

DEVELOPMENT OF AHS FOR TRAFFIC CONGESTION IN SAG SECTIONS

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ABSTRACT

The authors have been engaged in research and development of “AHS for smoother traffic” as countermeasures utilizing Advanced cruise-assist Highway System. As part of this work, they have reviewed a “Service to adjust lane utilization rates” which aims at reducing congestion, adjusting the balance of lane utilization by providing drivers with appropriate information in sag sections just before congestion occurs.¹⁾

This paper presents the results of a study performed in connection with the development of this service. In this study, vehicle behaviors were analyzed from consecutive video recordings. The paper then proposes some service methods.

KEYWORDS

AHS(Advanced Cruise-Assist Highway Systems), Sag, Expressway, Congestion

BACKGROUND

On Japan’s intercity expressways, traffic congestion most frequently occurs in sag sections and tunnels, accounting for 40% of overall congestion (data for 2004 is presented in Figure 1). Now that congestion at toll gates has been reduced thanks to the expanded use of ETC, measures against congestion in sags and tunnels have become the primary issue.

FACTORS CAUSING CONGESTION IN SAG SECTIONS

The sag sections of expressways are known as traffic bottlenecks, and research has long been performed to clarify traffic flow phenomena at these locations and the factors that cause congestion. Past research showed that drivers frequently slow down unconsciously in sag sections because they are not aware of changes in the degree of slope. Traffic also concentrates in passing lanes and congestion begins there, with the available traffic capacity not fully

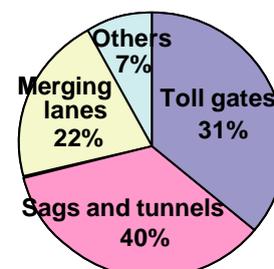


Figure 1: Breakdown of Frequency of Occurrence of Congestion on Inter-City Expressways

Source: Documents of Japan Highway Public Corporation, 2004

exhausted.²⁾ Being aware of the difficulty of specifying cause-and-effect relationships in traffic congestion on the basis of this sort of macroscopic understanding of vehicle behaviors, some researchers have posited that the formation of vehicle groups owing to the behaviors of some specific vehicles (e.g., slow drivers) is a factor, and research has been conducted based on this hypotheses.^{2), 3), 4)} Although findings have been put forward concerning the mechanisms and causes of congestion in sag sections, a definitive explanation has not to be offered yet.

Building on these past findings and hypotheses and on investigations¹⁾ into traffic phenomena on actual roads in past years, the authors posit four factors involved in the occurrence of congestion in sag sections, reasoning from the perspective of the cause-and-effect relationship between driver psychology and vehicle behavior: i) vehicle behavior forward (misunderstanding of changes in degree of slope), ii) imbalance in lane utilization, iii) disorderly traffic flow due to lane changing behavior by specific vehicles, and iv) formation of vehicle groups due to behavior of specific vehicles, for example slow driver (See Table 1).

Table 1: Causes of Congestion in Sag Sections (hypotheses)

Cause of congestion	Remarks
i) Behavior of vehicle in direction of travel (Unconscious reduction of speed)	- Many drivers unconsciously slow down because of careless driving or misunderstanding of changes in degree of slope. - A speed reduction shockwave develops and spreads and is transmitted to vehicles behind, leading finally to congestion.
ii) Unbalanced use of lanes (Concentration of traffic in passing lane)	- Immediately before congestion, vehicles in a rush concentrate in the passing lane and congestion is generated in the passing lane. - Immediately after the start of congestion, vehicles in the passing lane trying to avoid the slowdown shift back into the less crowded cruising lanes all at once, and cruising lanes quickly become congested. - Consequently, overall traffic capacity is not used efficiently.
iii) Disorderly traffic flow caused by lane changing by specific vehicles (Inducement of speed reduction shockwave)	- A conflict occurs because of aggressive cutting into lanes by specific vehicles, which induces a speed reduction shockwave.
iv) Grouping of vehicles due to behavior of specific vehicles (Formation of conditions where speed reduction shockwaves are likely to occur)	-Vehicle groups are formed by specific vehicles (e.g., slow drivers or vehicles with poor acceleration performance). -When vehicle groups arrive at a sag section, a speed reduction shockwave caused by deceleration of the lead vehicle spreads and is transmitted to cars in the rear. -Finally, congestion occurs due to highly-dense large vehicle groups.

CONCEPT OF “AHS FOR SMOOTHER TRAFFIC”

Measures against traffic congestion in sag sections and other bottlenecks have mainly consisted of “hardware” measures such as road widening. Future efforts, however, should focus on “software” measures that can be realized at low cost without changing road structures through the use of IT. A representative measure among these is one that provides information to drivers.

Table 2: Causes of Congestion in Sag Sections and Countermeasures

Causes of congestion in sag sections		Policies of Countermeasure	Proposals of countermeasures (services)
After congestion occurs	i) Unconscious speed reduction	- Shorten headway of vehicles	(1) Service to recover speed ()
		- Urge careless drivers to accelerate	(2) Service to prevent speed reduction ()
Before congestion occurs	ii) Imbalance in lane utilization	- Equalize lane utilization and utilize unused traffic capacity of cruising lanes - Rectify traffic flow by curbing behaviors which cause disorders	(3) Service to adjust lane utilization rates () (4) Service to adjust lane utilization rate by use of road shoulder () (Dynamic additional lane operation)
	iii) Disorderly traffic flow		
	iv) Formation of vehicle groups	- Prevent or resolve formation of vehicle groups	(5) Service to prevent the formation of vehicle groups () (Provision of information to specific vehicles which cause vehicle groups, etc.)

: NEXCO Testing complete

: Object of short-term development

: Object of short-term development

Table 2 presents measures against congestion in sag sections in line with the hypotheses of the causes of congestion previously discussed, along with proposals for the services.

Some of the measures that operate through information provision have already reached the stage of practical use,⁵⁾ but these measures mainly deal with congestion after it has occurred. A more effective means of achieving smoother traffic flow would be preventing the occurrence of congestion by predicting when congestion is about to occur and then providing appropriate information in a timely manner.

The Ministry of Land, Infrastructure and Transport has developed a Cooperative Vehicle-Highway System based on the AHS (Advanced Cruise-Assist Highway System) concept. This system consists of sensors to detect the conditions of traffic ahead, processing units that generate information appropriate to traffic conditions, and sign boards or communication antennas which provide information to drivers timely through the on-board units.

The AHS for Smoother Traffic applies this Cooperative Vehicle-Highway System to the congestion prevention. It is designed to ensure smoother traffic flow by providing information appropriate to traffic conditions just before congestion occurs. The system uses sensors to obtain an overview of traffic conditions, then generates appropriate information and transmits it to drivers. As a result, the system achieves orderly traffic flow and reduces congestion. The service to adjust lane utilization rates under study as part of this R&D project is an information provision service that aims for effective use of overall traffic capacity by preventing or improving lane utilization imbalances immediately before congestion would otherwise begin.

TEMPORALLY AND SPATIALLY CONSECUTIVE ANALYSIS OF TRAFFIC PHENOMENA IN SAG SECTIONS

Consecutive observation of traffic flow in sag sections

To create an effective service to adjust lane utilization rates, it is necessary to specify the cause-and-effect relationships involved in the occurrence of congestion by understanding the spatial and temporal characteristics of traffic phenomena before and after sag sections. Then, the means of information collection and provision must be determined along with the location and timing

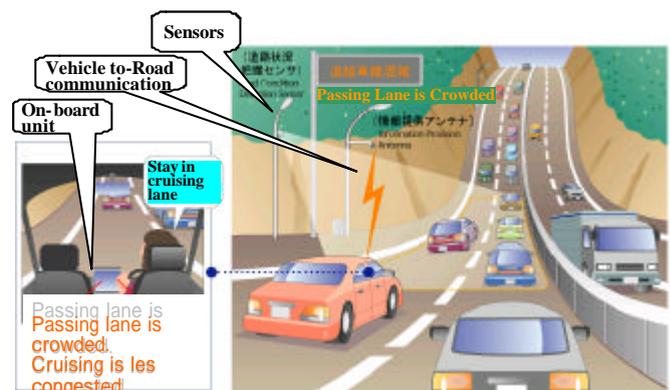


Figure 2: Conceptual image of AHS for Smoother Traffic (Service to adjust lane utilization rates)

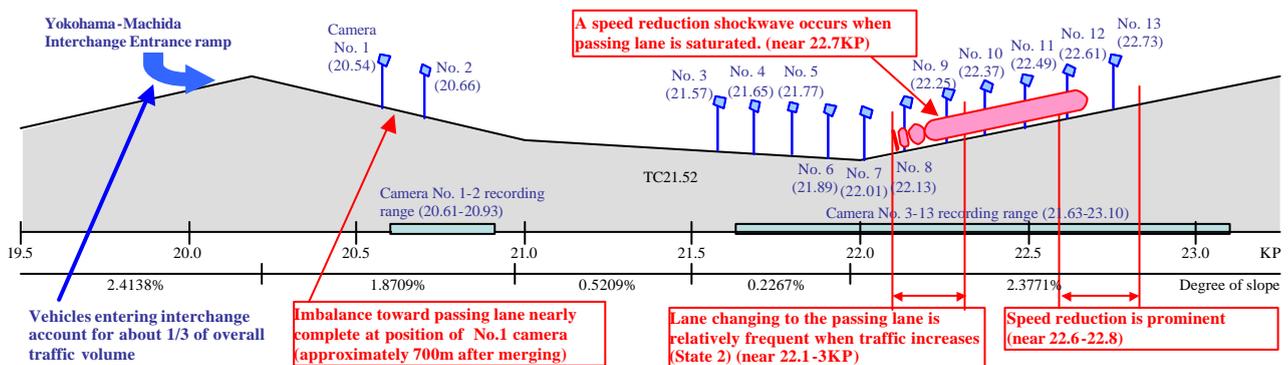


Figure 3: Overview of Installation of Traffic Observation Cameras and Characteristic Traffic Phenomena (Tomei Expressway outbound Yamato sag section)

of provision and the information content. To specify these cause-and-effect relationships, it is necessary not only to macroscopically understand traffic flow, but also to consecutively track individual vehicle behavior in the direction of road allotment and temporal axes. For this reason, the authors carried out consecutive observation by means of video cameras and performed an analysis of the temporal and spatial characteristics of traffic phenomena.

Yamato section on Tomei-Expressway (3 lanes outbound) was selected to be observed, which typifies sag congestion locations in Japan (in 2004, congestion occurred 58 times, with an average duration of 3hrs per occurrence). Thirteen cameras were placed at intervals of about 120 meters along a two-kilometer stretch, which included the starting position of congestion which was found out through the previous investigations. Video recordings are collected using these cameras, and vehicle detector data are also collected forward and backward points of this stretch. Figure 3 presents an overview of road structure and camera positions along the stretch and the characteristic traffic phenomena based on the results of analysis to be discussed below.

Analysis of traffic phenomena based on consecutive observation

Temporal and spatial characteristics of lane utilization

Figure 4 presents an example of results obtained by totaling through traffic volume and frequency of lane changes within the range of observation of the video cameras for an incident of traffic congestion that occurred on Saturday, 10 December 2005. “State 2” and “State 3” as given in Figure 4 are classifications of traffic conditions, as shown in Figure 5, which are defined based on traffic volume by lane and average speed by lane as measured by vehicle detectors (21.52KP) during the video recording period (5:00-8:00).

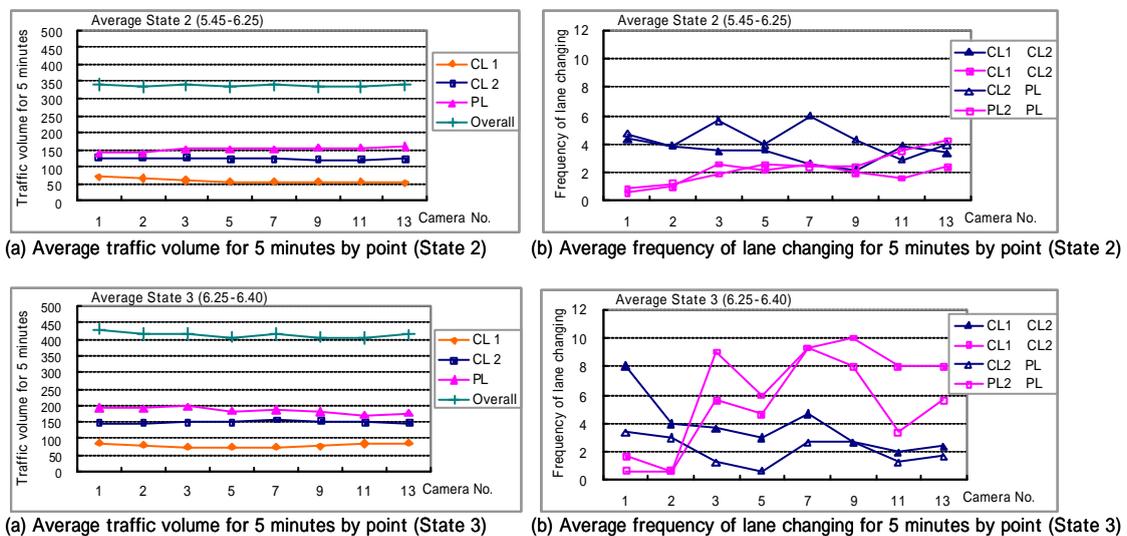


Figure 4: Traffic Volume and Frequency of Lane Changing by point (12/10/2005)

Based on the consecutive observation data and video images, temporal and spatial characteristics of lane utilization before and after congestion occurred are presented in Figure 6.

State 2-4 confirmed the imbalance of traffic in the passing lane. Although a slight increase in the lane utilization rate of the passing lane can be seen in State 2 on the uphill slope, it is for the most part constant along the entire observation stretch (20.6-22.8KP), and an imbalance in lane utilization had already formed at a location about 1.5 km ahead of the bottom of the sag (22.0KP) (position of Camera 1, 20.54 KP). Many vehicles enter from the Yokohama-

Machida Interchange (19.7 KP) about 700m backward of Camera 1. Considering that during

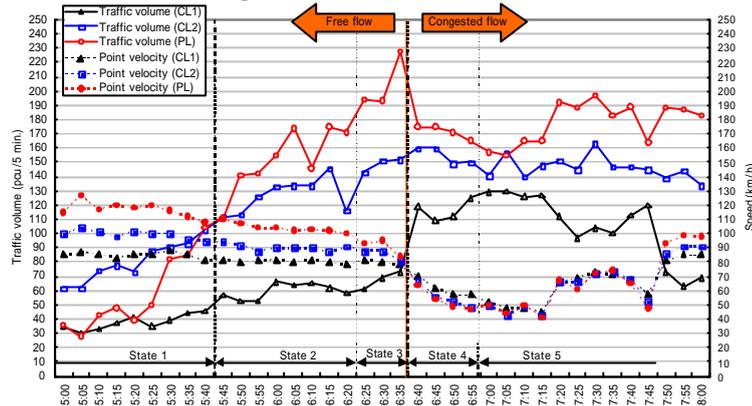


Figure 5: Traffic Volume and Speed Fluctuation and State Category (21.52KP vehicle detector)

- State 1 (5:00-5:45);
- Increase in traffic volume in passing lane ($Q_3 > Q_1$)
- State 2 (5:45-6:25);
- Increase in traffic volume in passing lane ($Q_3 > Q_2 > Q_1$)
- State 3 (6:25-6:40);
- State of saturation in passing lane ($Q_3 = 190-230$ vehicles/5 min.)
- State 4 (6:40-7:00);
- Congestion starts, speed drops in all lanes
- State 5 (7:00-8:00);
- Complete congestion ($V = 40$ km/h)

where,
 Q_1, Q_2, Q_3, Q : No.1, No.2, Traffic volume in passing lane and total traffic volume of all lanes
 V_1, V_2, V_3, V : No.1, No.2, Average velocity by passing lane and average velocity in all

peak hours this traffic accounts for about one-third of overall traffic volume, it can be seen that the increase in traffic volume in cruising lanes through entry of vehicles is only temporary because after entry, lane changes toward the right are immediately completed.

Frequency of lane changing

Next, as we focus attention on the number of lane changes along the observation stretch, it can be seen that in State 1-2 there is a tendency for drivers to change to the faster right-hand lanes. Consequently, there is a slight increase in the lane utilization rate of the passing lane before and after the sag section. In the range of observation of Camera 3-11 (21.7 – 22.5KP) in State 2, the lane utilization rate increased from 45% to 47%, and this increase corresponds to about 7% of traffic volume in the passing lane.

State category	Threshold of traffic indicator (Based on 21.5KP vehicle detector data, etc.)	Time of occurrence Duration	Overview of Traffic Behavior
0 Periods of light traffic	$Q_2 > Q_1 > Q_3$ $V_3 > V_2 > V_1$ $V_3 = 120$ km/h	~5:00	Yokohama-Machida IC entrance Sag bottom Downhill slope Uphill slope
1 Increase in traffic in passing lane 1 ($Q_3 > Q_1$)	$Q = 140$ pcu/5 min.~ $Q_3 > Q_1 = 40$ pcu/5 min.~	5:00~45 minutes	22.7KP
2 Increase in traffic in passing lane 2 ($Q_3 > Q_2$)	$Q = 270$ pcu/5 min. $Q_3 > Q_2 = 110$ pcu/5 min. $V_3 = 110$ km/h	5:45~40 minutes	700 meters after merging (camera No.1) 22.1-3KP
3 Saturation of passing lane, unstable condition	$Q = 422$ pcu/5 min.~ (of which 149 were entering interchange) $Q_3 = 190$ pcu/5 min. Camera No.11 177 $V_3 = 90-100$ km/h	6:25~15 minutes	
4 Start of congestion	$Q = 443$ pcu/5 min. (of which 153 were entering interchange) $Q_3 = 170$ pcu/5 min. $V_1 > V_2 > V_3$ $V = 70$ km/h	6:40~20 minutes	
5 Complete congestion	$Q = 450$ pcu/5 min. $Q_3 = 160$ pcu/5 min. $V = 40$ km/h	7:00~	

Note: The length and thickness of the black arrow indicates the relative size of traffic volume. The blue arrow indicates the tendency of lane changing.

Figure 6: Traffic Spatial-Temporal Characteristics in Yamato Sag Section Before and After Congestion (December 10,

In State 3, the speed-reduction shock wave is transmitted backward beginning in 22.6-7KP, and lane changing from the passing lane to the left-hand cruising lanes by vehicles that noticed the speed-reduction shock wave was frequently observed forward of the Camera 3 position (the endpoint of the range of consecutive observation).

In State 4, after the start of congestion in the passing lane, drivers change to faster cruising lanes all at once to avoid the speed reduction, and then congestion spreads to the cruising lane 2 and the cruising lane 1.

Occurrence and transmission of speed-reduction shock wave

From the video images collected, individual vehicles were tracked using the AHS image processing equipment. Sequential matching of images was performed based on the time codes recorded on the images, and vehicle tracing diagrams were prepared and organized into a data

base. Figure 7 is an example of the vehicle tracing diagrams of the passing lane in the incident of congestion on Saturday, 17 December (State 3). Although remarkable congestion did not occur on that day, traffic in the passing lane reached saturation, and the State 3 phenomena as shown in Figure 6 occurred, enabling confirmation of the occurrence and transmission of the speed-reduction shock wave.

In the sag section, each of the vehicles slowed down slightly when they arrived at the uphill slope at a speed of about 80-90km/h, and this tendency gradually expanded and was transmitted to the following vehicles(especially in 22.6-22.8KP). Then lane changing occurred from the cruising lane 2 into the forward spaces of vehicles which maintained a comparatively wide headway (at about 6:38:55, 22.3-22.5KP). At the same time, vehicle headway decreased and the speed-reduction shock wave transmitted backward could not be absorbed, causing vehicles to quickly slow down (6:39:15, 22.65KP). At that time, vehicles which had been maintaining a large amount of headway accompanied a dense vehicle group behind, and for this reason the speed-reduction shock wave expanded and was transmitted to this vehicle group, and vehicles in the very back reduced speed to 20km/h (6:40:30, 22.2KP). Afterward, many vehicles in the passing lane made lane changing to the cruising lane 2 avoiding the speed-reduction, and with the expansion of headway and dispersal of the vehicle group, speed was recovered without occurrence of congestion.

Since conditions similar to the above have been found in other cases, it could be verified that lane changing behavior of aggressive cutting-in conflicts with the high density traffic flow before occurrence of congestion and is a possible factor in the occurrence and transmission of speed-reduction shock waves developing from the rapid deceleration of following vehicles. However, the findings presented here are based only on a partial analysis of observations, and for this reason, efforts to verify these findings are underway using further samples for analysis.

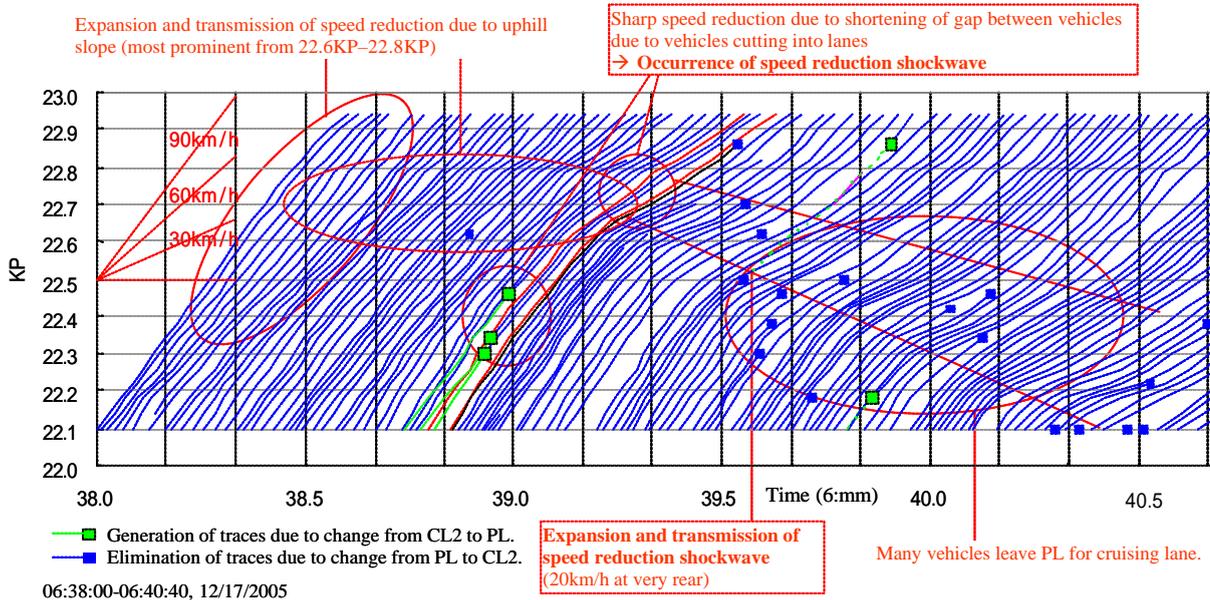


Figure 7: Vehicle Tracing Diagram (Passing Lane) Based on Continuous Observation

STUDIES AIMED AT REALIZING SERVICE TO ADJUST LANE UTILIZATION RATES

Study of specific service proposals

Based on the findings obtained from the above analysis, two specific measures for a service to

adjust lane utilization rates can be proposed. Proposal 1 is to urge drivers to change to left-hand cruising lanes before sag sections. Proposal 2 is to discourage drivers from changing to faster right-hand lanes along sag sections. These proposals are presented in Table 3 and Figure 8. These proposed measures could be implemented together.

Table 3: Service to Adjust Lane Utilization Rates (draft)

	Traffic phenomena under study (Results of analysis of observation data in this research)	Services Proposed	Aim of Services
Proposal 1	- Imbalance toward passing lane nearly complete up to 1.5km before sag section (position of Camera No.1: 20.54KP)	Providing information to urge drivers to shift into left-hand lanes (to cruising lanes) before sag sections	- To equalize traffic lane utilization rates along sag section
Proposal 2	- In State 2, the passing lane utilization rate in the 600m interval immediately before and immediately after the sag section (in the vicinity of 21.7KP-22.3KP) increases from 45% to 47% (about 7% of passing lane traffic volume). - In State 3, the occurrence of conflict due to the effect of lane changes into passing lane can induce a speed reduction shockwave.	Providing information to discourage drivers from shifting into right-hand lanes (into the passing lane) along sag section	-To prevent further imbalance in use of traffic lanes toward passing lane along sag section - To prevent occurrence of speed reduction shockwave due to lane changes

Considerations toward systematization

Systematizing the service to adjust lane utilization rates is required to be reviewed from the following standpoints.

Determining locations of service provision

In view of temporal and spatial characteristics of traffic based on the analysis results discussed above, it will be necessary to determine effective locations for providing each service proposed.

Selection of information provision method (media)

Candidates for information provision media include the existing VICS on-board unit for three media, the ITS on-board unit using 5.8GHz DSRC, variable message sign boards, and Highway Advisory Information Radio (highway radio). Another possible method is to regulate lane changing that is currently permitted through road surface indications (including one with dynamic, variable operation). Given the characteristics of each method, it will be necessary to select a particularly effective method, including the use of multi-media.

Determination of content of information provided

It will be necessary to consider such matters as driver psychology and the restrictions on the various media and then design an HMI (Human-Machine Interface) for the content of information displayed on variable message sign boards, the displays on on-board units, and content of voice messages. For the information content, one method would be to provide factual information on congestion conditions for each lane and then let the driver decide. Another possible method would be to first communicate the state of sag congestion to drivers and urge them to avoid congestion by changing lanes or staying in lanes.

Determining parameters such as requirements of service provision

It will be necessary to determine the method of setting the timing to provide service, the method of traffic data sensing, and the positions of sensing. These requirements for

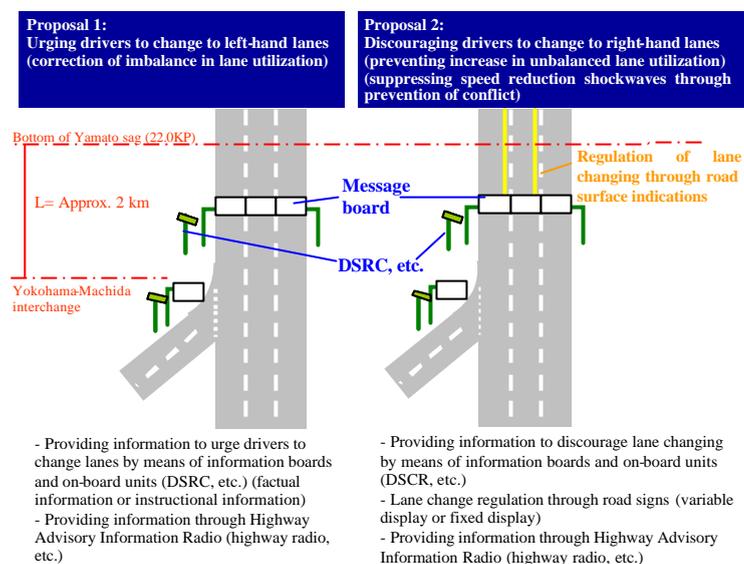


Figure 8: Specific Proposals for Service to Adjust Lane Utilization Rates

systematization will be taken up in studies to be conducted based on the development of more precise traffic phenomena analysis and experiments to study driver behavior using driving simulators.

CONCLUSION

This paper presented part of the results of a study which observed traffic phenomena by consecutive video recording along the Yamato sag section on Tomei-Expressway, which typifies those locations where congestion occurs in sag sections, and confirmed that the traffic phenomena given below is associated with the occurrence of congestion in sag sections. The paper also offered proposals for systematizing a service to adjust lane utilization rates based on the results of an analysis of the above observations.

Temporal and spatial characteristics of traffic phenomena in sag sections

- The imbalance of traffic in lanes before congestion occurs and the temporal and spatial characteristics associated with lane changing behavior were ascertained.
- It was confirmed that the occurrence of conflict due to the effect of changing to passing lanes on uphill slopes is a possible factor inducing speed-reduction shock waves.
- Temporal and spatial characteristics associated with the occurrence and transmission of speed-reduction shock waves in passing lanes immediately before and after the start of congestion were ascertained along with the accompanying shift to left-hand cruising lanes.

Specific proposals for systematizing the service to adjust lane utilization rates

- Two specific proposals were offered based on observations and the results of analysis: Urge drivers to change to left-hand cruising lanes before sag sections and discourage them from changing to faster right-hand lanes along sag section.
- The determinations required to systematize the service were clarified.

Future work will focus on establishing the service and conducting studies on its systematization based on the findings reported here. The acceptability of the service will be verified through experiments using driving simulators while road tests will be conducted aimed at practical use of the service in 2007.

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