Applicability of AHS Service for Traffic Congestion in Sag Sections

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Abstract
Sag sections and tunnels cause 35% of the congestion on expressways in Japan. One of the factors in congestion is imbalance in traffic lane utilization such as traffic concentration in the passing lane and leeway in the cruising lane. Therefore the National Institute for Land and Infrastructure Management (NILIM) and the Advanced Cruise-Assist Highway System Research Association (AHSRA) have been studying AHS services that would optimize the traffic lane utilization rates by providing drivers with information before congestion occurs. This paper will report on our analysis of actual traffic conditions at a congestion location in a sag section (in the Tomei(Tokyo-Nagoya) Expressway). It will also report on the results from examination of the possibility of providing service, the algorithms for determining the timing for service.

KEYWORDS

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

1. An overview of congestion in sag sections and tunnels

The loss from congestion on expressways is approximately 940 billion yen per year. Congestion occurs mainly at toll gates, followed by sag sections and tunnels (Figure 1).
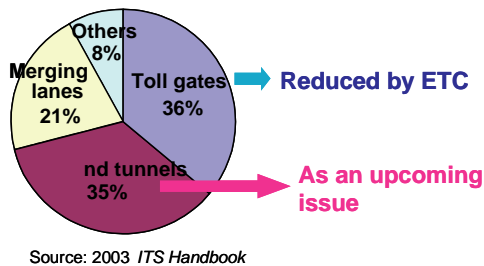
Others 8%
Merging lanes 21%
Toll gates 36% → **Reduced by ETC**
nd tunnels 35% → **As an upcoming issue**

Source: 2003 *ITS Handbook*

Figure1. Breakdown of congestion incidence
        on expressways by road structure

Average congestion (km-h/day)

43.3 (Apr.2002)
30.9 (Apr.2003) — Congestion was reduced by half.
22.9 (Apr.2004)

Percentage of ETC-equipped vehicles (at toll gates of all main lines): 2.5% → 7.3% → 21.0%

* The average amount of congestion is an aggregate figure for 18 toll areas.
Source: 2004 ITS Handbook

Figure2. Reduction of congestion due to increasingly
        widespread use of ETC (toll gates on 18
        Metropolitan Expressway lines)

The implementation of ETC in toll gates and the widespread adoption of on-board unit have been reducing toll gate congestion on an annual basis in Japan (Figure 2). At present, therefore, the resolution of congestion in sag sections and tunnels is the next issue.
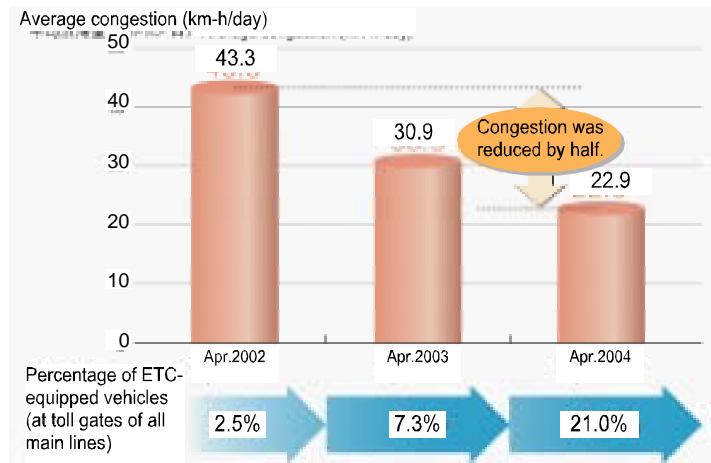
2. Mechanism of congestion in sag sections

Sag sections are considered to be traffic capacity bottlenecks. The causal factors in congestion occurring here are considered to be as follows:

(i) Vehicle behavior in the direction of travel: Careless driving leads drivers to unconscious reductions of speed in sag sections, so that the interval between vehicles becomes excessively long. This interferes with the efficient utilization of
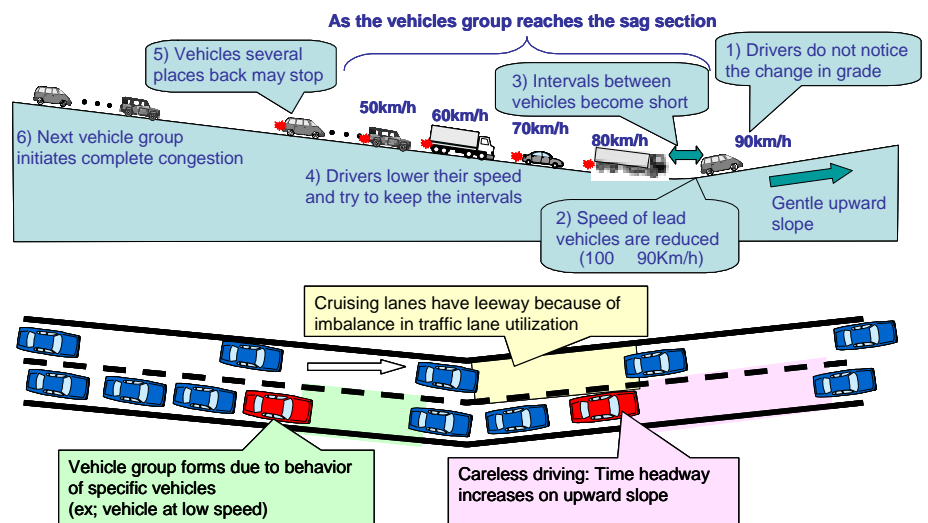
As the vehicles group reaches the sag section
5) Vehicles several places back may stop
1) Drivers do not notice the change in grade
3) Intervals between vehicles become short
50km/h 60km/h 70km/h 80km/h 90km/h
6) Next vehicle group initiates complete congestion
4) Drivers lower their speed and try to keep the intervals
2) Speed of lead vehicles are reduced (100 90Km/h)
Gentle upward slope

Cruising lanes have leeway because of imbalance in traffic lane utilization

Vehicle group forms due to behavior of specific vehicles (ex; vehicle at low speed)

Careless driving: Time headway increases on upward slope

Figure3. Basic mechanism of congestion in sag sections

the traffic capacity of individual traffic lanes.

(ii) Traffic lane utilization:

When vehicles concentrate excessively in the passing lane, it makes congestion that begins in the passing lane. At that time, there is leeway in the cruising lane so that the traffic capacity as a whole is not utilized efficiently.

(iii) Behavior of specific vehicles:

When a group of vehicles arrives at the sag section, the reduction in speed by the leading vehicle creates a speed reduction shock wave. When another, larger vehicle group of greater density arrives after it, then the next vehicle group catches up with the front and the shock wave is causing congestion. The sizes of the vehicle groups are thought to be determined by whether or not they include causal vehicles that want to travel at low speed, or that have poor acceleration performance.[1]

3. Congestion countermeasures

The essentials of countermeasures against congestion in sag sections can be summarized as follows: (i) Eliminate causes of reductions in speed in bottleneck sections;
(ii) Adjust the balance of traffic lane utilization rates in advance; and (iii)

Table1. Congestion causal factors and countermeasures

Problems in Sag Sections		Focusing point for improvement	Countermeasures(Services)
Current problem	i) Decreased capacity due to careless driving	Urge the drivers to accelerate	(1) Service to prevent speed reduction
		Reduce time headway	(2) Service to recover speed
Future problem	ii) imbalance in traffic lane utilization	Adjust the balance of traffic lane utilization	(3) Service to adjust traffic lane utilization rate
			(4) Service to adjust traffic lane utilization rate by use of road shoulder
	iii) Inefficient lane utilization due to vehicle groups	Induce leading vehicle in vehicle group to change to the cruising lane	(5) Service to prevent the formation of vehicle groups

Object of short-term development	JH testing complete	Object of medium to long term development

Avoid forming vehicle groups. When these are achieved, it is possible to utilize road sections to the maximum extent of their innate traffic capacity.

We propose various services shown in Table 1 "(1) to (5)". The provision of information to drivers is a method that can be realized at low cost without changing road structure.

The Japan Highway Public Corporation (JH) proposed the above services (1) and (2) for use in sag sections of the Tomei Expressway in the Yamato district from 2003. These are warnings of speed reductions by means of message signs installed in sag sections, and the provision of information to encourage the recovery of speed.[2] The JH reports that this information provision has brought a 7% improvement in the traffic capacity when there is congestion.

Conventional congestion countermeasures are mainly focusing on after congestion phenomena The AHS services such as items (3) traffic lane utilization rate adjusting service and (5) service to prevent the formation of vehicle groups, however, are new countermeasures intended to reduce congestion by means of information provision before congestion occurs. Here the roadside systems obtain a comprehensive view of overall traffic flow and provide

drivers appropriate caution. These methods can be expected to realize an overall harmonious traffic flow and so to have the effect of reducing congestion.[3] An overview of the services is presented as follows.

Traffic lane utilization rate adjusting service

- An approach in terms of the efficient utilization of traffic capacity, this is provision of information with the aim of achieving an appropriate traffic lane utilization rate immediately before congestion occurs (Figure 4).
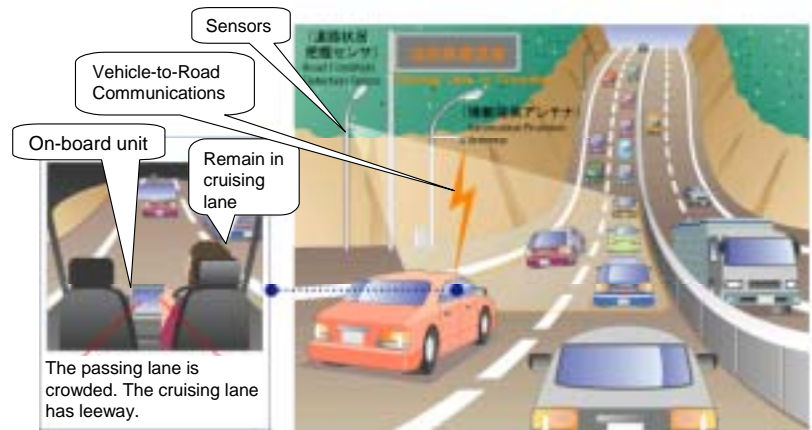

Figure 4. Conceptual image of sag section congestion countermeasures

Service to prevent the formation of vehicle groups

- This service urges appropriate caution by the drivers of certain vehicles with the aim of preventing the formation of vehicle groups, which are likely to trigger congestion, or eliminating such groups.

4. Analysis of sag section traffic conditions

4.1. Traffic lane utilization conditions in sag sections

We observed Traffic lane utilization conditions in sag sections of the Tomei Expressway in the Yamato district (three traffic lanes on one side, see Figure 5) in order to study the feasibility of a traffic lane utilization rate adjusting service.
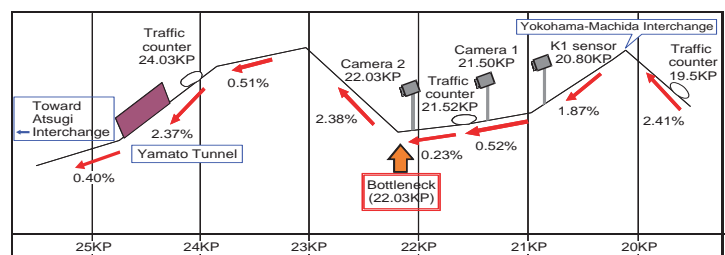

Figure5. Longitudinal slope and measurement points in the Yamato district

Traffic volume and speed by lane at a point approximately 500 m backward of the sag section (Figure 6) are obtained from vehicle sensor (traffic counter) data, video cameras newly installed on the roadside, and motion path data acquired using an AHS image processing sensor(K-1 sensor).

Immediately before congestion (State 3), the 1st cruising lane (CL1) has less traffic than the passing lane(PL) or the 2nd cruising lane (CL2) by 75–100 PCU/5 minutes. Subsequently, the occurrence of congestion in PL and CL2 is followed by CL1 also making a transition all at once to a condition of congestion (State 4). The difference in traffic volume between CL1 and CL2 immediately before congestion is approximately 10% of the spot traffic volume. It means that at least 10% of the whole traffic capacity remains unutilized. Consequently, balancing of

4

traffic lane utilization rates will make it possible to increase traffic capacity in the bottleneck section.

4.2. Possibilities of lane changing

We introduced an indicator called "the lane change possibility rate" for the purpose of microanalysis of cases in which drivers are encouraged to return to a cruising lane. The lane change possibility rate is the expected value for the probability that a vehicle can find a headway (time interval between vehicles) in a neighboring lane that allows changing lanes while the vehicle travels a unit distance. Here this is calculated using the following formula for each traffic lane based on motion path data for individual vehicles.

Figure6. Traffic volume and speed in the Yamato district during typical congestion

State 0: Traffic is flowing freely, with less traffic in PL than in other lanes.
State 1: Traffic is flowing freely, with more traffic in PL than in CL1
State 2: Traffic is flowing freely, with more traffic in PL than in CL2.
State 3: Critical state immediately before congestion
State 4: State after congestion has occurred

$$Pg_{i+1,i} = \sum_j \frac{Lg_{i+1,i,j}}{L}$$

The quantities here are:
$Pg_{i+1,i}$ Lane change possibility rate for change from traffic lane $i+1$ to i
$Lg_{i+1,i,j}$: Distance traveled side by side by Vehicle j with headway in which lane change is possible
L: Section length

Figure 7 explains the concept of this indicator. Assume that a single vehicle travels for one kilometer in CL2, and at point (1) the driver sees a headway in neighboring CL1. That state continues until reaching point (2), a distance of 700 m. The value that expresses the degree of possibility that this vehicle could change lanes from CL2 to CL1 (the ease of lane change) can be calculated as follows:

[Distance traveled side by side with headway]÷ [Section length]　700÷ 1000=0.7

This indicator also expresses how far before the bottleneck portion service must be provided in order for the driver to be able to change lanes. Assume, for example, that a traveling distance of 350 m is required as an absolute minimum for
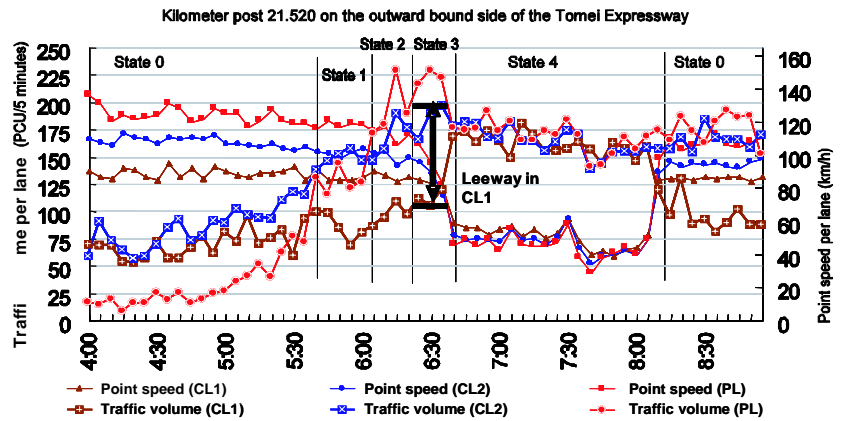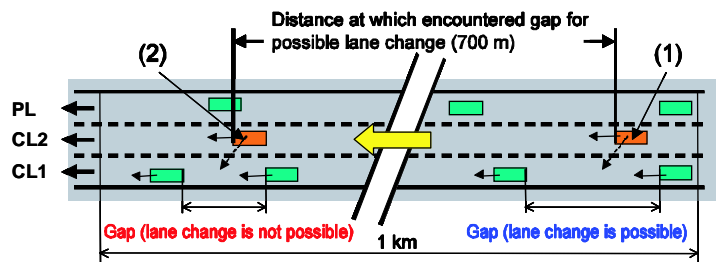
Figure7. Concept of the lane change possibility rate

lane change. Then under conditions where the lane change possibility rate is 70% in the section before the bottleneck, providing service a distance of 350÷ 0.7=500 m in advance will assure that the driver has the leeway needed to make it possible to change lanes.

In order to calculate the lane change possibility rate, it is necessary to ascertain the time headway for possible lane change. The distribution of headway between leading and following vehicles during lane changes in the specified section was determined for that purpose by analysis of video data (Figure 8). There was a headway of
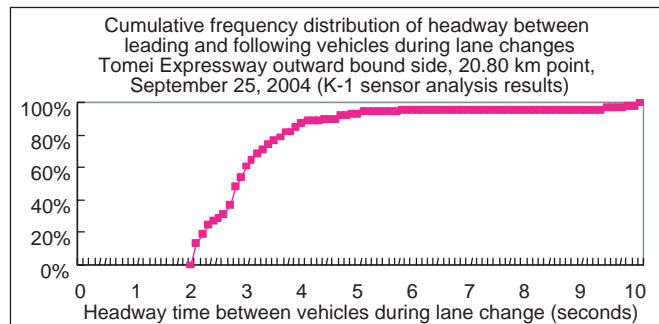

Figure8. Cumulative frequency distribution of headway between leading and following vehicles during lane changes

three seconds or more in approximately 50% of the cases (an average of 3.18 seconds). When the headway was less than three seconds, lane change occurs mainly after the speed is reduced after congestion occurred. It is hypothesized from above that the absolute minimum headway needed to make it possible to change lanes in conditions up to the point immediately before congestion is three seconds.

The lane change possibility rate calculated by the above method is merged with the traffic volume and speed by traffic lane at the same location as before (Figure 9). When congestion occurs (at 6:35), the lane change possibility rate for a change from CL2 to CL1 diminishes
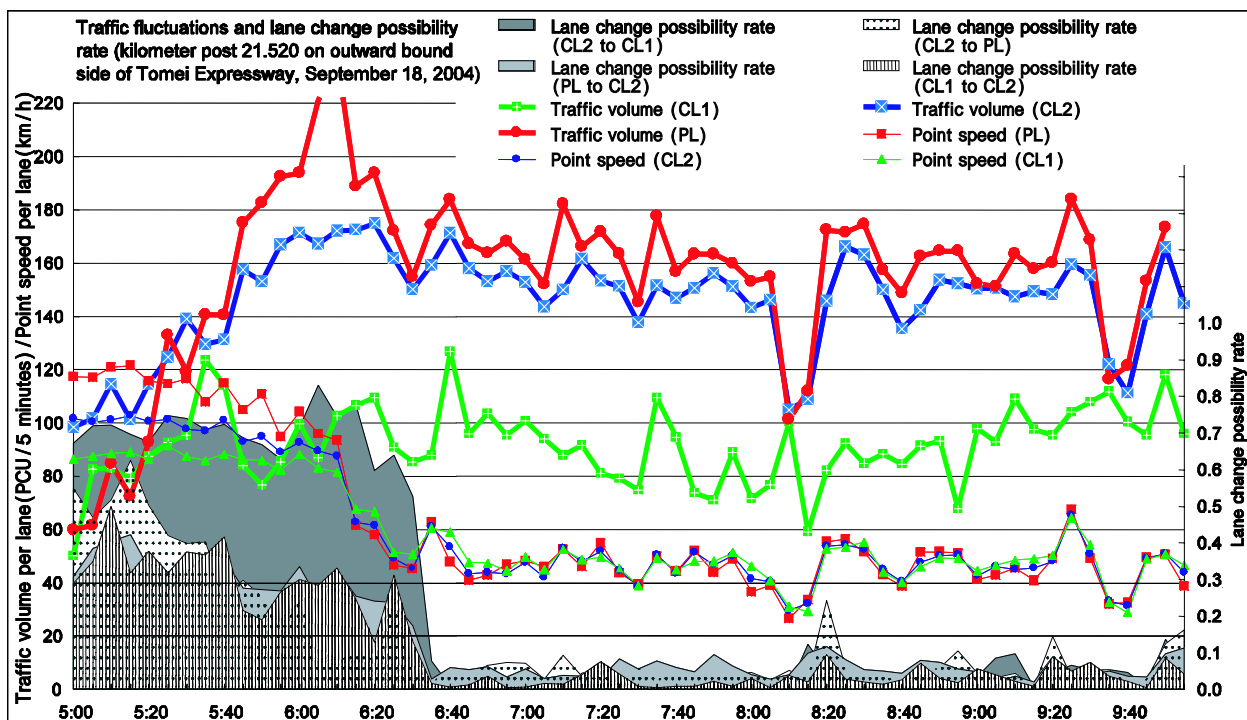

Figure9. Relationship between the lane change possibility rate and traffic volume and speed
(Data for September 18, 2004)

drastically from 0.6 to 0.1. This fact gives an indication that lane change is not possible during congestion. According to the traffic states described earlier, the lane change possibility rate is fully high enough in States 0 to 2. It is also apparent that the lane change possibility rate for changes from CL2 to CL1 remains at a relatively high value in State 3 (critical state) up to the point before congestion occurs.

5. Algorithms for determining the timing for provision of service

The traffic lane utilization rate adjusting service conducts realtime information provision in accordance with traffic conditions. Therefore, it would be ideal to predict the timing for occurrence of congestion and to provide the service only at that time. Consequently, we studied algorithms for determining the timing for provision of services based on traffic counter data.

It is difficult to predict the exact timing for occurrence of congestion itself using macro indicators such as average speed and traffic volume per five minutes that can be collected by means of traffic counter data.[3] In constructing the algorithm for determining the timing of service provision, therefore, our approach is not to take the accurate prediction of the timing for occurrence of congestion. The proposal here is rather to take an approach founded on the assumption that when traffic conditions are such that congestion appears likely to occur with more than a certain degree of certainty, then information is to be provided in a form that accounts for the risk that congestion may not occur.

The criteria for determining State 2 and State 3, which are conditions immediately before congestion occurs, are defined below. We also analyzed Statistical data to verify the appropriateness of timing the provision of service to occur when traffic flow undergoes a transition to State 2 or State 3. The results of that analysis are described in the following.

Figure 10 shows the average speed and traffic volume per five minutes by traffic lane according to the traffic counter at the location noted above (21.52km post), for all days in 2003 when congestion occurred in the Yamato sag section, plotted on a traffic volume and speed (Q-V) plane. The time zones are
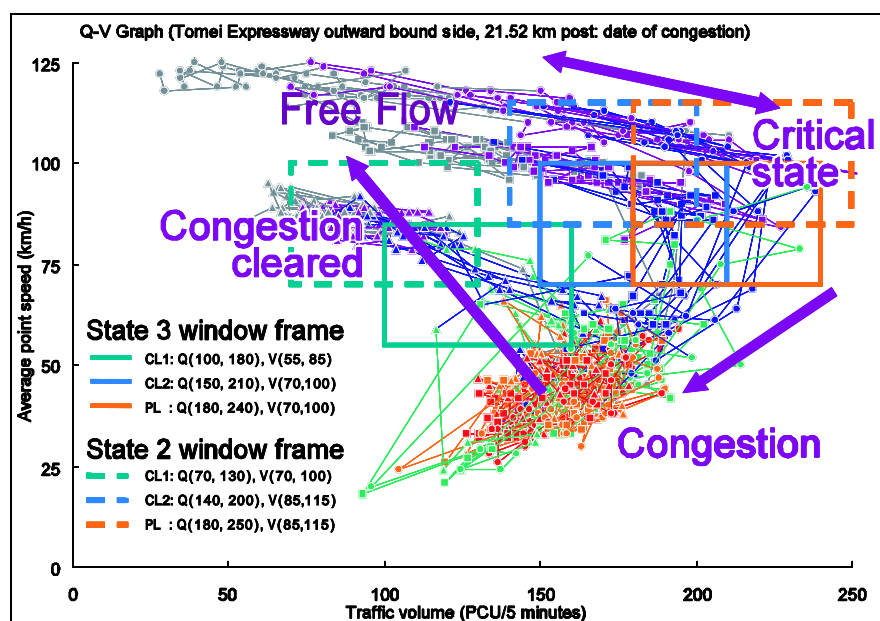

Figure10. Relationship between traffic conditions and window frame

classified on the basis of the times at which congestion occurred on the days in question (plots 90-60 minutes before congestions occur are gray, 60-30 minutes before are purple, 30-0 minutes before are blue, 0-30 minutes after congestions occur are orange, 30-60 minutes after are red). It becomes apparent that the ranges plotted are generally determined by the time zones before congestion. This suggests that the transitions between traffic conditions (State 0 to State 3) up to the time when congestion occurs generally follow the same pattern.

State 2 and State 3, which are timings for service provision, are also represented in Figure 10 by frame. The continuous times of service provision and whether or not congestion actually occurred after service was provided were statistically distributed, and the following findings were obtained as a result.

After traffic conditions underwent a transition to State 2, those conditions were maintained for an average of 17 minutes. If State 2 had been used for the timing of service provision, the hit ratio for service provision with respect to occurrence of congestion would have been 71%, while the missdetermination rate would have been 70%.

After traffic conditions underwent a transition to State 3, those conditions were maintained for an average of 14 minutes. If State 3 had been used for the timing of service provision, the hit ratio for service provision with respect to occurrence of congestion would have been 70%, while the missdetermination rate would have been 32%.

Here these terms are defined as follows:

Hit ratio　(Number of times service was provided) / (Number of times congestion occurred)
Missdetermination rate　(Number of times congestion did not occur after service was provided) / (Number of times service was provided)

The missdetermination rates were not low whether State 2 or State 3 was used for the timing of service provision. When traffic counter data is used for determination, as described above, then it becomes important to consider the content of information to be provided and of warnings issued in order to account for the risk that congestion will not occur. Taking into consideration the results from analysis of the lane change possibility rate, State 2 and State 3 differ in the ease of changing lanes. Consequently, it should be appropriate to take measures suited to traffic conditions by changing the content of services provided or by some other such means. It is conceivable, for example, that the content of information provided (the message) would be changed, or that information would be provided to a different traffic lane.

Figure 11 presents an overview of the algorithm for determining the timing of information provision using traffic counter data. This is the algorithm created here in light of the above investigations.
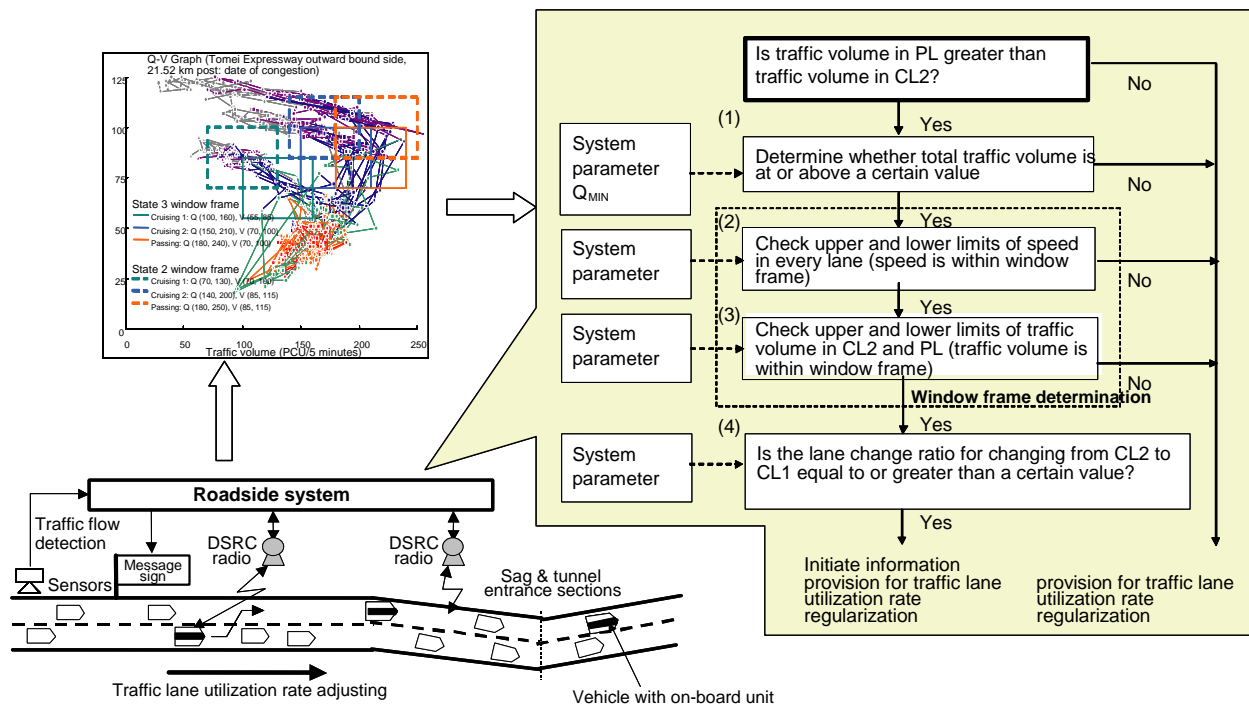
Figure11. Overview of traffic lane utilization rate regularization system and the algorithm used by that system

Conditions for information provision

(1) The traffic volume in PL is greater than that in CL2, and the total traffic volume in every lane meets or exceeds a threshold value.

(2) The upper and lower limits of traffic speed in every lane are checked and the speed is found to be within the frame (State 2 or State 3).

(3) The upper and lower limits of traffic volume in every lane are checked and the traffic volume is found to be within the frame (State 2 or State 3).

(4) The lane change possibility rate for a change from CL2 to CL1 is at or above a certain fixed level.

A situation in which all of these conditions are met is determined to define the timing for provision of the traffic lane utilization rate adjusting service. In the event that the determination of (4) is to be made from existing traffic counter data, however, then alternative methods will be required, such as the use of spot speeds for individual vehicles rather than aggregated data.

6. Conclusion

The analysis of actual data regarding times of congestion in sag sections confirmed that, immediately before congestion occurs, traffic concentrates in the passing lane so that the traffic lane utilization become imbalanced, and that congestion begins to occur first in the

passing lane, where traffic density is higher. We found the fact that traffic capacity in the 1st cruising lane had available leeway even when the congestion begins to occur, and a traffic lane utilization rate adjusting service was considered as a countermeasure for congestion in sag sections. This yielded the following conclusions:

Evaluation that used the lane change possibility rate as an indicator revealed it possible to implement a traffic lane utilization rate adjusting service by means of information provision.

Algorithms that determine the timing for provision of information based on traffic counter data were studied.

7. Future consideration

The authers are going to study effective services by conducting continuous measurements and analysis of traffic behavior as it relates the formation of groups of vehicles, the reduction of speed farther backward from the beginning point where the shock wave is generated, and other such factors. Verification will also be conducted by means of testing in a virtual testing environment[4] that combines traffic simulator and driving simulator, as well as in field operational tests. The authers plan to move ahead with research aimed at the practical application of services in order to bring about a full-fledged ITS society in the year 2007, as proposed by the Smartway Project Committee.

8. References

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