Analysis of Traffic Congestion and Route Choice Behavior Influenced by Traffic Information

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Drivers' route choice behaviour together with traffic information about traffic conditions on a road network is analysed to evaluate the effect of traffic information provided by Traveller Information System technology. One of the difficulties for executing this practical analysis is caused by interaction between the traffic conditions which result from drivers' behaviour and the change of drivers' behaviour depending on the traffic conditions. The authors show a particular example at a critical section of the Tomei Expressway westbound in Japan where the information on Variable Message Sign boards, traffic congestion, and route choice behaviour can be observed.

Keywords: Traffic Information, Route Choice Behavior, Traffic Congestion

1. Introduction

To evaluate the effect of the Traveler Information System (TIS), it is more important to understand what influence is noted on a traffic phenomenon if traffic information is given to drivers in various forms such as on-board information equipments, dynamic route guidance system, and predicted traffic information which supplants real-time traffic information. The future ITS technology would provide more intelligent information such as predicted information provided by on-board information equipments than that of present condition, but for clarify the manner of 'intelligent' information provision, the drivers' response behavior to provided information must be investigated, particularly the behavior observed in the real world.

Traffic congestion phenomena in road network traffic are so closely correlated with route choice behavior that it is very difficult to obtain actual verification data, because of their dynamic nature; traffic congestion on a route is dynamically affected by travel demand concentration in response to drivers' route choice decision, and each driver's route choice decision is always affected by traffic information about the severity of traffic congestion on each route.

The actual changes of route choice behavior in response to traffic information and the actual fluctuation of each route's traffic congestion is analyzed in relation to traffic information shown on variable message sign (VMS) boards for the selected road network section (two routes options, right and left route, are available) between the Ohi-Matsuda (OM) interchange and the Gotemba (GT) interchange on the Tomei Expressway westbound.

2. Difficulty of practical study

There exist two main techniques for the analysis of the route choice behaviour influenced by traffic information and the traffic phenomenon produced as a result of this influence. One is the method of investigating the route choice behaviour in an imaginary situation by means of an indoor experiment or a questionnaire (for example [1]), and another is the method of analyzing a traffic phenomenon based on a traffic simulation which implements a route choice model (for example [2]). There are problems associated with both; the former technique, identifying the traffic phenomena quantitatively caused as a result of route choice behavior and the latter one, proving the validity of any route choice model which is a requisite for a traffic simulation.

It seems that very few practical studies have been done in the past. One of the authors was involved in a surveillance project [3] in which the relationship between traffic information and route choice behavior was analyzed. However, on an actual road network, it is difficult to identify a clear causal relationship between route choice behavior and traffic phenomena because there are other influences on the traffic phenomena of other drivers' behavior than the one investigated.

There are three possible difficulties in analyzing the relationships among route choice behavior, traffic conditions, and traffic information. First, in order to analyze the route choice behavior of a driver on an actual road network, it is necessary to pursue the choices of routes of the vehicle, and also to acquire simultaneously the contents of the traffic information the driver received.
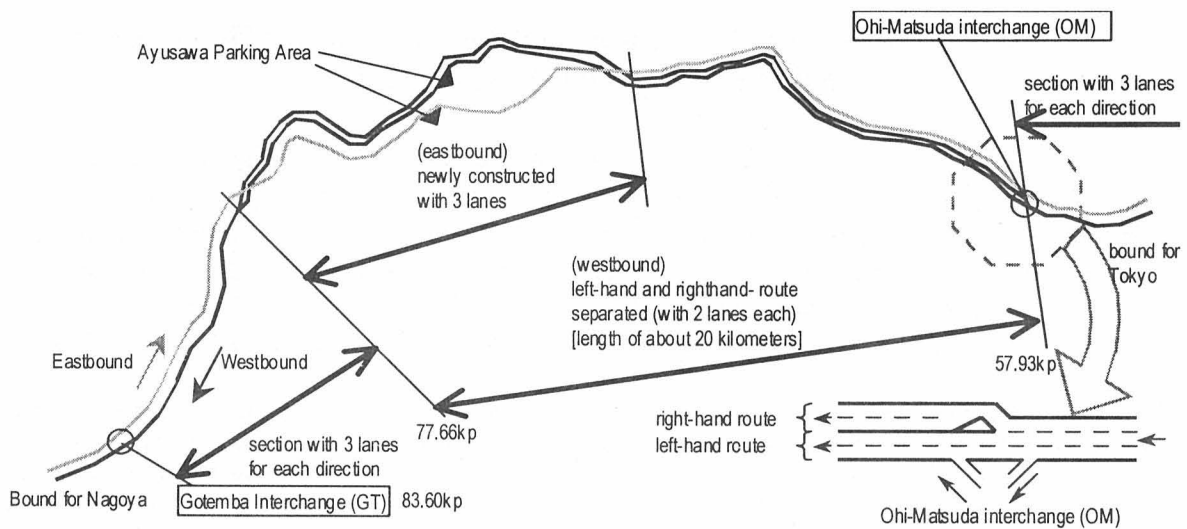
Figure 1 Road network under study on Tomei Expressway between OM and GT.

Second, the observation of traffic conditions is based on information obtained by sensors arranged densely along the lanes of expressways, but the sensor observation locations are very limited and other locations have no sensors to observe the traffic conditions with sufficient precision. Therefore, where there is a large number of drivers, whose origin-destination pairs and routes are widely distributed, it is difficult to obtain useful traffic information easily. Third, because of the restrictions of such the sensor installation locations, sensors cannot be fully covered over a road network.

3. The objective road section condition

3.1. General condition

The section under study is one example of a location at which three difficulties mentioned above are resolved to some extent. The road network is very limited, with one origin-destination pair with a choice of two routes, all vehicles must choose one of the two routes, and the result of the choice can be observed as traffic volume on those routes. The traffic state variables on those routes are available every 5 minutes for every 2 kilometer stretch of road, and traffic information for the routes is shown on the Variable Message Sign (VMS) boards installed upstream of the point of divergence. When there are very high traffic demands such as during the early summer holidays (called Golden Week in Japan), interaction among route choice behavior, traffic volume on those routes, and the presentation of travel information on VMS boards is observed to occur. Traffic demand concentration on one route will lead traffic congestion on the route, then the concentration causes traffic congestion on the route, and the congested condition of this route is displayed as traffic information

on the VMS boards, and the display of information leads to change of route choice behavior as a result.

3.2. Road network

On the Tomei Expressway, which is one of the most important inter-city radial expressways westbound from Tokyo, there are three lanes in each direction (westbound and eastbound) for the length of 35 kilometers from the Yohga (YG) interchange (starting point of Tomei Expressway) to the Atsugi (AG) interchange. However, there used to be two lanes for each direction beyond AG. At that time, there were many bottlenecks caused by excess traffic demand along the section of two-lane roadway in each direction, between AG and the Gotemba(GT) interchange, therefore traffic congestion occurred at the bottlenecks and long queues often formed which last for long periods. The distances from the starting point of an expressway are generally expressed in 'kilometer post (kp)' in Japan; the kilometer posts of YG, AG, OM, and GT are 0 kp, 35 kp, 57.9 kp, and 83.6 kp, respectively.

Therefore, currently, the section between AG and GT, a length of about 50 kilometers, now has six lanes in both directions (parts, seven lanes), as a result of reconstruction works which increased the number of lanes. However, there is a mountainous district between OM and GT, and two tunnels of two-lane width were already dug for both directions and also the roadways for both directions in some sections were built as separate structures upstream and downstream of the tunnels, and therefore it was not always possible to add one lane on the outside of each two-lane roadway. In the eastbound direction, a newly established roadway with three lanes has been constructed, and in the westbound direction, the former eastbound section with two-lane has changed in use in the westbound direction; as a result there is a total
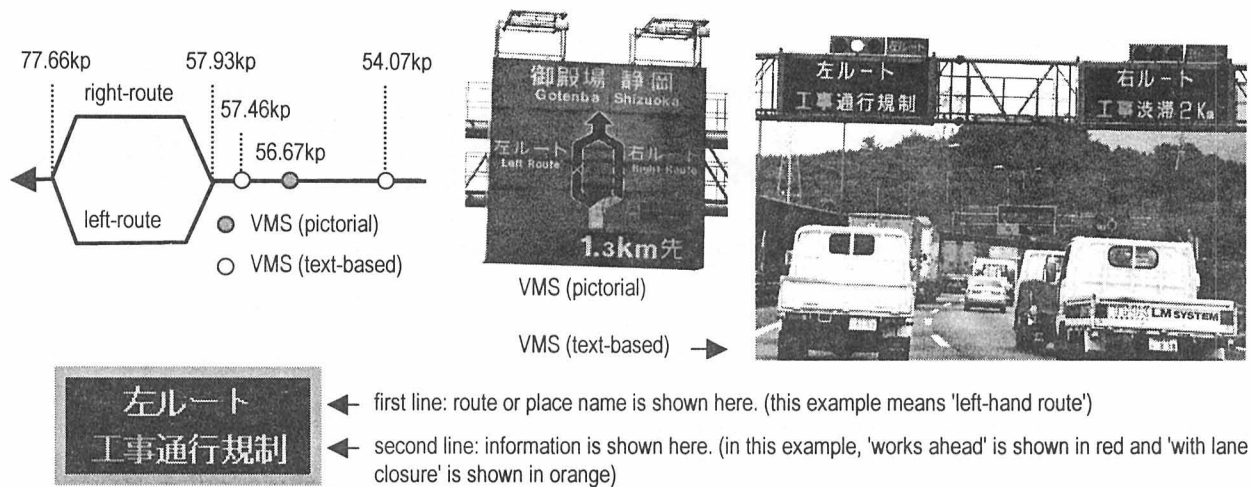
first line: route or place name is shown here. (this example means 'left-hand route')

second line: information is shown here. (in this example, 'works ahead' is shown in red and 'with lane closure' is shown in orange)

Figure 2 Locations and contents of pictorial-type VMS and text-based VMS.

of four lanes. However, the westbound section cannot be operated uniformly as a four-lane roadway for its total length, since it diverges into two separate routes, the right-hand route which is the former reverse direction and the left-hand route, and each has a two-lane roadway; in the downstream section after the end of the separated section, they join again and there are three lanes of unified traffic operation.

Figure 1 depicts the condition around this section of the Tomei Expressway. Since they cannot get on or off the separated section, westbound drivers can choose either route arbitrarily regardless of their destination, but they must choose only one of the routes.

In addition, the point of divergence to right-hand route and left-hand route is located near the Ohi-Matsuda (OM) interchange, therefore only the left-hand route can be used by drivers coming from the OM interchange in the case of normal operation. Moreover, the Ayusawa parking area is accessible only from the left-hand route, and therefore the right-route and the left-route are not completely equivalent for the driver desiring to use the parking area.

3.3. Traveler information system

Route guidance for the diverging section and lane guidance are provided by several guidance signs which are repeated upstream of the point of divergence in order to call attention to it. In addition, VMS boards are installed to offer information about the traffic conditions on the two separated routes. Figure 2 shows the installation positions and the contents of those VMS boards.

There are two kinds of VMS; pictorial VMS and text-based VMS. A pictorial VMS board is located at one position, text-based VMS boards are located at two positions, and there is a pair of text-based VMS boards at one position as shown in figure 2. Each of the VMS

boards can provide information about traffic congestion, road works, accidents or other incidents, etc. in a predetermined format, and this information is updated every 5 minutes (formerly, now 1 minute).

In addition, similar information on both routes is provided by road-side radio broadcast ('highway radio') and is accessible by telephone ('highway telephone'), and is also received by VICS on-board equipment [4].

3.4. Data for the analysis

There is a total of four lanes in the separated section, and three lanes upstream and downstream of this section. Because of the widening from two lanes, recurrent traffic congestion due to traffic demand concentration at capacity bottleneck has rarely occurred with completion of the reconstruction in 1992. However, during the 'Golden Week' holidays at the beginning of May and during the summer holiday season in August, in 2000, 2001 and 2002, queues formed from the GT interchange or other bottlenecks located downstream, and extended to the separated section, on one or both routes. On those occasions, the VMS boards provided traffic congestion information; drivers looking at the VMS boards changed their route choice, and therefore there were sharp fluctuations in the route utilization rate. Analyses for the purpose of this study was performed on May 3 and August 12 in 2000, and May 4 and August 10-11 in 2001, when these phenomena occurred.

Sensors (vehicle-detectors) are installed at intervals of about two kilometers, and there are nine sensors for each of the separated routes (a total of eighteen sensors). At the OM and GT interchanges, sensors are installed only on the outflow ramp (off-ramp) from the main routes. Although only traffic volume is observed by this sensor, the sensors on the main routes can measure not only the traffic volume but also the average speed of traffic every 5 minutes, with the identification of both large vehicles
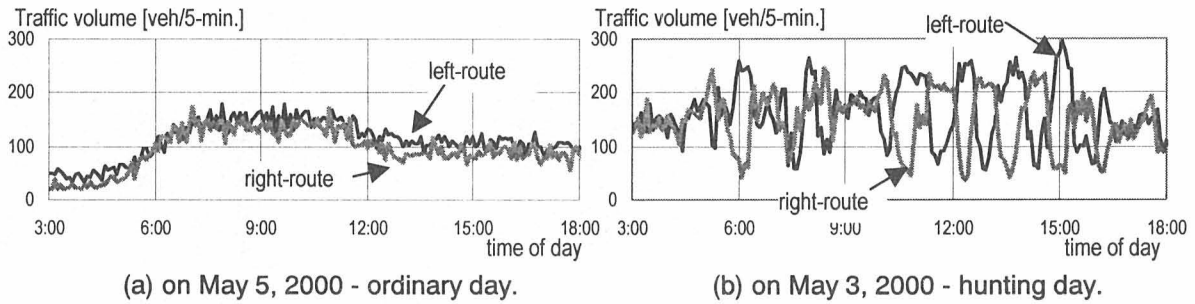
(a) on May 5, 2000 - ordinary day.　　　(b) on May 3, 2000 - hunting day.

Figure 3 Examples of the volume change at 62.64kp(left-hand route) and 62.85kp(right-hand route).

(5.5 meters or more in length) and small vehicles for every lane. The sensors not only on the separated section but also those on the upstream and downstream are investigated in order to analyze the traffic conditions, the generation position and time of traffic congestion (bottleneck), the extension and reduction of queue length, and so forth, on the days under study.

The content of information displayed every 5 minutes on the text-based VMS boards is collected on the days under study. For the purpose of comparison, traffic condition data for ordinary days (without any traffic congestion) is also collected on a total of seven days, including both weekdays and weekends, in May 2000.

4. Analysis of traffic conditions

4.1. Traffic conditions on ordinary days

Although the route choice behavior of each driver cannot be observed directly by vehicle detectors, the route utilization rate can be calculated by measuring the traffic volume on both routes. Here, the sensor installed at 62.64 kp on the left-hand route, and the one at 62.85 kp on the right-hand route are used for estimating the route utilization rate because these two sensors are located at the almost equivalent points.

The left-route utilization rate ($\hat{r}_l$) can be estimated every 5 minutes by using the next equation.

$$\hat{r}_l = \frac{\hat{Q}_{dn}^l}{\hat{Q}_{dn}^l + Q_{dn}^r} = \frac{\left(Q_{up} - Q_{off}\right) - Q_{dn}^r}{\left(Q_{up} - Q_{off}\right)} \tag{1}$$

where, Q_{dn}^r is the volume observed on the right-route by the sensor at 62.85 kp,

$\hat{Q}_{dn}^l$ is the volume estimated on the left-route,

Q_{off} is the volume observed on the off-ramp at the OM interchange,

Q_{up} is the volume observed at 57.31 kp, on the section immediately upstream of the point of divergence.
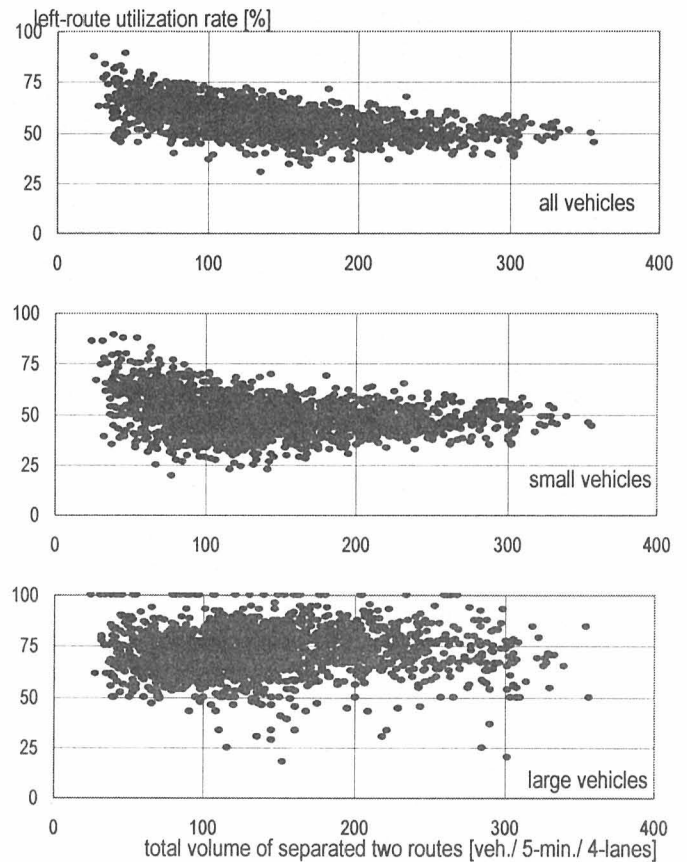

Figure 4 Relationship between total volume and route utilization rate on ordinary days.

However, equation (1) is not valid in the case of volume at 5-minute intervals for real conditions with traffic flow fluctuation because of the difference in installation positions and in the arrival time of traffic at the positions of the sensors. In addition, the volume observed by the sensors contains observation error. Therefore, the left-route utilization rate value estimated using equation (1) is not necessarily precise. With respect to these conditions, the simple ratio of the left-route volume at 62.64 kp to the total volume at 62.64 kp of the left-hand route and at 62.85 kp of the right-hand route is defined as the 'actual left-route utilization rate'

text-base VMS for left-route		text-base VMS for left-route
Left-route ahead queue length 3km	11:00	right-route to GT queue length 10km
	11:15	right-route to GT queue length 8km
		ahead of merging point to GT queue length 6km
		ahead of merging point queue length 2km
Left-route queue length 14km	11:30	right-route queue length 4km
Left-route queue length 11km		ahead of merging point queue length 2km
Left-route queue length 6km	11:45	
	12:00	right-route queue length 4km
Left-route queue length 4km		right-route queue length 6km
	12:15	right-route queue length 8km
Left-route queue length 8km	12:30	
Left-route queue length 11km	12:45	ahead of merging point queue length 6km

Figure 5 Example of contents of text-base VMS board at 57.46kp on May 3, 2000.

(r_l) shown in equation (2). The authors implicitly use the 'actual' r_l defined in equation (2) below.

$$r_l = \frac{Q_{dn}^l}{Q_{dn}^l + Q_{dn}^r} \qquad (2)$$

where, Q_{dn}^l is the volume observed on the left-hand route by the sensor at 62.64 kp.

In the case of using the daily traffic volume instead of the 5-minute volume, it is known that the actual left-route utilization rate (r_l) is higher than the estimated left-route utilization rate ($\hat{r}_l$) by about from 3 to 4 percent.

Figure 3 shows the two different cases of traffic volume change with time, one is for a normal day and the other is for a special day with frequent and drastic changes discussed in detail later. Figure 3(a) shows the fluctuation with time of the traffic volume measured by the two sensors on the left-hand route and the right-hand route on May 5, 2000, which is an example of an ordinary day. Although the traffic volume becomes higher than about 150 [vehicles/5-minutes/2-lanes]

during the morning on this day, traffic congestion does not occur on either the right-hand route or the left-hand route. It turns out that the utilization rate of each route is almost the same.

Figure 4 shows scattered plots of the total volume of the separated two routes versus the left-route utilization rate for every 5 minutes on the seven ordinary days, including the day shown in Figure 3, excluding special conditions such as those associated with construction works and accidents or other incidents. Although the ratio of the drivers choosing the left-hand route is confirmed to be higher than 50 percent at low total traffic volumes, the right-route utilization rate increases as the traffic volume increases. It is found that the left-route and right-route utilization rates become almost the same when the total traffic volume exceeds about 200 [vehicles/5-minutes/cross-sectional 4-lanes].

Figure 4 also shows the left-route utilization rate for each vehicle type; large vehicles and small vehicles. Although the left-route utilization rate for small vehicles (mainly passenger cars) is almost the same as that for all vehicles, the left-route utilization rate for large vehicles is high than that for all vehicles. The correlation between total traffic volume and the left-route utilization rate for large vehicles is not clear. The reasons why the tendency of route choice behavior for large vehicles differs slightly from that of the small vehicles are that a climbing lane for slower vehicles is designated only on the left-hand route, large goods trucks are guided on to the left-hand route with a guidance sign, and there is a regulation stating that large goods trucks must keep running in the most left-hand side lane on a expressway with three or more lanes for one direction.

The frequency distribution of the left-route utilization rate for the cases of total vehicles, small vehicles, and large vehicles can be approximated to normal distributions. The averages for the cases of the total, small, and large vehicles are 54%, 47%, and 73%, and the standard deviations are 6.4 %, 7.5 %, and 10.8%, respectively (total number of samples is 1471 for each case).

4.2. Traffic conditions with traffic congestion on either route

Figure 3(b) shows the fluctuation with time of the traffic volume measured by the sensors on the right-hand route and the left-hand route on May 3, 2000. Upon comparison with Figure 3(a), it is evident that traffic volumes of the left-hand route and right-hand route have repeated alternate increases and decreases from 6:00 in the morning to 18:00 in the evening. Although the volume of each route reaches about 150 [vehicles/5-minutes/2-lanes] at the maximum in Figure 3(a), in Figure 3(b) there is a period of time when the traffic volume inclines so extremely that the volume of one
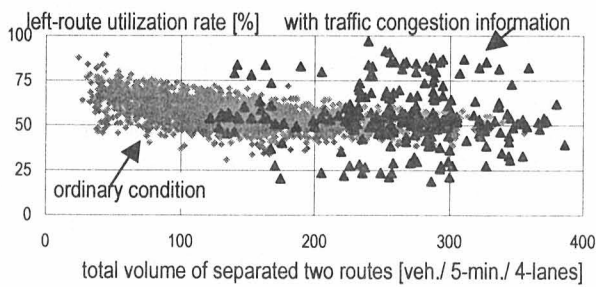
Figure 6 Relationship between total volume and route utilization rate on the day with traffic congestion.

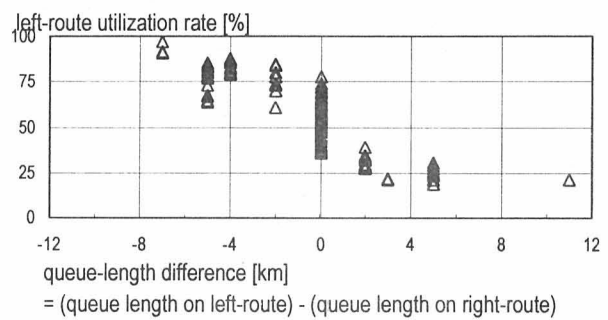= (queue length on left-route) - (queue length on right-route)

Figure 7 Relationship between queue-length difference and route utilization rate.

route reaches about 250 [vehicles/5-minutes/2-lanes] or more while that of the other route falls below 100 [vehicles/5-minutes/2-lanes]. This inclination in traffic volume toward a particular route has alternated in turn with time, from right-route to left-route and vice versa, and this phenomenon is called the 'hunting phenomenon'. This phenomenon was already known in many traffic simulations or in experimental studies in laboratories, but this study shows the phenomenon quantitatively in an actual traffic for the first time.

Figure 5 shows examples of the contents of information displayed on the text-based VMS board at 57.46 kp, the upstream location nearest to the point of divergence, on the same day as shown in Fig. 3(b). Comparing Figure 3(b) and Figure 5, it is very clear that the traffic volume becomes concentrated on the route where the traffic information has indicated a relatively short queue length compared with that on the other route at the same time. Therefore, it can be interpreted that drivers looking at the VMS boards make a route choice in order to avoid traffic congestion, and then traffic volume begins to increase on the route where there was previously little traffic congestion, and the sharp inclination of the route utilization rate occurs.

5. Traffic information on VMS boards and route choice rates

5.1. Hypothesis and analysis framework

The authors deal only the case when the traffic information shown on the text-based VMS boards indicates queues but no incidents on either route, and the heads of the queues displayed for both routes are the same, i.e., the bottlenecks of the two queues are the same. Drivers looking at the VMS boards can simply compare the lengths of the queues for the two routes. The information about route or position name shown in the first line of the text-based VMS is fixed and only shows the route name, such as 'left-hand route' or 'right-hand route'. Therefore, we can simply evaluate the effect of

queue length and/or the difference in queue length between the left-hand route and right-hand route. The bottlenecks that cause queue(s) both or either routes are mostly around the GT interchange.

It is about 5 km from the 57.46kp where the text-based VMS boards are located upstream of point of divergence, to the position of the sensors (left route 62.64kp, right route 62.85kp) with which the route utilization rate is calculated. It takes about five minutes at 60 km/h and three minutes at 90 km/h to travel along 5-km-long section. Therefore, the information shown on the VMS boards should not be correlated with the route utilization rate calculated in the same 5 minute time-slice. The route utilization rate calculated by the sensors at a certain 5 minute time-slice should be compared with the information shown on the VMS boards in the previous time-slice. For example, the route utilization rate at 7:30 should be compared with the information shown at 7:25. When the information of a certain 5 minute time-slice is changed from that of the previous time-slice, the drivers, looking at the information of these two time-slices, can be intermingled, therefore the left-route utilization rates of these time-slices are ignored. In addition, when the queue length of traffic congestion is extended to the sensor(s) on both or either routes with which the route utilization rates are calculated, the data in this case is ignored, because the data does not indicate the route choice behavior.

5.2. Influence of traffic volume

Figure 6 shows the relationship between the total volume of the separated two routes versus the left-route utilization rate every 5 minutes, on the day shown in figure 3(b) with hunting phenomena, with the same relationship on an ordinary days shown as a light color. When traffic information about traffic congestion is shown on the VMS boards, the relationship between the total volume and the route utilization rate scatters much compared with those on ordinary days. This means that the route choice behavior of the drivers who are affected by the traffic congestion information shown on the VMS
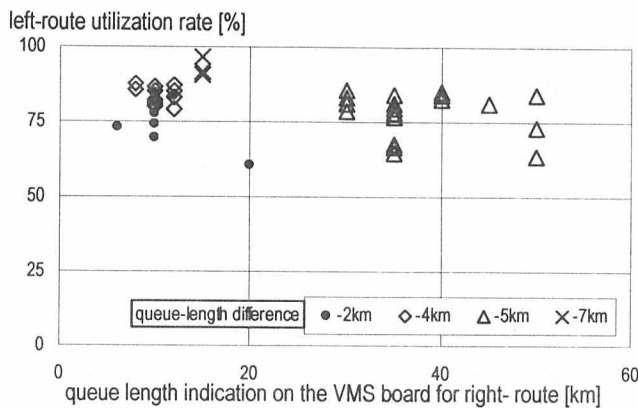
Figure 8 Relationship between queue length indication on VMS for right-route and left-route utilization rate.

boards change from that with no traffic congestion information.

5.3. Influence of queue-length difference on the VMS boards

The queue-length difference is defined as the subtraction of the queue length on the right-hand route as shown on the text-based VMS board from the queue length on the left-hand route as shown on the text-based VMS board. Figure 7 shows the relationship between the queue-length difference and the left-route utilization rate. Although there is considerable variation in the left-route utilization rate, it is evident that there is a general tendency for drivers to choose the route with the shorter queue length when the queue-length difference becomes large. Sometimes a very extreme inclination of route use occurs forward the route with shorter queue length, perhaps more than 90 % or less than 20 % of the left-route utilization rate. However, the average of the left-route utilization rate corresponding to the negative 5 km queue-length difference is slightly smaller than the value expected roughly by the general tendency.

5.4. Influence of queue-length on the VMS boards

Figure 8 shows the relationship between the queue length itself shown on the text-based VMS boards for the right-hand route, and the left-route utilization rate, in the case of negative values of queue-length difference (-2km, -4km, -5km, and -7km). When the value of queue-length difference is equal to negative 5km, traffic congestion information indicating a queue with length as long as 30 km or more is shown on the VMS board for right-hand route. On the other hand, with other values of queue-length differences, traffic congestion information indicating queues with length as long as 20 km or less.

Therefore, not only the queue-length difference between the two routes but also the queue length itself shown on the VMS board is found to have some influence on route choice behavior.

It is evident that the feature of route use to the route with the shorter queue length is weaker in the case of a relatively long queue length compared with the case of a relatively short queue length with the same queue-length difference. In the case of a relatively short queue length, the effect of queue-length difference on route choice behavior is significant (high sensitivity). When the queue length becomes long, the effect of queue-length difference on the behavior becomes relatively small (low sensitivity) even if the absolute value of queue-length difference becomes large.

6. Conclusion

The effects of traffic information shown on text-based VMS boards are analyzed along with actual drivers' behavior and roadway traffic conditions. The effects of queue-length difference and queue length itself become clear. The hunting phenomenon should have certain total lost time compared with the optimum traffic condition that results in smaller total lost time. Therefore, the effective technology of ITS with 'intelligent' information such as predicted information provided by on-board information equipments, which enables optimum traffic condition, should be investigated.

Acknowledgments

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