A Study on the Costbenefit Analysis of a LRT Development Project

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Abstract
Recently, there have been some infrastructure projects conducted by Private Finance Initiative (PFI), most of these projects relatively small scale. However, in the future, it is considered that PFI method will be used for transportation planning. In these projects it is important to have an economic analysis so that we may confirm whether or not these project managements work well. Moreover, public concern of the effect of cars on environmental contamination has been increasing recently, and so it seems necessary to consider their impact. For such a reason, an economic analysis on a Light Rail Transit (LRT) project with consideration for an environmental tax for cars as well as external costs of road transport (air-pollution, noise, accidents etc.) was conducted.

Keywords
LRT, environmental tax, external cost

1. INTRODUCTION
After the establishment of PFI law in 1999, some infrastructure projects and plans using PFI have been carried out and some research with respect to PFI has been documented. However, most of these projects were relatively small scale. In the future, it is considered that PFI method will be useful for some large scale transportation planning. In these projects, it is important to have an economic analysis, so that we may confirm whether or not these project managements work well. Nevertheless, the benefit and cost of a provider and user was considered in almost all the economic analysis carried out by former infrastructure planning.

Moreover, public concern of the affects of cars such as emission, noise, and traffic accidents (i.e., external costs) on environmental contamination has been increasing recently, so it seems necessary to consider their impact. These effects are, in most cases, caused by an increase of traffic jam and traffic volume.

For such a reason in this research, infrastructure re-construction project (especially traffic facilities) is attended. Also an economic analysis on a Light Rail Transit (LRT) project with consideration for environmental tax for cars as well as the external costs of road transport (i.e., air-pollution, noise traffic accidents) was conducted. To be specific, this research shows a traffic demand model using a discrete choice model and a supply model on LRT planning, and investigates the benefits of this project considering social benefit. Social benefit includes supplier's benefits, consumer's surplus, and external costs. In these benefits, consumer's surplus can be calculated from the discrete choice model. At the same time, the change of these benefits in the case of innovating the environmental tax is also analyzed.

2. LITERATURE REVIEW AND CONCEPTIAL FRAMEWORK
In the past, research on PFI has largely been performed by finance and economic categories. But recently, it has been researched in the field of city and transport planning. A model using Benefit Incidence Matrix was constructed for estimating the approved feasibility of the infrastructure development by private sectors [Ueda et al., 2000]. Otazawa suggested the guarantee-of-liability model to investigate the efficient risk sharing scheme between the private and public sectors [Otazawa et al., 2001]. Also, methods of measuring the effectiveness of infrastructure development are composed of a method by a comprehensive model and a method by individual measurement [Morisugi, 1997]. The former method inclusively estimates the entire effect of traffic facility, and the latter calculates each of it's subsequent effects. This research employs methods that measure individual utility. In one case of the individual measurement methods, it was shown that the sum of an indirect utility function estimated by a logit model and a consumer surplus indicated by marginal utility could be defined as passenger's benefits [Williams, 1977]. A characteristic of these methods is that each benefit can be measured individually in the case of changes of time and cost, for example [Jara-Diaz, 1990]. Next, a lot of research has been performed on the topic of externality of using cars [Verhoef, 1994]. Kamioka described an uneconomic externality (i.e., air pollution, noise) of road transport [Kamioka, 1996].

In view of these reviews, this research presented a study of the feasibility of LRT facilities project that change from train service to LRT as an example of a transport re-development project. A possibility of each project management with consideration for an environmental tax that might compensate for externality and social benefit was investigated; Namely, a self accounting system and a system where the supplier is subsidized by a local government.

3. MODEL

In this research, for making a comparative study of each case (a self-supporting accounting system and a subsidy from local administration), it is necessary to establish a passenger's demand function as well as a supplier's behavior function. A common model of this demand function is that it has the same structure regardless of the presence of subsidization, but it is conceivable that restrictions of the supply function are different in each situation. The reason is that the supplier is able to set up a charge and frequency at will in the case of the self-sustained project, and it is plausible that an administrator can intervene in a service level if the supplier received financial help from an administrative organ. A measurement process of the increase of consumer surplus and social benefit that were caused by a progress of the service level is discussed in section 3.3.

3.1 A supplier's behavior

It is expected that the supplier's main focus is profit maximization under the given constraint. So supply function is defined as the following equation.

$$MaxP_L = \sum_i \sum_k (Y_{ikL} \cdot C_{ikL}) - \{(Q_L \cdot RC_L + MRC_L) \cdot H + N \cdot MNC_L\} + T \sum_i \sum_k x_{ik} \cdot Y_{Cik} \cdot ED \quad , i \neq k \quad (1)$$

P_L: Gross profits of LRT supplier
Y_{ikL}: The number of LRT users between zone i - k
C_{ikL}: LRT fee between zone i - k
Q_L: A frequency of LRT service
RC_L: LRT service cost (yen/km)
MRC_L: LRT management cost (yen/km)
H: LRT management distance (km)
N: The number of vehicles
MNC_L: Maintenance costs of a vehicle
x_{ik}: 1: crossing a bridge between zone i - k
0: none
Y_{Cik}: The number of car users between zone i - k
ED: Environmental tax
T: 1; imposing an environmental tax
0; none

subject to the vehicle constrain (in case of the self-supporting type)

$$MaxZ_{ab} \leq Q_L SL$$

Z_{ab}: The number of users between station a-b
SL: The full quota of a vehicle

3.2 A user's behavior

It is assumed that the passenger's behavior is decided with consideration to the fee and flight frequency. So, the user's demand function is shown as the following equation.

$$Y_{nik} = A_{ik} \times p_{ik}(n) \quad (2)$$

$$p_{ik}(n) = \frac{e^{u_{ikn}}}{\sum_n e^{u_{ikn}}} \quad (3)$$

$$u_{ikn} = a_{n0} + \sum_m a_{nm} \times \mathbf{X}_{nikm} \quad (4)$$

n: Transportation (L: LRT, B: Bus, C: Car)
A_{ik}: The number of users between zone i - k
a_{nm}: The th coefficient of mode
X_{nikm}: The th independent variable of mode n between zone i - k
u_{ikn}: The utility of mode between zone i - k

3.3 Social benefits

It is seen that the benefits resulting from the development of a rail transport are mainly the increase of user's utilities on the change of service levels, the increase of resident's profits along the railroad line, the increase of a local government's revenue, and the decrease of social costs such as air pollution, noise and traffic accidents [Morisugi, 1997, Verhoef, 1994].

3.3.1 User's benefits

In this paper, the method of measuring the consumer surplus is shown in Figure 1, so that user's benefits are estimated on the change of service (e.g., time, fee, and frequency of transfer) caused by transportation development. Significantly, a logsum variable expressed by equation (5) is used as the horizontal axis in this research [Williams, 1977]. A feature of the effects of transportation improvement can be estimated without using a general time value (i.e., an average income per an average working hour).

$$\Lambda_i = \ln \sum_n \exp(\mu V_{ikn}) \quad (5)$$

Λ_i: A logsum variable between zone i - k
V_{ikn}: A utility fixed paragraph of mode n between zone i - k

The curved line D in Figure 1 shows a demand function of transportation. Where D_1 and Λ_1 are a demand and utility before improving transportation, and then D_2 and

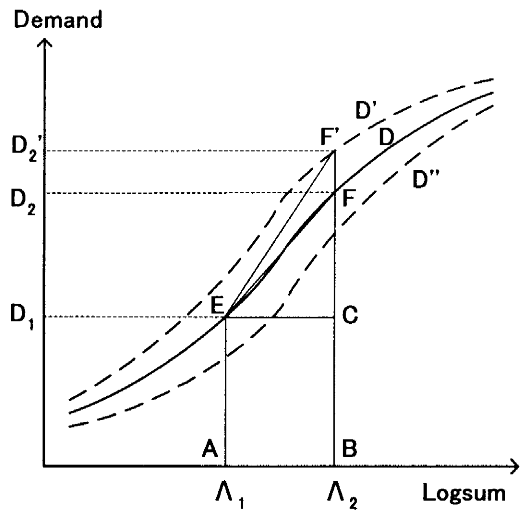

Fig. 1 Consumer surplus

Λ_2 are a demand and utility after improving it. The increase of consumer surplus of passengers who have been using rail transportation up to now is shown by the rectangular area ABCE. The increase of consumer surplus of passengers who will use it after it's improvement is shown by the triangular area CEF.

It is can be seen that this demand function is a demand function of LRT, when the amount of trips is constant, and the service levels of other alternative transportations are changeless. And this demand function D is shifted to D', if the service levels of alternative transportation are changed for some policies (i.e., the environmental tax is levied on car users). The consumer surplus of LRT users caused by this policy is shown by triangular area EFF'.

3.3.2 External costs

A value of external costs of road transport in Japan was discussed by a guideline of assessment of road investment [an investigation committee about a guideline of assessment of road investment, 1998]. Using this value of external costs, a benefit measurement method of an environmental improvement was suggested in the case of developing a railroad [the ministry of transport railway bureau, 1999]. Koyama et al. estimated the value of external costs per kilometer for each factor (i.e. SOx, noise) that influences the environment [Koyama et al., 2001]. In this paper, the basic cost unit for each factor estimated by Koyama et al. is applied to the measurement of the change of external costs by the LRT development project.

4. CASE STUDY

LRT is considered to be one of the main urban transportation in the future. Nevertheless, although a large number of European countries have constructed LRT, it is interesting to note that there are many cases in Japan where Light Rail Vehicle (LRV) has only been used in exchange for the tram. For this reason, a cost-benefit analysis is necessary for the investigation of the LRT project, when it is conducted to a certain virtual case regardless of the reality of the projects. In this research, Toyama city was used as an example, and the feasibility of the project that provides LRT after connecting the exiting tramroad with railroad was examined. Specifically, this project of LRT facilities development plan is shown in Figure 2.

Origin-destination traffic data used for making a model of transportation analysis was obtained from a person trip investigation in the Toyama and Takaoka metropolitan area. Data of dependent variables (LOS (level of service) variables) was obtained from the timetable and a roadmap.

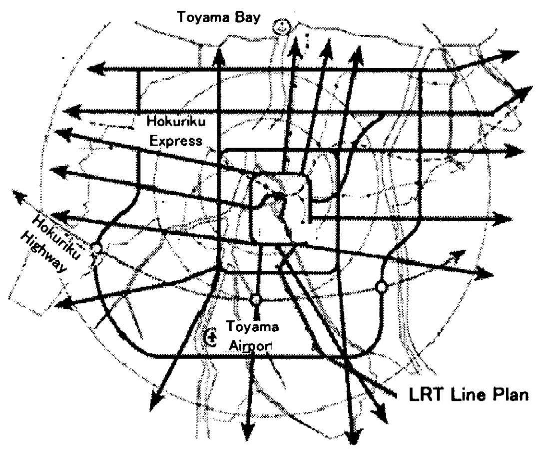

Fig. 2 LRT development project

4.1 Estimation results of demand model

In this paper, two demand models of peak time (from 7 a.m. to 9 a.m.) and others were estimated. As shown in Table 1 and 2, the most effective dependent variables for each model were decided after trial and error. Although some dummy variables were used as a kind of dependent variable in both models, a station dummy indicates whether there is a station that the railway user can use or not, and a transfer dummy indicates whether there is a necessity that the railway (bus) user transfers to a train (bus) or not. A bridge dummy exhibits the necessity for car users to cross a bridge, a destination dummy shows whether the car user's destination is in a central area, while a distance dummy indicates whether car user's trip distance is within 5 kilometers or not. These dummy variables are established as follows:

1; yes (necessity), 0; not.

Table 1 Estimation results of the model (peak time)

	Coefficient estimate	t statistic
Car constant	3.67	(38.0)
Cost [100yen]	-0.0683	(-10.7)
Time [minute]	-0.0148	(-28.1)
Transfer constant	-0.0898	(-3.4)
Bridge constant	-0.556	(-24.1)
Station constant	0.536	(18.2)
Destination constant	-0.304	(-11.9)
Distance constant	-0.300	(-9.8)
N=76843		

Table 2 Estimation results of the model (off peak)

	Coefficient estimate	t statistic
Bus constant	-0.0782	(-2.6)
Car constant	2.82	(42.5)
Cost [100yen]	-0.0156	(-3.5)
Time [minute]	-0.103	(-46.2)
Bridge constant	-0.243	(-14.4)
Station constant	0.284	(10.3)
Destination constant	-0.638	(-35.1)
N=276310		

Estimation results from two models of users behavior shown in Table 1, 2. All estimated parameters had correct signs and most of them were statistically significant. The feature predicted from estimation results of demand model at peak time is that almost all commuters chose a public transport or car. Furthermore, it is presumed that at off peak time the commuter prefers not to take a transfer. The absolute value of the coefficient of the bridge dummy is the largest in all of the car user's dummy variables, and the station dummy is the largest in all of rail user's dummy variables. It is conceivable that these points imply that the car user is reluctant to cross a bridge, and that the rail user attaches importance to accessibility to the station.

4.2 A study of the feasibility of a LRT facilities project in a self-supporting accounting system

Estimation results of the model which can be seen in the foregoing paragraph encouraged us to investigate the possibility of the self-sustained LRT facilities project. It is assumed that the LRT supplier is able to fix the fare and frequency freely in order to maximize the self-profit in the case of the self-sustained project. However, it is conceivable that it is necessary to avoid a remarkable decrease in the level of service after the project, because LRT is a public transport. For this reason, we considered constraints such as that the fee is within twice the present charge, and the frequency is within 1/3 of the existing service with having service at least once an hour. When estimating costs and benefits, it was assumed that the total demand was constant. A flat fare or two kinds of fare (moving from city to city and from suburb to suburb, or traveling from city to suburb) are charged in order to increase an efficiency of delivery fare. Maintenance, management, and service costs are calculated by employing the 1999 fiscal year Railway Statistics Annual Report. Also, the first expenditure that includes a purchase cost of vehicle (2.2 hundred million yen / 1vehicle) and a repair cost of rote (the electricity, a LRV stop and a railroad; total 34.4 hundred million yen) is computed [Bureau of City Planning Tokyo Metropolitan Government, 1999]. Supplier's gross benefits, estimated by using values of these LOS variables and the first expenditure, are shown in Table.3. A total profit of 15 years was calculated by a using social discount rate as 4 percent, as the average life on a LRV is about 15 years. As benefit/cost is about 1.3, this result shows the large feasibility of this self-sustained project, when user's fare is doubled.

Table 3 Supplier's benefits

Total profit of one years	Total profit of 15years	First expenditure
7.70	89.0	69.6

(hundred million yen)

5. A STUDY OF VALIDITY OF PUBLIC SUPPORT WITH CONSIDERATION OF THE ENVIRONMENTAL TAX AND THE SOCIAL BENEFIT

As mentioned in the preceding section, it was ascertained that the possibility of this LRT project in a self-supporting accounting system was great. But the load of money is greatly given to a part of users in this case. In the public transport development project, it is thought that not only the supplier's profits but also the social benefit needs to be considered. When analyzing the maximum social benefit, the results that the fare was set as cheaply as possible and the frequency was set as high as possible were obtained. However, these results led to a low feasibility of this self-sustained project.

In consideration of these results, the social benefit was estimated under the condition that management is stable, when a local government set the fare instead of a subsidizing supplier. An increment of the social benefit is measured by using a process that can be seen in subsection 3.3.1. And the calculated value can be converted into money, as follows [Williams, 1977]: The logsum variable Λ_i of equation (5) is differentiated at the railway cost C_{Ai}, and as a result equation (6) is obtained.

$$\frac{\partial \Lambda_i}{\partial C_{Aij}} = P_{ij}(a)\beta_c \qquad (6)$$

$P_{ij}(A)$: Railway choice probability between zone i - j

β_c: Coefficient of cost in addition,

$$\Delta C_{Aij} = \frac{\Delta \Lambda_i}{P_{ij}(a)\beta_c} \qquad (7)$$

So, the utility can be converted into money by using equation (7). Furthermore, the measurement subject of the external cost of the car was considered to be air pollution, global warming, noise and traffic accidents. The cost of each subject was computed by using the estimated value per unit kilometer of the external cost of car [Koyama, 2001].

Table 4 Social benefit (the self-sustained project)

	1 year	15years
Supplier's benefit	7.70	89.0
User's benefit	2.07	24.0
The effect of decreased external costs of cars	0.18	2.1
Social benefit	9.95	115.1

(hundred million yen)

Table 5 Social benefit (the project subsidized)

	1 year	15years
Supplier's benefit	6.03	69.7
User's benefit	7.43	85.9
The effect of decreased external costs of cars	0.25	2.9
A subsidy from government	▲0.2	▲2.3
Social benefit	13.51	156.2

(hundred million yen)

Table 6 Social benefit (levying environmental tax)

	1 year	15years
Supplier's benefit	8.40	97.1
LRT user's benefit	7.40	85.5
The effect of decreased external costs of cars	0.28	3.2
Car user's benefit	▲4.7	▲54.3
Social benefit	11.40	131.5

(hundred million yen)

The social benefit of the self-sustained LRT project is shown in Table 4. This result indicates that the supplier's profit has the majority of the whole profit.

Moreover, the case that a local government set the fare instead of the subsidizing supplier was considered. In this case, the fare was freely set under the condition that can be seen in Section 4.2, subsequently maximizing the supplier's profit, where the subsidiary was set within 20 million yen a year. The estimated results of social benefit are shown in Table 5. When the project subsidized by a local government was compared with the self-sustained project by employing the results in Tables 4 and 5, it is apparent that the social benefit increases by 30 percent or more.

Finally, we considered the case that a subsidy was disbursed not from a general account but from an environmental tax imposed on cars, because the environment was affected by car emissions and noise. Therefore, it is considered that the tax is imposed on cars concentrated from the suburbs at peak time. Concrete method of taxation is that the tax (100 yen) is levied on cars crossing a bridge at peak time. Estimated results were shown in Table 6. However, a half of 100 yen was the expenditures assumed for collecting taxes from users. In this case, supplier's benefit has greatly increased compared with the case in Table 5, but social benefit has decreased. Moreover, the consumer surplus from the LRT user has decreased as a result of imposing the environmental tax on using a car.

6. CONCLUSION

In this paper, we focused on LRT as the city transportation for the future, and an economical analysis on it's project was conducted. Firstly, for developing a comparative study of three cases (a self-supporting accounting system, a subsidy from local administration, and the environmental tax imposed on cars), a passenger's demand function and a supplier's behavior function were established. Secondly, the supplier, user, and social benefits of each case were estimated by using these models. As a result, to make management stable, the effectiveness of the environmental tax used as a subsidy of municipality on the LRT project was shown. However, citizens' understanding is necessary for successful introduction of the environment tax. Therefore, it is recommended that an educational campaign for the public be carried out.

References

Bureau of city planning Tokyo metropolitan government, *An investigation report concerning LRT*, 1999.

Jara-Diaz, S., Consumer's Surplus and The Value of Travel Time Savings, *Transportation Research*, Vol. 24B, 73-76, 1990.

Kamioka, N., *Uneconomical Study of Car*, Hokuto Publication, 1996.

Koyama, S., and A. Kishimoto, External Costs of Road Transport in Japan, *Transport Policy Studies' Review*, Vol. 4, No. 2, 19-29, 2001.

Morisugi, H., *Benefit Evaluation of Infrastructure*, Keiso Shobo, 1997.

Otazawa, T., K. Kobayashi, and S. Yokomatsu, Public Guaranty-of-Liabilities and Financial Feasibility of PFI Projects, *Papers on City Planning*, No. 36, 937-942, 2001.

Small, K., and H. Rosen, Applied Welfare Economics with Discrete Choice Models, *Econometrica*, Vol. 49, 105-130, 1981.

Ueda, T., T. Nakazawa, J. Fukumoto, and A. Hasegawa, A Model Analysis on The Feasibility of Infrastructure Development by Private Sectors, *Proceedings of Infrastructure Planning of JSCE*, Vol. 23 (2), 31-34, 2000.

Verhoef, E., External effects and social costs of road transport, *Transportation Research A*, Vol. 28, No. 4, 273-287, 1994.

Williams, H., *On the Formation of Travel Demand Models and Economic Evaluation Measures of User Benefit Environment and Planning A*, Vol. 9, 285-344, 1977.

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