles are in operation

SHIFT IN TRAVEL TIME

The unbiased use over lanes increases traffic capacity. Tie-ups form later and start to disperse earlier. In such cases, the travel time would be shortened. Figure 10 shows a shift in travel time in the case of a 2 km speed control section being provided. The improved driving condition is exemplified by a shorter travel time, which is equivalent to a 60% decrease in the case on May 2nd 2002, where a tie-up extended over 4.6 km.

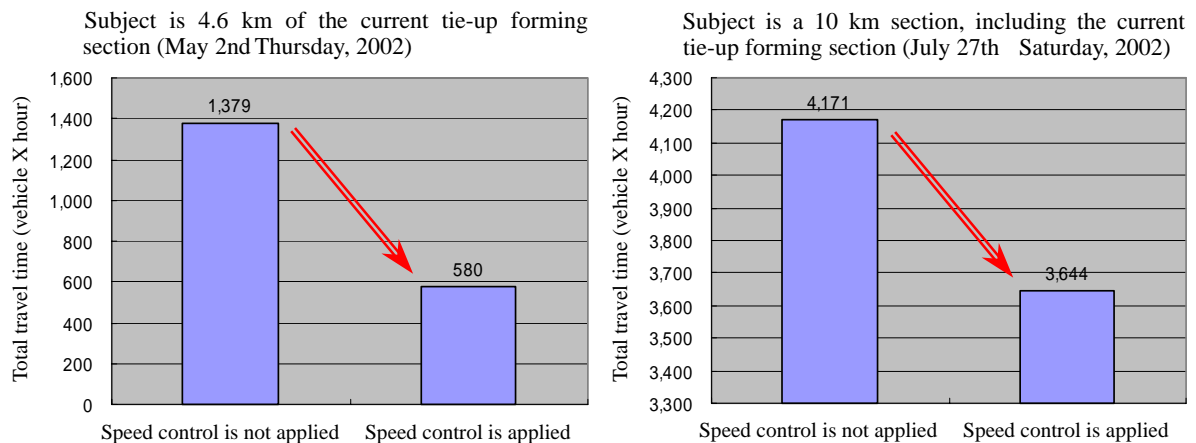


Figure 10: Shifts of total travel time (speed control section extends 2 km)

CONCLUSION

The study using simulations has verified that unbiased lane use in sag/tunnel section creates a positive impact on dispersion of tie-ups. The speed control approach using message boards or on-board units keeps the cost low to achieve appropriate vehicle speed and balanced lane use. The recent progress of information technology together with the mandatory installation of a speed-limiter for large vehicles will add to the impact of this approach.

A point worth heeding is consensus building among drivers. Each individual driver's desire for operational speed is restricted to a certain level under the control. Since drivers are sometimes subject to negative benefits depending on where a control is imposed regarding the timing when and what level of speed limit is imposed, they have to be informed of the impact of the speed controls and operator must conduct appropriate controls. The modeling for simulations in this study has supposed that lane changes and deceleration are conducted within a certain set range; however, in terms of driver's behavior, these subjects have not been clarified in traffic engineering study. The further study on acceptability of the abovementioned approach by drivers and data gathering regarding the related subjects are required for future progress in this field.

REFERENCES

- (1) Prime Bottleneck Points 2002, Japan Highway Public Corporation
- (2) Technology Center of Metropolitan Expressway, Traffic Technology of Expressway, for example.
- (3) Home page of Highways Agency, <http://www.highways.gov.uk/>
- (4) Home page of ERTICO, <http://www.ertico.com/>
- (5) Traffic Engineering Handbook, Japan Society of Traffic Engineers, for example.
- (6) Home page of National Institute for Land and Infrastructure Management, <http://www.nilim.go.jp/japanese/its/index.htm>. Home page of Japan Society of Traffic Engineers, <http://www.jste.or.jp/sim/verification/index.html>