A STUDY ON FACTORS THAT DETERMINE THE EFFECTIVENESS OF TOLL DISCOUNTS

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ABSTRACT

In Japan, the low ratio of use of expressways causes various social problems including congestion on general roads running parallel with the expressways, worsening of the roadside environment and traffic safety. One reason why expressway usage is so low is that most expressways in Japan change tolls, which drivers tend to feel are too expensive. Diverse and flexible toll measures are being implemented to make Japan's expressways more user friendly and encourage drivers to use them more often. In this study, we analyzed the effects of such toll measures on expressway of traffic volume. Our analysis revealed that (1) for the country as a whole, it is the index of traffic congestion on general roads running parallel with expressways that affects the volume of traffic on expressways; (2) in the case of commuter and business traffic, it is the existence of large cities that affects the volume of traffic on expressways; and (3) in the case of through traffic, it is the time when drivers enter expressways and the ratio of large vehicles on general roads running parallel with expressways that affect the volume of traffic on expressways. In the future, we intend to apply the results of this study to make additional proposals for more diverse and flexible toll measures.

1. INTRODUCTION

The ratio of use of expressways in Japan is lower than that in European countries and North America, as potential users of expressways choose to drive on general roads instead. This has caused various social problems, including congestion, deterioration of the roadside environment, and traffic accidents on general roads running parallel with expressways.

One possible explanation for the unpopularity of expressways is that drivers hesitate to pay high fees to use them. Expressways in Japan have been built under a toll road system in which the construction and other costs of building the expressway are covered by borrowed money, which is then paid back from the revenues raised by collecting tolls after the expressway is built. Consequently, the high toll fees charged for using the expressway discourage drivers from using it. To resolve this problem, diverse and flexible toll measures are being implemented under which traffic demand when general roads running parallel with expressways are congested is managed by lowering the tolls charged by expressways that can accept more traffic.

This paper examines the trend of growth of traffic volume on expressways and identifies factors that affect this growth trend when a toll discount is implemented.

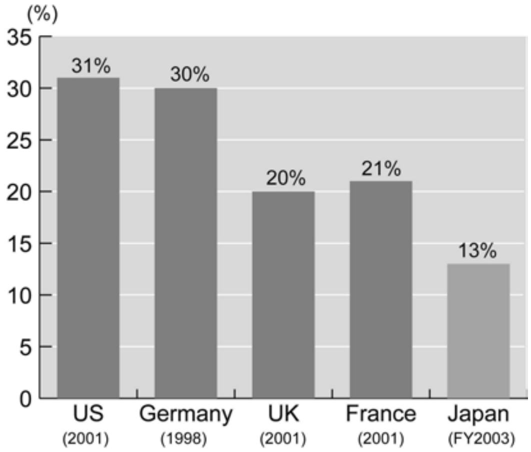

Figure 1 - Comparison in percentage of use of expressways

2. IMPLEMENTAYION AND EFFECTS OF TOLL DISCOUNTS

2.1. Implementation of toll discounts

In 2003, the Ministry of Land, Infrastructure and Transport set up demonstration projects related to toll road fees and implemented toll discounts including demonstration projects proposed by regional bodies all over JAPAN. Since 2004, policy proposals for toll systems have been made to establish diverse and flexible toll systems implemented by the four road-related public corporations. On the basis of these demonstration projects and policy proposals, as well as in order to pass on to users the benefits of privatizing the four road-related public corporations, toll discounts are now available for only ETC users on national expressways.

In this study, we analyzed the effects of offering discounts for the demonstration projects proposed by regional bodies and toll discounts for only ETC users on national expressways.

2.1.1 Demonstration projects proposed by regional bodies

Between 2003 and 2006, a total of 83 demonstration projects proposed by regional bodies were conducted. Under the scheme of these demonstration projects, after the national government first makes a public offering and selects a project, a council comprised of local bodies and others conducts projects in which toll methods tailored to meet the unique local needs of individual regions are set up. In addition, an agreement is entered into with organizations undertaking toll road works concerning various matters including keeping the cost low enough to ensure that the profitability of the expressway is not affected. Moreover, the national government bears part of the cost of the projects, including for keeping the cost low.

2.1.2 Toll discounts for only ETC users on national expressways

In 2004, accompanying the privatization of the four road-related public corporations, in order to pass the benefits of cost reductions on to users, a toll discounting system was implemented. The discount applies only to those vehicles equipped with an ETC device. Discounts are given in the form of mileage discounts to promote the use of expressways and their benefits based on actual expressway usage and time discounts to utilize national expressways which can accept more traffic. There are two types of mileage discount: (1) discounts for general users and (2) discounts for large and frequent users. There are three types of time discount: (1) community discount, (2) midnight discount, and (3) early morning and nighttime discount. The community discount effectively utilizes expressways that can accept more traffic during morning and evening peak rush hours when general roads running parallel with national expressways are congested. The early morning and nighttime discount optimizes the balance of daytime traffic when expressways are congested and nighttime traffic when expressways have room to accept more traffic. The midnight discount traffic promotes midnight use of expressways throughout Japan when they have room to accept more traffic.

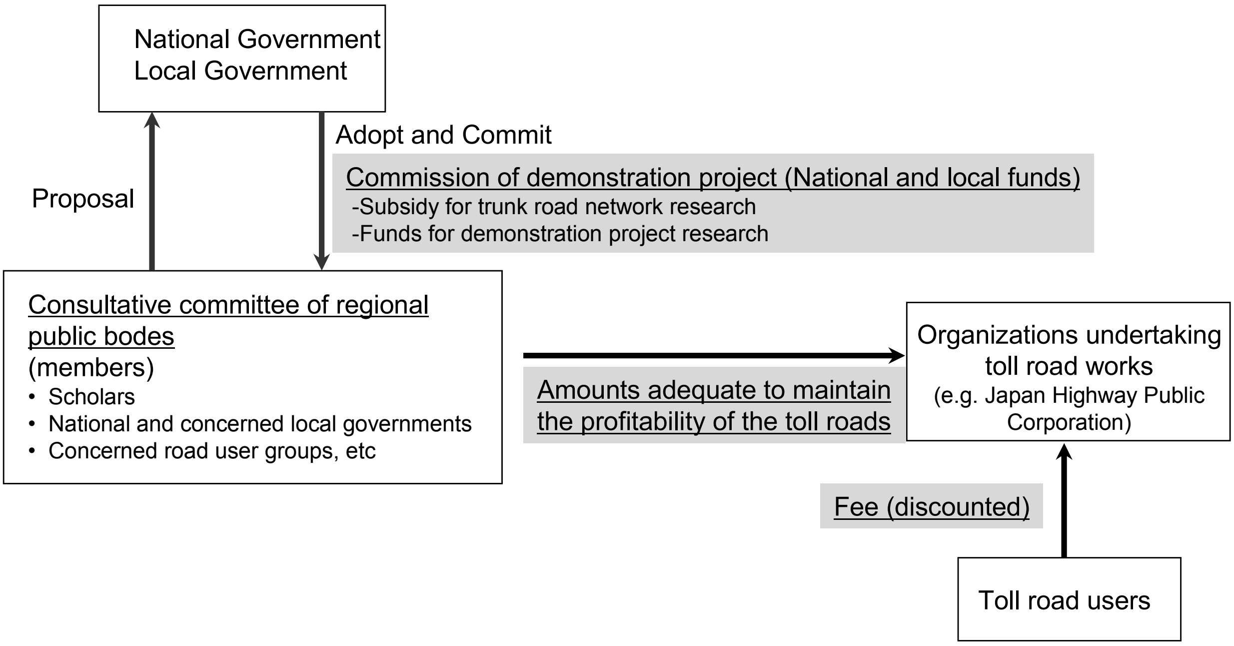

Figure 2 - Scheme of the demonstration projects proposed by regional bodies

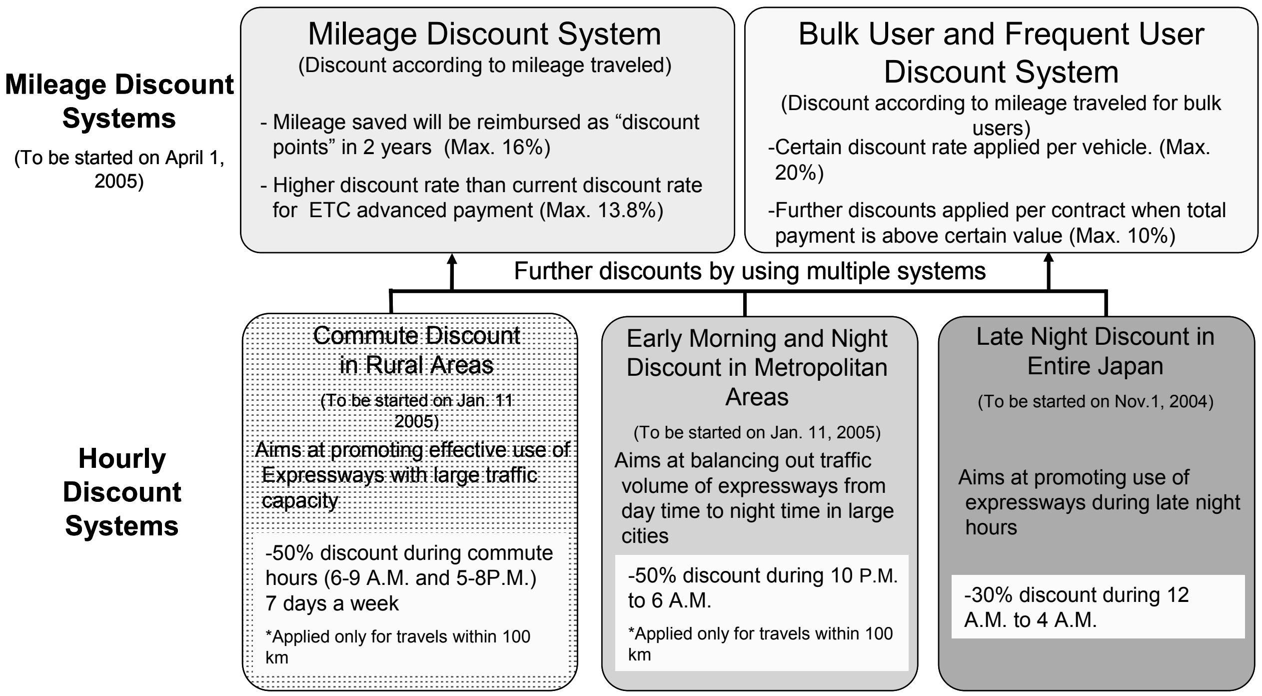

Figure 3 - Toll discounts for only ETC users on national expressways (as of March, 2007)

2.2. Effects of toll discounts

The toll discounts for only ETC users on national expressways were introduced in 2005. In that year, we analyzed the relationship between the usage ratio of time discounts by prefecture and the ratio of expressway use. The time discount was divided into five categories according to the extent of usage. A comparison of the average ratio of expressway use for each category reveals that the regions with higher ratios of discount usage tend to have a higher rate of increase in expressway use, suggesting that the discount is helping to increase the rate of expressway use. Accidents occur less frequently on expressways than on general roads and CO2 emissions are also lower. Thus, if the use of expressway rises, accidents and CO2 emissions should decrease in theory. Additionally, many have observed an increase of expressway use and reduction of traffic volume on general roads, thus easing traffic congestion.

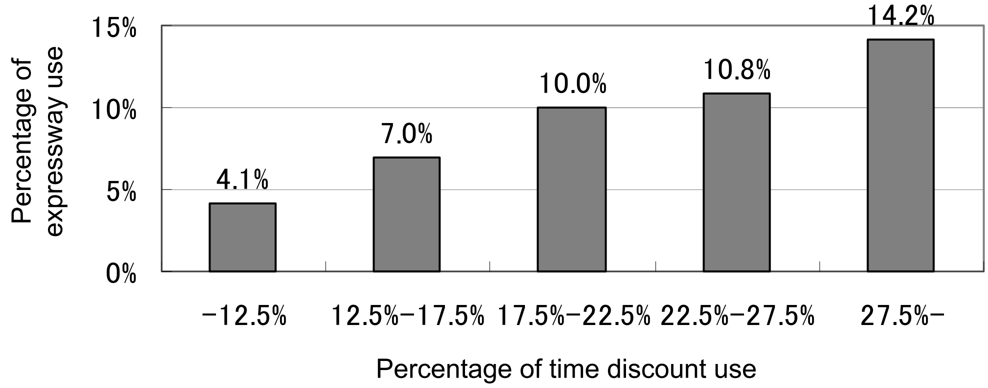

Figure 4 - Relationship between percentage of time discount use and use of expressways

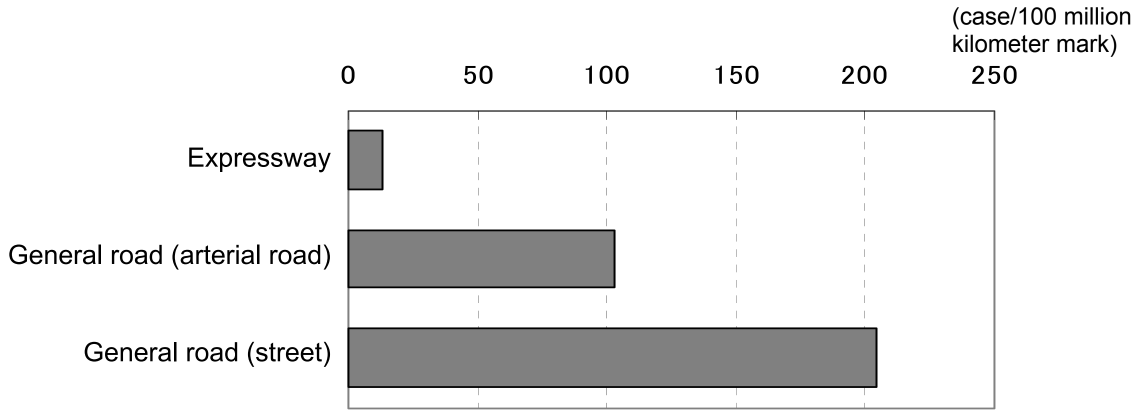

Figure 5 – Rate of accidents by type of road

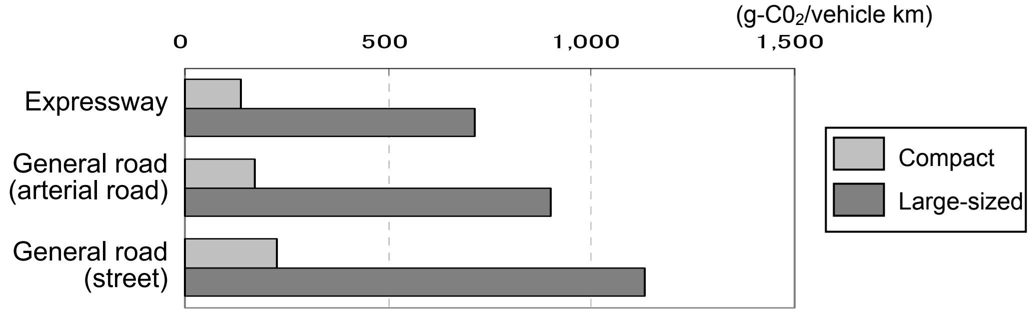

Figure 6 - Source of CO2 emission by type of road

3. ANALYSIS OF EFFECT OF TOLL DISCOUNTS

With regard to the time discount for only ETC users on national expressways and demonstration projects proposed by regional bodies, we analyzed the relationship between the trend toward increased traffic volume on expressways and some indexes of general roads running parallel with them. Regarding the time discount for only ETC users, we analyzed the commuting discount.

3.1. Analysis of the relationship between growth of cross section traffic volume on expressways and traffic congestion

With regard to the time of day (6 am – 9 am and 5 pm - 8 pm) when the commuting discount is given, we analyzed the relationship between the increase in cross section traffic between exits (2005/2004) and the extent of congestion on expressways and general roads running parallel with them. In calculating the growth of cross section traffic volume between exits brought about by the discount, we used the cross section traffic volume between exits and subtracted from it the cross section traffic volume between exits of vehicles without ETC in 2004 and the cross section traffic volume between exits in 2004 and 2005.

Congestion on expressways was divided into heavy and light categories. The congestion on general roads running parallel with them was divided into heavy, moderate and light categories (Table 1). We compared the average increase in cross section traffic between exits in each of the six categories. The results are shown in Figures 7 and 8. In sections where the congestion on expressways is light (0.4 or lower), we see that the greater the congestion on general roads running parallel with expressways, the greater the growth of

Table 1 - Result of categorization by index of congestion (sample number)

		Index of congestion on expressways	
		Below 0.4	0.4 or higher
Index of congestion on general roads running parallel with expressways	Below 1.0	78	54
	1.0 or higher to 1.5 or lower	93	90
	1.0 or higher	51	93

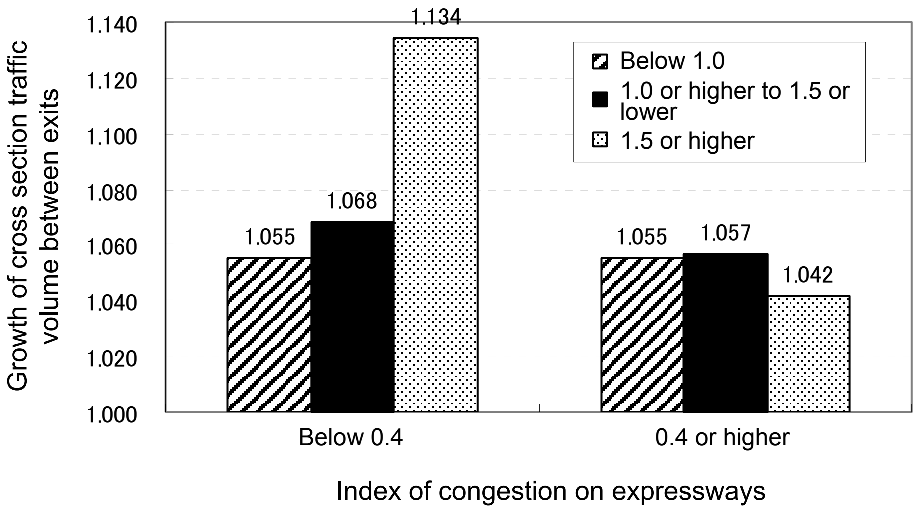

Figure 7 - Relationship between congestion on general roads running parallel with expressways by congestion on expressways and growth of cross section traffic volume between exits

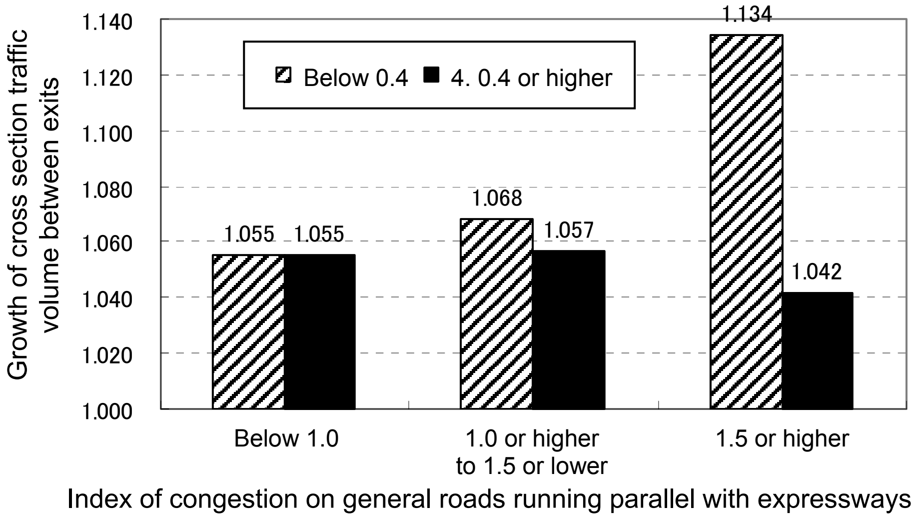

Figure 8 - Relationship between congestion on expressways by congestion on general roads running parallel with expressways and growth of cross section traffic volume between exits

the cross section traffic volume between exits. By contrast, in sections where the congestion on expressways is heavier (0.4 or higher), we do not see much difference in the growth of cross section traffic volume caused by the difference in the index of congestion on general roads running parallel with expressways. Additionally, even when the index of congestion on general roads is the same, we see that the rate of increase in cross section traffic volume between exits is higher on expressways with light congestion than on those with heavy congestion. From these findings, we can see that congestion on expressways and congestion on general roads running parallel with them are one of the factors of the decision of drivers to switch from general roads to expressways. Particularly, in case an expressway has a relatively large capacity to accept traffic and the general road running parallel with it is congested, drivers are more likely to be persuaded by a discount toll to switch to the expressway. Conversely, drivers are less likely to switch when the expressway is congested or the general road running parallel with it is not very congested.

3.2. Analysis of influence of regional characteristics

In a past study, W. Matsuda [1)] categorized by traffic characteristics the regions where the demonstration projects proposed by local bodies are to be conducted, identified the regional characteristics by type, and analyzed the principal findings of the demonstration and the ways they are manifested. Matsuda found that only cities with a population of about 50,000 or less exist within the sections categorized as “through traffic type.” On the other hand, in sections categorized as either “commuter/business type” or “mixed type,” there are cities with a population of at least 100,000 or more. Additionally, in the demonstration of sections categorized as “through traffic type,” the distance from a general road to a terminal exit was very short, between 0 to. 0.7 km. On the other hand, in the demonstration of sections categorized as “commuter/business type” or “mixed type,” in part because the expressways are generally built to circumvent urban areas, the distance from a given urban area to the nearest exit is, at 1.2 km to 7.5 km, not very close. On the basis of these findings, Matsuda maintained that the different ways in which the effects of the demonstration are manifested are influenced by regional characteristics.

In our study, for the “commuter and business traffic types,” we analyzed the time discount for only ETC users, and for the “through traffic type,” we ascertained the quantitative growth of traffic volume by applying the results of the demonstration projects we have conducted to date.

3.2.1 *Analysis of commuter and business traffic*

First, we compared the association between population size and the sections where the effects of the commuting discount are manifested or not. Here, we used the number of exit users as an index representing the size of the population. The targets of our analysis were OD (origin-destination) pairs between exits presumably with the most number of commuter users and no more than 50 km between origin and destination. The exits were divided into groups and assigned ranks (A-E) in accordance with the number of vehicles that use them, starting with the exit having the most users, so that each of the five ranks would have the same number of users. As an index showing the manifestation of the effects of giving the commuting discount, the top 10 percent or 371 OD pairs were tabulated in terms of the five ranks by size of city, and the value obtained by dividing the results of that tabulation by the number of OD pairs in the total number of user vehicles was employed.

The results are shown in Table 2. In the use of expressways covering a distance of less than 50 km, the rate of using the commuting discount is high at exits with a large population (number of user vehicles: 12,728 units/day or more). In particular, there is a high percentage of OD pairs with a high rate of commuting discount use between rank A exits where the population is the largest and group D exits where the population is the smallest. We believe this is because the commuting discount assists communication between the big cities in local areas and the suburbs.

Next, by selecting a number of cities with a population of more than 100,000 so as to avoid regional bias (Table 3), we analyzed the exit pair traffic volume at locations within 100 km from the exit nearest the built-up area of each city. In the analysis, with regard to the exit that is paired with the exit nearest the built-up area of each city, we compared the exit pair traffic volume in July 2004, the year before the commuting discount was introduced, with that in July 2005, the year after it was introduced, for each distance between exits. Since the discount project had not yet started in July 2004, the exit pair traffic volume that would have been targeted by the commuting discount had the discount been introduced was selected for comparison.

Table 2 - Ratio of the top 10 % pairs use of commuting discount that account for all of the OD pairs in sections less than 50 km long

Number of vehicles using exits (no. vehicles/day)	Rank	A	B	C	D	E
12,768 or more	A	10.0%				
6,854 – 12,728	B	13.8%	10.4%			
4,041 – 6,854	C	12.8%	7.0%	6.7%		
2,072 – 4,041	D	15.4%	7.1%	6.9%	7.6%	
132 – 2,072	E	7.8%	4.5%	3.7%	4.2%	0.6%
Average		10.0%				

Table 3 – Cities targeted for analysis

Population size	Names of cities
1 million or more	Sendai, Hiroshima, Fukuoka
500,000 or more to 1 million or fewer	Maehashi + Takasaki, Shizuoka, Matsuyama, Kagoshima
300,000 or more to 500,000 or fewer	Nagano, Wakayama, Takamatsu
200,000 or more to 300,000 or fewer	Fukushima, Matsumoto, Tokushima
100,000 or more to 200,000 or fewer	Yokote, Tsu, Shunan

Figure 9 shows the relationship between increase in traffic volume at exits nearest urban areas and the distances between exits. The average rate of increase is the same for nearly all exits irrespective of the distance between them, but the rate of increase is bigger when the distance between exits is 90-100 km. This result reveals that, since the applicable distance for the commuting discount is less than 100 km, many drivers get off the expressway just before reaching the 100 km point and then drive on a general road, or get straight back on the expressway and resume driving. The average increase becomes big when the distance between exits is 10-40 km, and starts to decrease when it reaches 50 km. From this we conjecture that most drivers who use the expressway commute 40 km or less. On the other hand, the reason the usage is low when the distance between exits is 10 km or less is that, at 10 km, the distance between exits on Japan's expressways is notably long. Additionally, when the distance between exits is 50 km or longer, the volume of traffic increases slightly towards evening. This is probably due to the increase in the number of people returning from work.

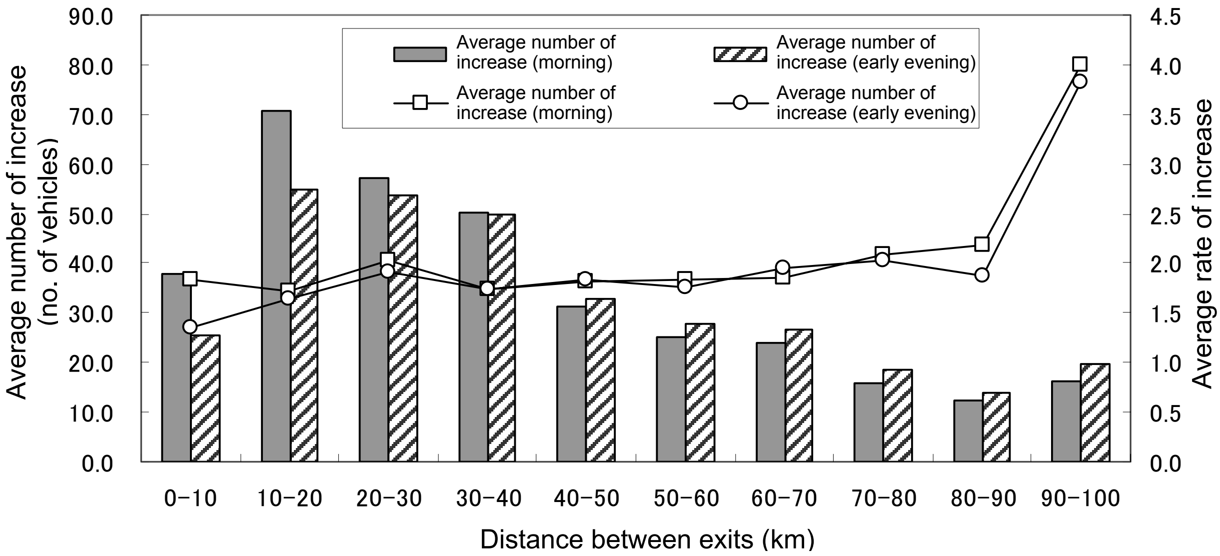

Figure 9 - Relationship between growth of exit pairs nearest urban areas and distance between exits (by morning/early evening)

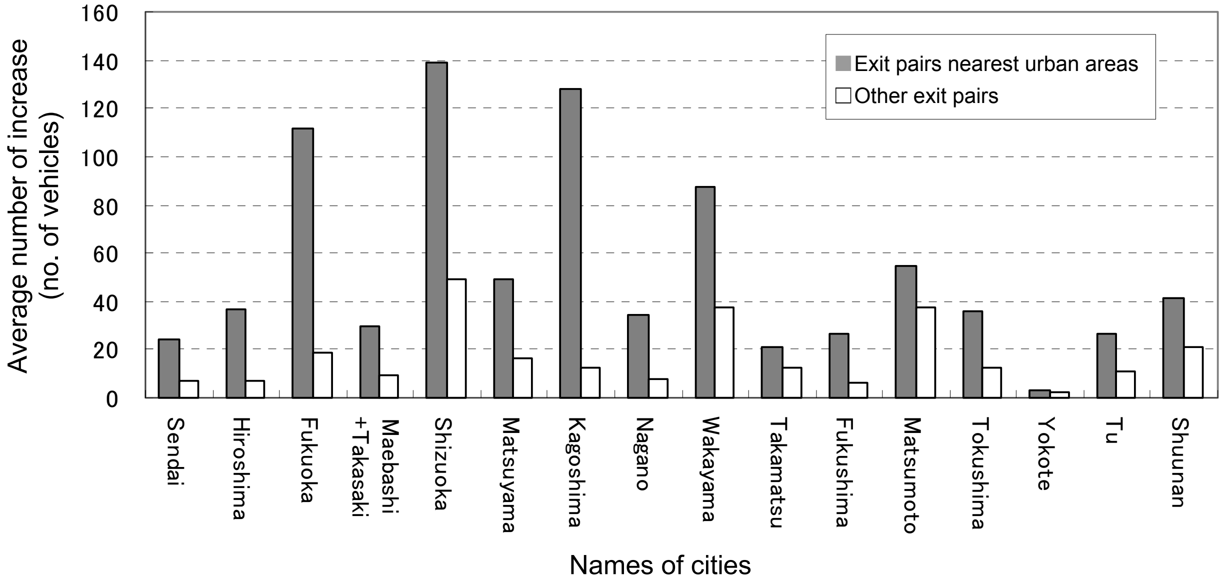

Figure 10 - Comparison of exit pairs nearest urban areas and average number increase of other exit pairs (morning)

In addition, we compared the average increase in traffic volume at the exit pairs nearest the urban area and the traffic volume at other exits pairs by limiting our comparison to exits located within a 50 km radius from the expressway exit closest to the built-up area in each city. The results are shown in Figure 10. In all cities, the increase in average traffic volume at exit pairs nearest urban areas is bigger than at other exits, leading to the conclusion that the effect of providing commuting discounts is substantial for exit pairs nearest urban areas.

3.2.2 Analysis of through traffic

With regard to through traffic, we tabulated the terminal exit pair traffic volume nationwide in sections targeted for toll discounts in the demonstration projects proposed by regional bodies and analyzed the results in relation to the traffic condition on general roads running parallel with expressways. For the analysis, we used the toll elasticity value instead of the increase in traffic volume. The toll elasticity value is an index that expresses the degree of responsiveness of traffic volume to changes in toll, and is represented by the following equation:

$$\text{Toll Rate Elasticity Value} = -\frac{\dfrac{Q'-(Q+Q')/2}{(Q+Q')/2}}{\dfrac{P'-(P+P')/2}{(P+P')/2}} \qquad (1)$$

Q : traffic volume before the experiment
Q': traffic volume during the experiment
P : toll before the experiment
P': toll during the experiment

In addition, as indices that express the traffic condition on general roads running parallel with expressways, we used the large vehicle infusion rate and the access time ratio. The latter is defined by the following equation:

$$\text{Access time ratio} = \frac{\text{Travel time on access road}}{\text{Travel time on access road} + \text{Travel time on expressway}} \qquad (2)$$

Figure 11 shows the relationship between the large vehicle infusion rate on general roads running parallel with expressways and the average toll elasticity value. The large vehicle infusion rate is divided into three categories to ensure the same number of samples is used. A glance at the results reveals that the average toll elasticity value tends to be high in places where the average infusion rate of large vehicles on general roads running parallel with expressways is high. Given that the longer the trip the higher the percentage of traffic volume accounted for by large vehicles (Figure 12), it is possible to say that the traffic rate of a long trip using general roads (the percentage of the cross section traffic that long trips account for) has an impact on the toll elasticity value.

Figure 13 shows the relationship between access time rate and toll elasticity value. Access time rate, like large vehicle infusion rate, is divided into three categories to ensure the same number of samples is used. The results reveal that the toll elasticity value tends to be higher, when the access time rate is lower. This indicates that when extra time is required to access an expressway, it is difficult to switch from a general road to an expressway.

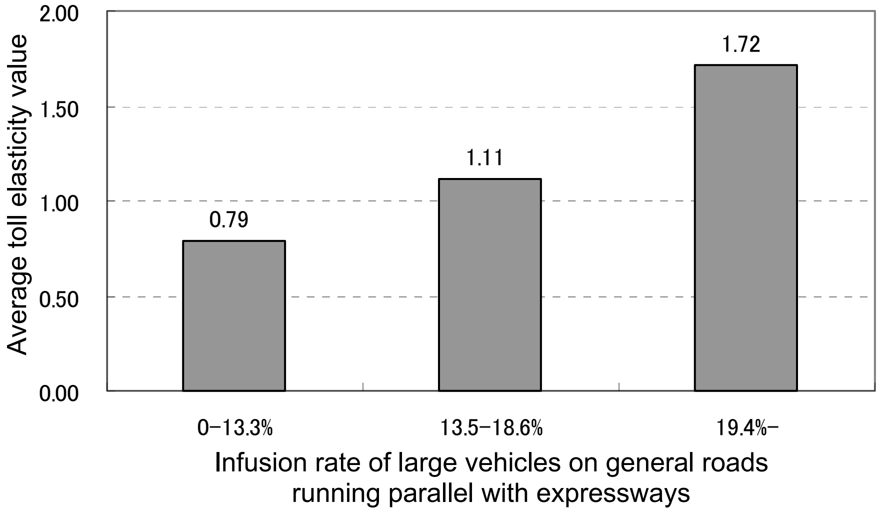

Figure 11 - Relationship between rate of infusion of large vehicles on general roads running parallel with expressways and average toll elasticity value

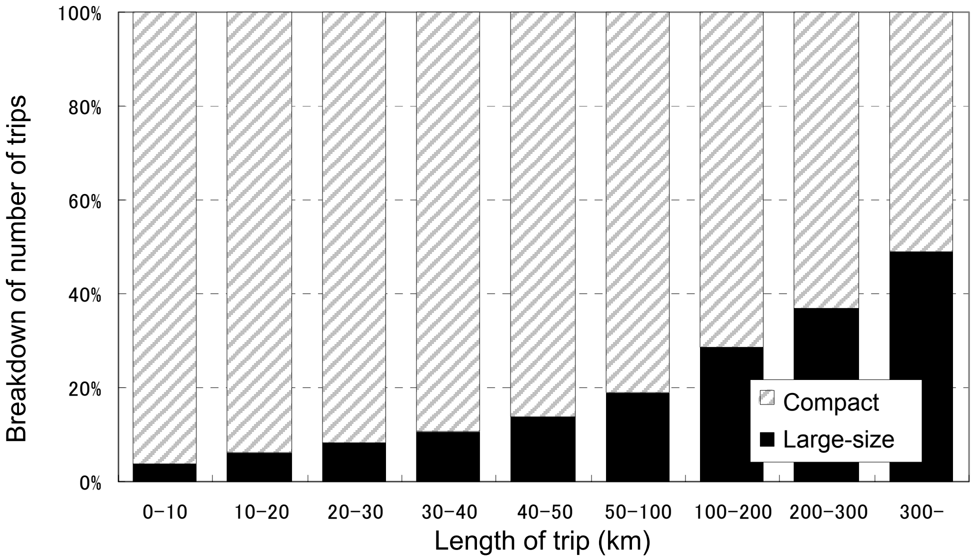

Figure 12 - Breakdown of number of trips by length of trip (by type of vehicle)

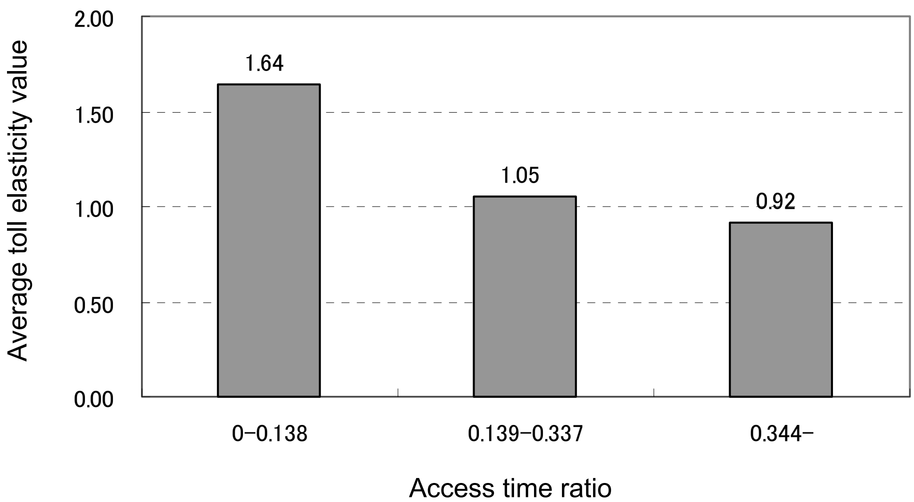

Figure 13 - Relationship between access time ratio and toll elasticity value

4. CONCLUSION

In this study, we stated that the frequency of use of expressways rises when the toll for expressways is discounted. We also stated that the greater use of expressways is expected to help reduce traffic accidents and lower CO2 emissions. The study also suggested the following: (1) the growth of traffic volume on expressways due to toll discounts is affected by congestion on expressways and general roads running parallel with them; (2) dividing traffic into commuter/business type and through traffic type as a regional characteristic reveals that the growth of traffic volume is large in the former when there are large cities and suburbs, especially when the distance between exits within a 50 km radius is long; and (3) in the through traffic type, the growth of traffic volume on expressways is affected depending on (i) the time drivers enter expressways and (ii) the infusion rate of large vehicles on general roads running parallel with expressways.

In Japan, new measures will be formulated from 2008 to efficiently utilize and strengthen the functions of the existing expressway network by lowering the toll charges. In 2007, demonstration projects will be implemented to ascertain the effects and impact of toll discounts. In the near future, we plan to analyze the effects and impact of our demonstration projects by using the results of the present study and to make specific proposals for lowering expressway toll charges.

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