THE EFFECT OF FLEXIBLE TOLLING ON HIGHWAYS

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Abstract

The Japanese government has implemented the pricing experiment on toll roads in recent years. In theory, toll rate of the second best pricing, where the road operator cannot charge all the roads in the network, is often lower than that under the first best tolling. If the cost were set close to the level of the first best tolling, the second best tolling can increase social welfare, while it usually undermines the revenue from tolling. In order to determine toll rates in practice, it is necessary for a road operator to take into account the various outcome of coordinating tolls. The flexible tolling experiment in Japan aims to utilize the uncongested period of toll roads and alleviate the congestion on non-tolled alternative. The result of experiment suggests that the policy can greatly improve not only the mobility of vehicles on non-tolled roads but also the environment of roadside residential areas. It suggests that construction cost based tolling on highways in Japan may severely undermine social welfare in practice. Moreover, the decline of the revenue can be small due to the high elasticity of demand on toll roads.

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1. INTRODUCTION

The expressway network in Japan utilizes toll system in order to realize rapid construction. The current standard toll rates of expressways for passenger cars is 150 yen (approximately US$1.4) plus 24.6 yen (approximately US$0.23) multiplied by kilo-meters travelled. This rate roughly doubles for large vehicles. The level of toll rates has been set so as to finance highway constructions while it considers the idea of 'fairness', which means that the toll should not be unreasonably high.

Due to the slow economy in Japan and advancement in cost management in logistic industry, road users tend to avoid travelling on toll roads. Thus, the high toll has caused traffic congestion, traffic safety problems, and environmental problems on non-tolled alternatives. Therefore, a flexible charging scheme is recognized to be necessary for managing the demand for road transport.

Although the standard pricing theory on highways focuses on the first best pricing where the operator can charge tolls on all the highways in the network, the practical pricing scheme in current technology is applied mostly to some access controlled highways. In current situation in Japan, there is a technical and moral problem of chasing the behaviour of all the movements of the vehicles and charge tolls accordingly. To realize the better welfare of the road users and residents who are affected by road environment and safety, we need to consider the toll level in terms of the second best pricing where we cannot charge all the highways in the network.

Under these circumstances, the flexible toll schemes, such as a discount for off peak hours and long distance use of toll roads, were experimented in fiscal year 2003. This experiment aims to coordinate the traffic volume between toll roads and paralleled non-tolled roads. The result of experiment finds that the flexible toll can be a useful measure to manage the road transport, and the decline in revenue can be small.

This paper is structured as follows. The next section introduces the background of the flexible tolling experiment in Japan. Section 3 analyzes the theoretical description of the flexible tolling and compares the distribution of welfare for the flexible tolling to those for Value Pricing Project in the US. Section 4 describes the result of the flexible tolling experiment in Japan and examines the implication of the experiment.

2. THE EXPERIMENT OF FLEXIBLE TOLLING IN JAPAN

2.1 Development of Toll Roads and Non-Tolled Roads in Japan

The road financing system in Japan after the WWII is quite unique in two aspects. Firstly, road development is supported by the earmarked funds derived from the fuel tax revenue. Secondly, Japanese highway system consists of many tolled access-controlled roads, while most developed nations adopted free highways and trunk roads at that time. The reason for this financing system is the underdevelopment of road system. In 1956, the Watkins Commission from the World Bank for Japanese road investigation, wrote in its report as follows: "The roads of Japan are incredibly bad. No other industrial nation has so completely

neglected its highway system." In fact, two thirds of the National Highway Route 1 connecting Tokyo and Osaka, which were two largest cities in Japan, was paved. As a result, although the first automobile arrived in Japan in 1899, automobiles were not used widely before the WWII. Following their advice, the Japanese government began rapid development of road networks. After 1970s, the society became more car-oriented, and the number of automobiles has been increasing continuously. In 2002, the number of vehicles-owned reached 73.6 millions, which means that more than a half the population owns a vehicle.

Although the government had recognized the importance of road improvement, it was difficult to secure its financial resource under the tight budget constraint of the government. Under such circumstances, two financing systems have supported the development of the Japanese highway network. These systems are the toll road system introduced in 1952 and the system of earmarked tax revenue for road projects introduced in 1953.

Japanese road projects are classified broadly into general road projects and toll road projects. A major part of the source of revenue for ordinary non-tolled road is derived from taxes on automobiles and fuels. The law restricts these revenues from fuel taxes and other specified taxes to be used only for development and maintenance of roads. This is the concept of "earmarked tax revenue for road projects." Road improvement and maintenance is based on the "5-year Road Improvement Program," which was first designed in 1954, and have been renewed every 5 years since then. Along with the increase in automobile traffic, the earmarked tax revenue has been secured by introducing new taxes and raising their tax rates. [4]

However, it was not enough only with earmarked tax revenue to improve highway network urgently. Then, following the enactment of the "law concerning special measures for highway construction," the toll road system was established. The law allows tolls not only for the National Expressways but also a part of national highways, prefectural roads and municipal roads.[5] During 1956 to 1970, four highway related public corporations were established. In FY 2004, the toll road projects conducted by the public corporations account for 18% of the total spending for roads, and, in 2001, the total length of the toll roads reached approximately 9,500 km.

Toll should be set to cover the entire cost, such as construction expenditure, maintenance and operating cost, interest, and all the other expenses within its collection period. Moreover, toll rate should be fair and valid. The pool system is adopted for a nationwide toll road network, and in some cases, regional toll roads that cover a broader area. The idea of the system is that several toll roads, which are "networked" on a nationwide and regional basis, can be regarded as a single road for calculating revenue and expenditure for redemption.[6]

[4] Recently, the "5-year Road Improvement Program" has been integrated into the "Long-Term Plan about the Main Development of the Social Infrastructure"

[5] The Japanese highway system is classified into four types, which are National Expressways, National Highways, Prefectural Roads, and Municipal Roads by the administrating entities.

[6] In recent years, for more efficient road management, there has been a discussion of privatization of the 4 highway-related public corporations. In June 2004, the laws regarding privatization of four highway-related public corporations were enacted, and these public corporations will be privatized in October 2005. Also Japan expressways holding and debt repayment organization (JEHDRO) which will be the one of the incorporated administrative agency of the Japanese government, will be founded to repay interest-bearing debt in 45 years, and six private companies will be established to be responsible for construction and management of toll roads by paying lease fees to JEHDRO.

2.2 The Demonstration Projects of Flexible Tolling on Toll Roads

While the government and the public road corporations have built highways using revenue from tolling, highways are not necessarily fully utilized by the users, especially in rural area. Since toll rate is basically set in terms of the construction cost of highways, as mentioned above, it does not necessarily satisfy the condition of welfare maximization. Moreover, due to the slow economy of recent years and advancement in cost management in logistic industry, road users tend to avoid travelling on toll roads. Then, higher toll has caused traffic congestion, traffic safety problems, and environmental problems on non-tolled alternatives, as well as decreasing the user benefit on toll roads. Therefore, a flexible charging scheme is recognized to be necessary for managing the demand for road transport.

As shown in Figure 1-a and 1-b, in Nagano Prefecture, many cost sensitive trucks, especially at night, use non-tolled alternative (National Highway Route 19) instead of the Chuo Expressway with tolls. As a result, the area along the National Highway Route 19 suffers from the noise that exceeds the environmental standards, and the ratio of death due to traffic accidents per vehicle-kilometers is nearly twice as large as the national average. This fact shows that the construction cost based toll setting on toll roads may severely undermine the welfare of the whole region as well as road users, since residents are likely to locate near non-tolled national roads rather than access-controlled toll roads.

In order to alleviate these negative externalities of tolling and match the local transportation needs, in 2002, the Council for Infrastructure have reported that the government should introduce more flexible tolling on roads. However, the effect of the tolling can be dependent on the regional environment and utilization of road networks, and it is difficult to predict or analyze the consequence of those flexible tolling and there should be various ways of addressing those problems or concerns. Then, the Road Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) has begun the demonstration project of flexible tolling, and set tolls temporally lower for specific time, vehicle types, and/or segments of networks.

3. THE EFFECT OF FLEXIBLE TOLLING

3.1 Theoretical Ground of Flexible Tolling: Analogy to Value Pricing

Since the experiment itself rather aims to alleviate practical congestion and related negative externalities of toll roads than to realize theoretically optimal pricing on roads, there is not much theoretical ground for setting of tolls in Japan. However, we can still retrieve the lessons learned from the experiment, and we may be able to achieve more theoretically desirable outcome of flexible tolling.

Before introducing the specific examples of the experiments, we can understand the nature of the outcome of flexible tolling in Japan, in comparison with the Value Pricing Projects in the US.[7] Although there are varieties of project schemes in both countries, we rather focus on the simplified version of the schemes. The typical flexible tolling project in Japan is the discounting on toll roads where there is a parallel non-tolled alternative. For the sake

[7] The description of the Value Pricing program is provided, for example, in DeCorla-Souza (2004).

of analytical simplification, we now focus on the case where there is the only single origin and destination for both roads. The counterpart model project for the Value Pricing Project is the construction of tolled lane along with the congested existing roads. Similar to the case of Japanese projects, we now assume that the there is a single origin and destination for the parallel lanes.

When we consider the paralleled roads in Japan are located close to toll roads, the situation of roads is similar to the case of value pricing project in the US. The difference is the basis for setting toll rates: toll rate on Japanese highways are basically set to recover the construction cost and the acquisition cost of right-of-ways and the toll for value pricing in the US is set to realize the smooth flow condition of tolled lanes while the revenue recovers the cost of increasing the number of lanes.

Following Small and Yan (2001), which analyzes the welfare of Value Pricing on the SR91 in California, we can describe the model to analyze the welfare of pricing. The model assumes that the two routes have the same length L and the different unit travel-time $T_r(N_r)$, which depends on the traffic volume N_r. A user of type *i* (*i* = 1, 2) travelling on roads from the origin to the destination incurs travel cost *c*, which consists of operating cost and time cost. For easier understanding, the difference in user types is refleced to the difference in individuals' value of time. Denoting the tolled roads or lanes and non-tolled roads or lanes as *A* and *B*, respectively, we can describe the user cost of using roads as follows:

$$c_{ir}(N_r) = \beta L + \alpha_i T_r(N_r) L , \qquad (1)$$

where $r \in A, B$. β is the unit cost for running some length of roads and α_i is the unit time cost that differs between user groups.

The demand by each group has the linear form

$$N_i(P_i) = a_i - b_i P_i , \qquad (2)$$

where a_i and b_i are positive parameters, and P_i is the "inclusive price" or "full price". Since users minimize the inclusive price for using the roads, P_i can be defined as the minimum combination of travel cost plus toll (τ) for the user group:

$$P_i = \min_r [c_{ir} + \tau_r] . \qquad (3)$$

In order to define the total welfare for road users, we use the inverse demand function for equation (2). Thus, the welfare of users is defined as follows,

$$W_U = \sum_{i=1}^{2} \int_0^{N_i} P_i(t)dt - \sum_{i=1}^{2} \sum_{r=A}^{B} N_{ir} c_{ir} \qquad (4)$$

It is beyond the scope of this paper to explore the solution for the optimal or suboptimal solution using the realistic parameter values based on actual road network in Japan. However, Small and Yan (2001)'s parametric analysis for the SR91 suggest that the second best toll, which means that we can charge toll only for route A, is shown to be below the profit maximization toll, where the road operator can charge toll in order to maximize its profit. Moreover, the second best toll is usually lower than the first best toll, where the road op-

erator can charge toll for both A and B and the heterogeneity in road users' value of time are not extremely large. Another implication for their analysis is that we may be able to gain quite large welfare by charging either one route, and provide the high speed toll road service and low speed and non-tolled road service at the same time, if the heterogeneity in road users' value of time is large. Thus, the second best toll is not easily determined by the standard theory such as the congestion pricing, and it is necessary for a road operator to experiment the effect of flexible tolling by practically changing tolls for a particular period.

Further, in the context of Japanese flexible tolling, we should take into account the welfare of road side residents who are affected by the situation of roads in terms of noise, air-pollution and accident. We simply define the welfare of residents as the negative value of cost incurred by traffic volume.

$$W_R = -\sum_{r=A}^{B} RC_r(N_r) \ , \qquad (5)$$

where $RC_A(N_A) \le RC_B(N_B)$ if $N_A = N_B$, $RC_r'(N_r) > 0$ and $RC_r''(N_r) > 0$. It can be said that equality of the equation (5) holds for the lane pricing of Value Pricing Program and the inequality holds for the flexible tolling where more residents are located near by the non-tolled route (route B). When we include this type of welfare for solving the welfare maximization, the toll should be set lower to absorb more traffic volume into the tolled lane under the second best tolling.

3.2 Political Feasibility of Flexible Tolling and Value Pricing

Before applying the theoretical implication to the practical road operation, we have to note that political acceptance for each measure is different with each other, while the economic implications of the both measures are similar. This can be exhibited by the following table that compares the distribution of welfare of the toll policy for the Value Pricing Project in the US and the flexible tolling in Japan.

Table 1-a shows that the allocation of benefit and financial cost of value pricing lanes. It shows that the measure may be acceptable to the area where there is heavy congestion on roads and there exists enough toll-lane users to cover the construction cost of lanes. We should note that there was actual opposition for introducing the value pricing, and one of the reasons for the opposition is that the pricing is regressive. Although, theoretically, the road user for the tolled lanes will benefit in any case by increased travel options, some critic called the lane as "Lexus Lane" and opposed the policy, since wealthier users would benefit more for such pricing. This possibility is exhibited in Table 1-a by the negative sign for financial cost and positive sign for the benefit for road users on high speed tolled lanes.

Table 1-b exhibits the allocation of the benefit and financial cost of introducing flexible tolls on roads. It shows that all the stakeholders obtain benefit from the policy, although there will be a loss of revenue by reduced toll rate. There will be no equity concern for this flexible tolling policy by lower financial costs. We can say that the budget constraint is the only reason that the government will not introduce the policy.

In either case, it is desirable to set up the public involvement stage for residents in the region to choose between the better travel service and additional funding. Moreover, at least for the case of flexible tolling, it is necessary for a road operator to fully capture and nationally provide the evidences for the effect of pricing, since national funds may be at stake

to cover the loss of revenue. For this purpose, either better theoretical derivation of the optimal pricing or the empirical observation of the actual behaviour of users with various tolls is necessary. The Japanese government have taken the latter strategy and we acquire various data and examples for analyzing the demand and benefit of the road users. We introduce some of the results that will help to form the future pricing strategy.

4. EXPERIMENTAL OUTCOME OF FLEXIBLE TOLLING

While the experiments exhibit various outcome of the toll setting, one of the most important measures for various experiments are the price elasticity of using toll roads. Figure 2 exhibits the price elasticity of the experiment, and it shows that the elasticity for these experiments is roughly between 0.4 and 1.0 for the roads that have more than 1,000 vehicles per day.[8] However, there are sometimes the cases where the elasticity may exceed unity. In the experiment in Aganogawa city in 2003, the half discount of toll caused large increase in traffic volume, especially on holidays. As showing in Figure 3-b, the average traffic volume during experiment was 173% compared to before the experiment and 195% on Saturday, Sunday and national holidays. As a result, the length of queue on non-tolled roads decreased almost as half as the original length. This suggests that the cost based tolling may have significantly undermined the user benefit of using road network, and lowering toll rates can not only greatly improve the consumer welfare for transportation users but also it recover significant portion of revenue supposed to be lost for lowering toll rate.

Even if the price elasticity of the road users are not that high, there is a case that the flexible tolling may provide significant benefit compared to cost based pricing for road operators. Figure 4-a and 4-b exhibits the effect of the discounting of toll roads to shift the traffic from paralleled non-tolled road in Hitachi city. The discount rate of toll is approximately 50% and the traffic volume on the segments became around 170% in weekdays during the experiment. While the loss of revenue by this experiment is about 600 thousands yen per day, the travel hour loss from congestion has decreased by 15 million yen per day.

The benefit of discounting on tolled roads is not limited to road users. The improvement of the living environment due to the experiment is reported in Hamana Bypasses experiment. The experiment is the extension of non-tolled period of four daytime-tolled Bypasses. The extension is made for AM and PM peak periods (6-9 AM and 8-9PM), when there are many commuters who use non-tolled national highways and the bypasses are relatively uncongested. It is environmentally desirable for the traffic to be shifted toward the bypass at least near Hamana Bypass, since more residents are located along the non-tolled national highway rather than along access-controlled tolled bypass. The result shows the increased traffic volume of Hamana Bypass by 60% (3,500 vehicles per day), and decreased traffic volume of paralleled non-tolled national highway by 30% (1,800 vehicles per day) for newly introduced free periods. Figure 4-b shows that the noise level for non-tolled national highway decreased during the experimental period to below the environmental standards. We can reasonably expect that decreasing tolls on these bypasses would realize lower noise level than environmental standards all day, and less air pollution due to particle matters and nitrogen oxide along the non-tolled national highways.[9]

[8] The experiment assures the declined revenue from lowering tolls by national and local governments, since the elasticity of demand is usually below unity.
[9] Other results of the experiments are provided, for example, in Matsuda et al (2005).

It is necessary for the government to consider the balance of these benefit and loss of revenue. However, various experiments suggest that the consideration of flexible tolling on roads is necessary and the loss from rigid construction cost based pricing on toll roads may be quite large. This is especially true when we consider the welfare of residents who are affected by the use of non-tolled alternatives. Further, a road operator should consider the combination of increase and decrease of toll rates on toll roads depending on the situation of roads, although the increase in toll rates will need public understating of its benefit. In any case, we should accumulate the actual example of the experiment, and draw more general characteristics and outcomes of flexible tolling by using the theoretical analysis based on the practical data.

5. CONCLUSION

The Japanese government has implemented the pricing experiment on toll roads in order to utilize the existing capacity of toll roads. The flexible tolling in stead of construction cost based tolling can bring about larger social welfare and it is politically acceptable, while it usually undermine toll revenue. The result of experiment suggests that the flexible tolling in Japan can greatly improve not only the mobility of vehicles but also the environment of roadside residential area. Moreover, the decline of the revenue can be small due to the high elasticity of demand on toll roads. It is necessary to accumulate more results of experiment to draw general implication of the flexible tolling.

6. REFERENCES

Masuda, Waka, Tsukada, Yukihiro and Kikuchi, Masahiko (2005) *Analysis of the Demonstration Project Results Concerning Diverse and Flexible Charge Measures for Toll Roads to Promote Road Policy. mimeo*

DeCorla-Souza, Patrick (2004) *Recent U.S. Experience: Pilot Projects*. in Georgina Santos Eds. "Road Pricing: Theory and Evidence". Elsevier. Ltd.

Small K A and Yan J (2001) *The Value of "Value Pricing" of Roads: Second-Best Pricing and Product Differentiation*, Journal of Urban Economics, 49, pp. 310-336.

Table1.a

Value Pricing on Increased Lanes (US)

	Benefit	Financial Cost
Road Users on Tolled & High-Speed Highways	+	—
Road Users on Non-Tolled & Low-Speed	+	±
Residents	±	±
Government	N/A	+ (If enough users exists)

Table1.b

Flexible (Discount) Tolling on Highways (Japan)

	Benefit	Financial Cost
Road Users on Tolled & High-Speed Highways	±	+
Road Users on Non-Tolled & Low-Speed	+	±
Residents	+	N.A.
Revenue	N/A	—

Figure 1-a

Chuo Expressway and National Highway Route 19

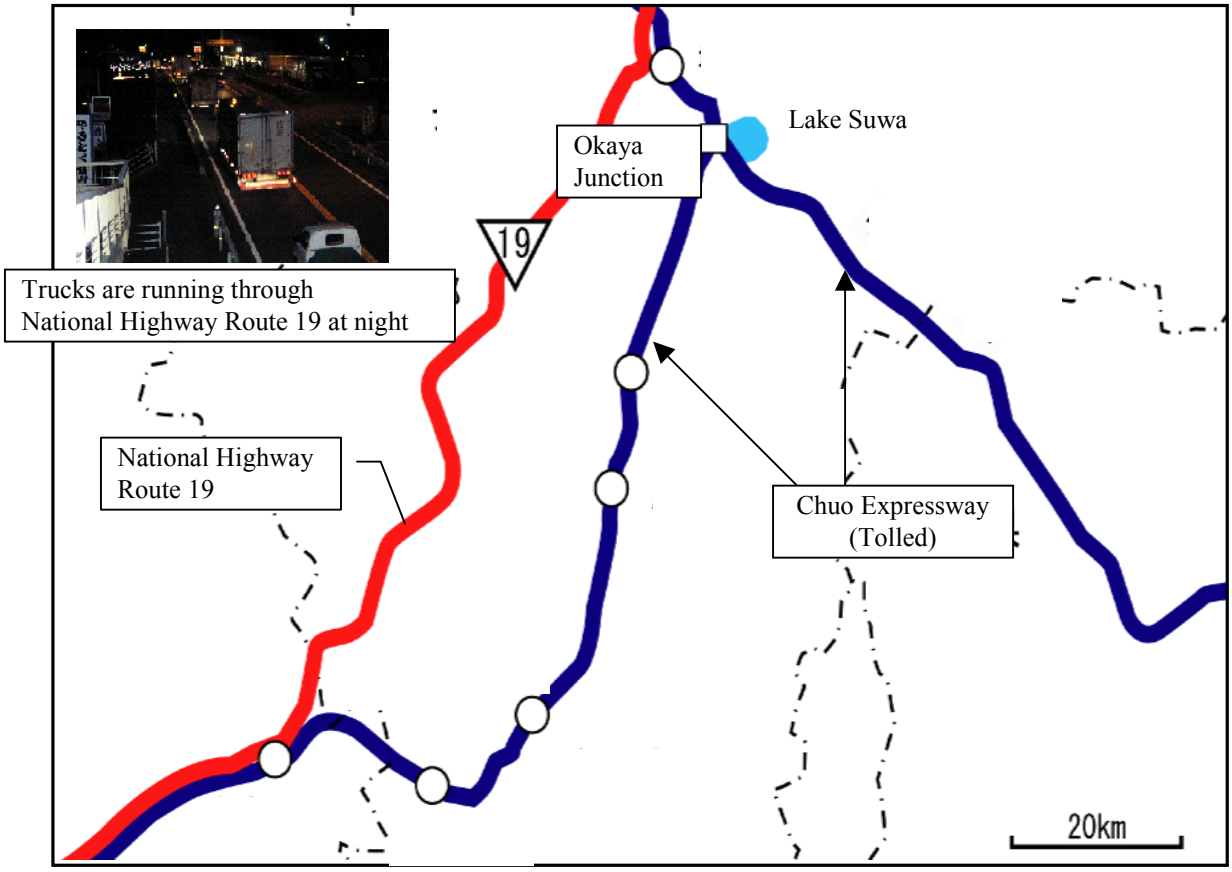
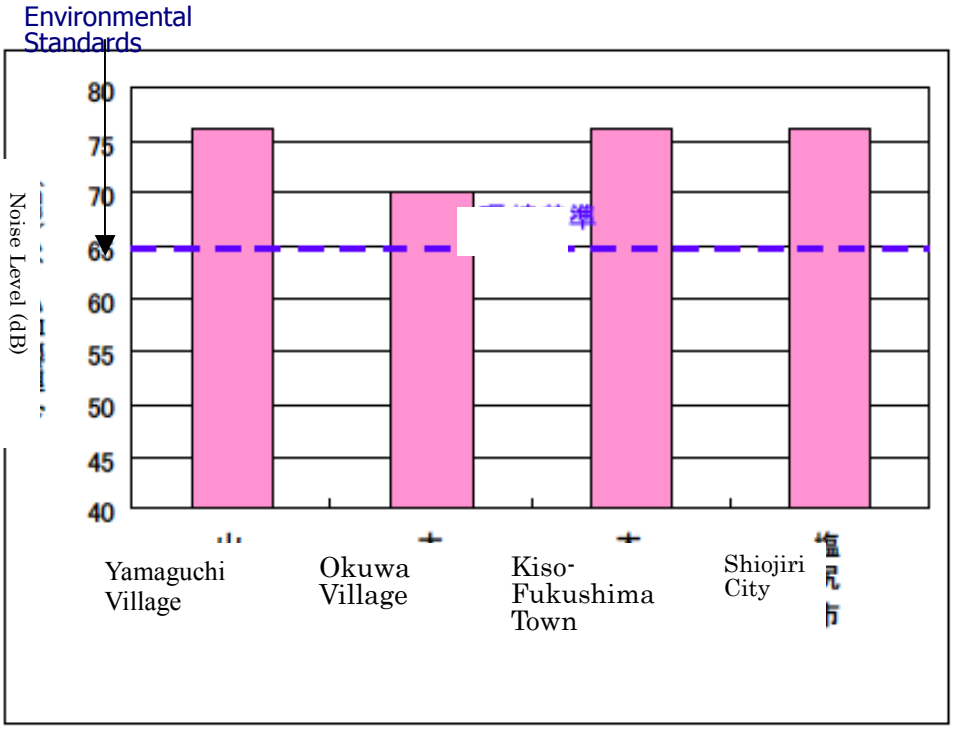


Figure 1-b

Noise Level and Accident Rate on Route 19



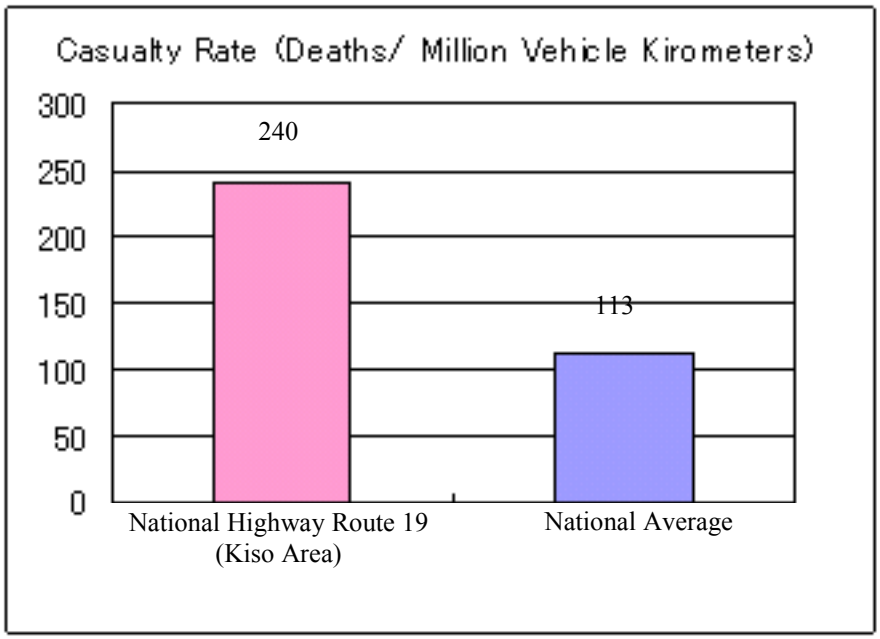


Figure 2: Elasticity of Demand for Flexible Tolling Experiment

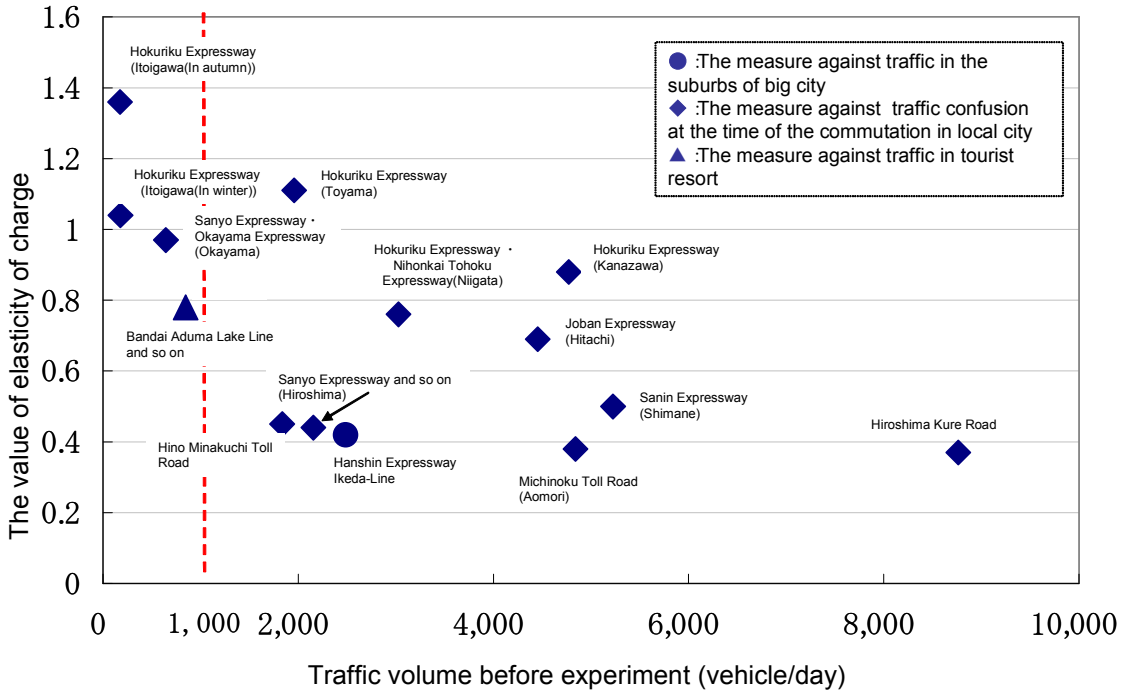


Figure3-a: Aganogawa Area (Description)

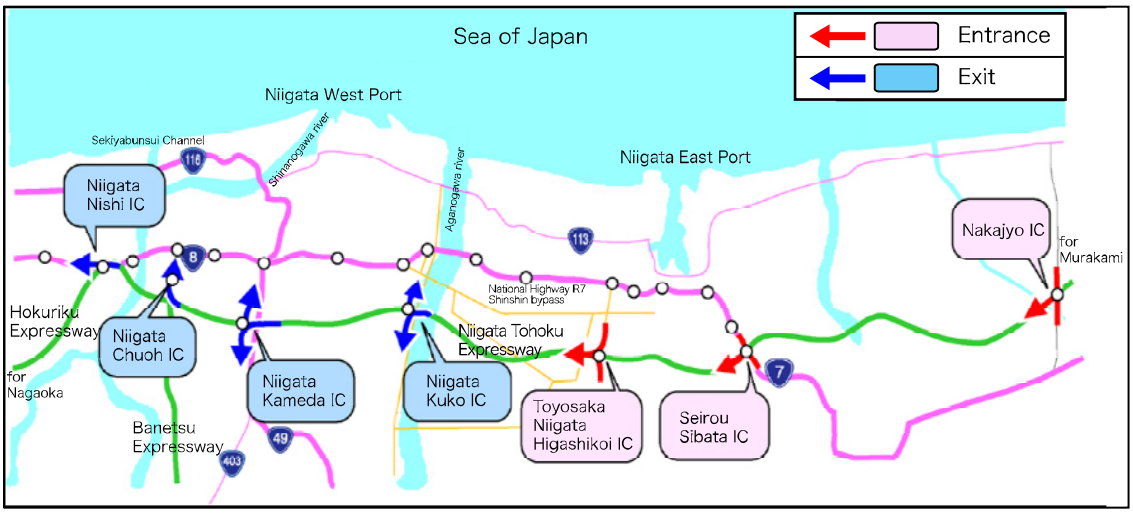


Figure3-b: Aganogawa Area(Result)

Change in Traffic Volume

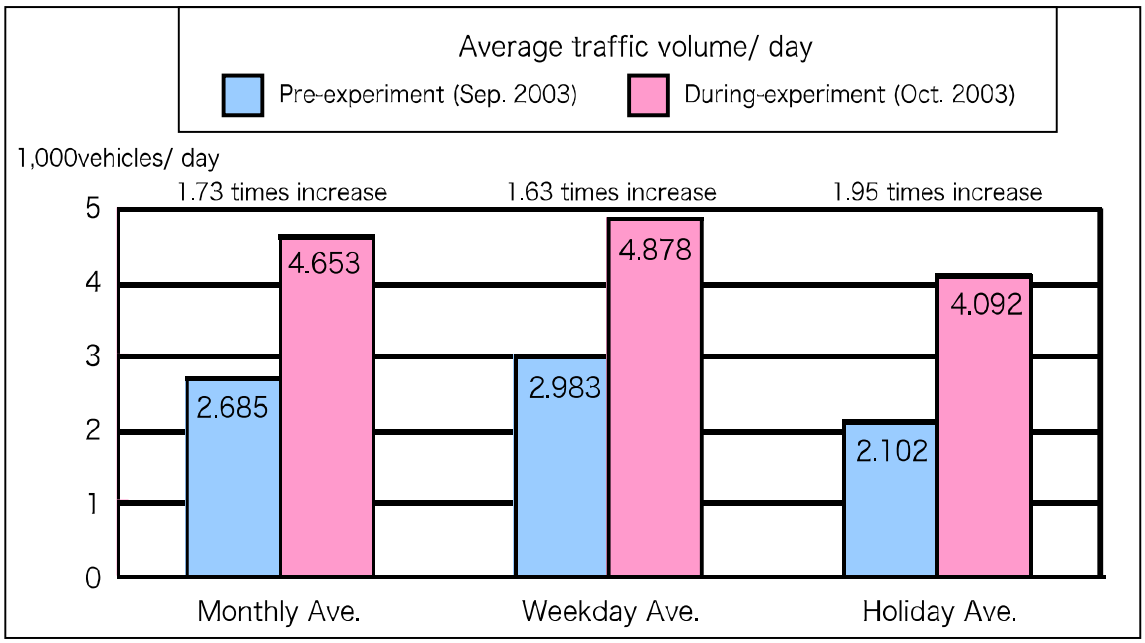


Figure4-a

Hitachi (Effect on Tolled Expressway)

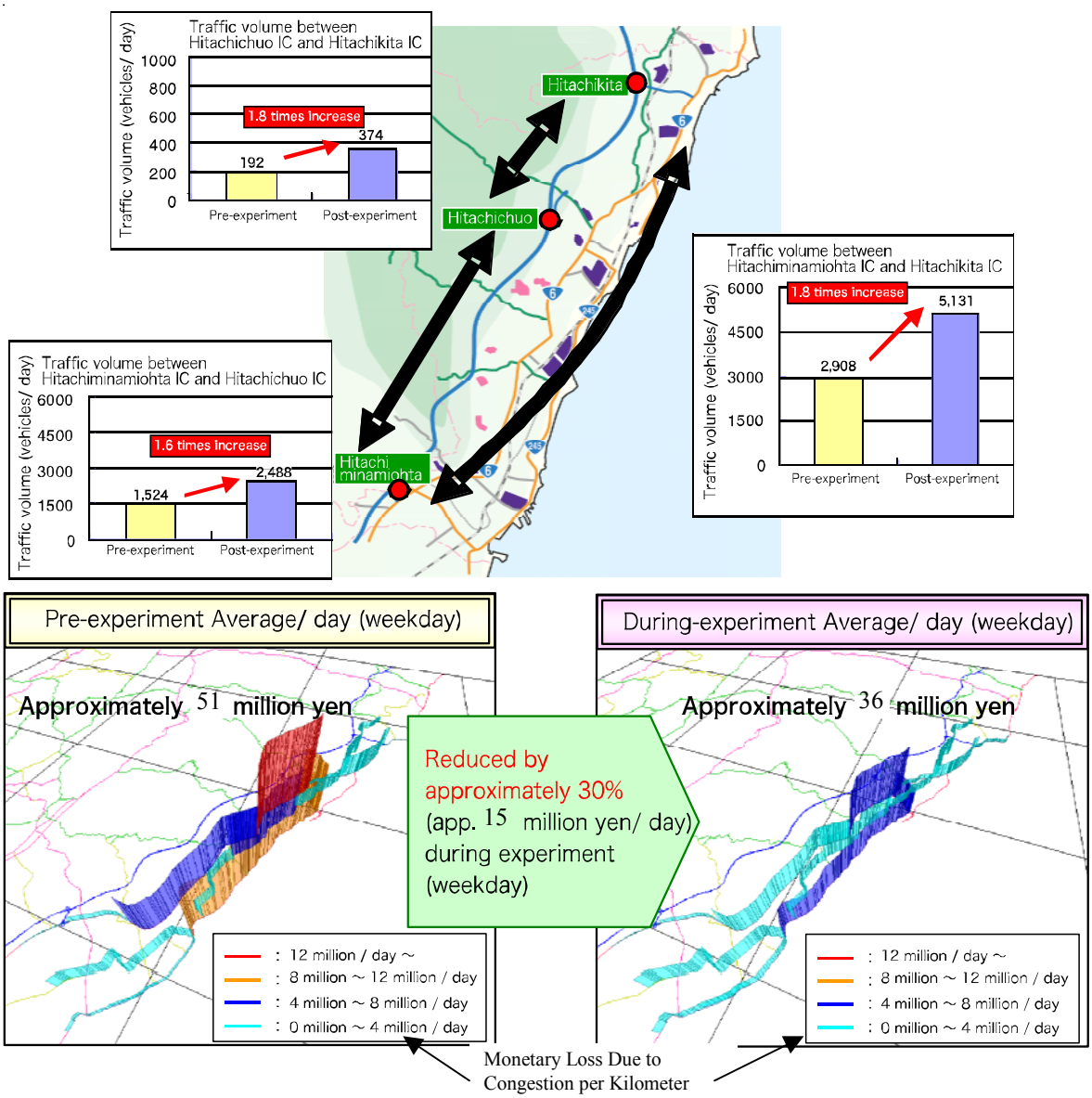


Figure5-a

Hamana Bypass (Description)

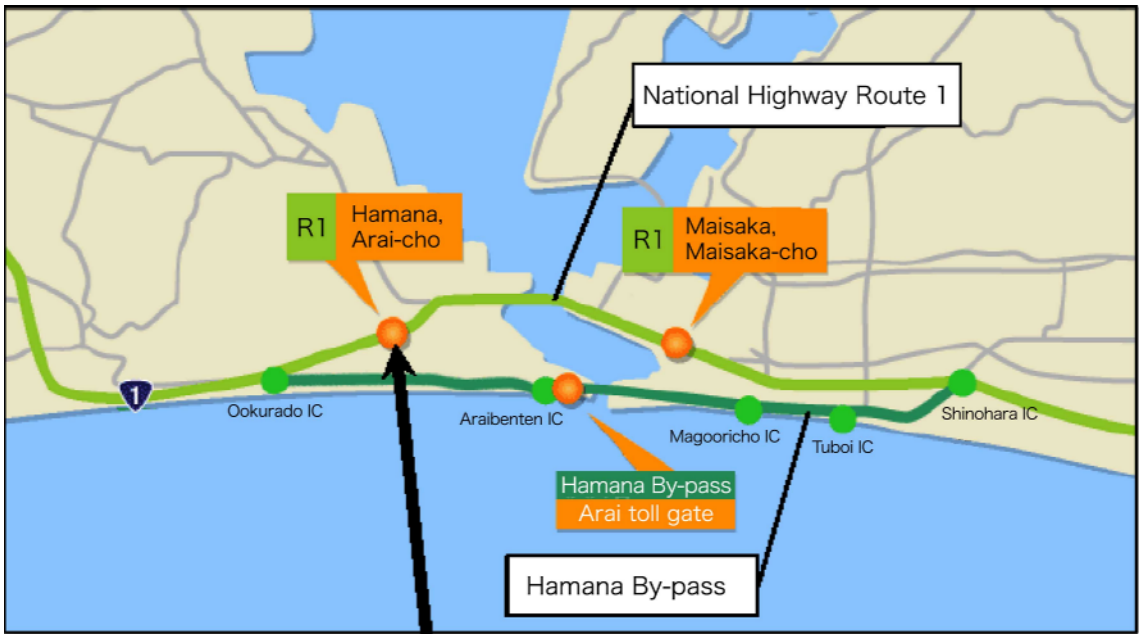


Figure 5-b

Hamana Bypass (Effect)