A STUDY ON URBAN TRANSPORT COST ACCOUNTING : SENDAI CITY CASE STUDY

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Abstract : We estimated how much the costs of cars were covered directly by users and how much were not. We also investigated what types of urban transport policies could correct those biased cost allocation and make the efficient use of existent urban transport infrastructure. In conclusion, first, the dominance of time cost of public transport was clear in Sendai City, which implied the problem of low modal share of public transport was not only the problem of fare, money cost, but the problem of access system. Second, by calculating indirect costs of car modes, we indicated the cost of traffic noise was relatively higher than the value estimated in preceding studies because of the high population density of central area in Sendai City. Third, though apparent from the second conclusion, in order to reduce indirect costs of car mode, cordon pricing was advantageous because it was more geographically discriminate policy.

1. INTRODUCTION

General concerns about the aggravation of the urban environment drive many transport researchers into studies on the relationship between urban transport and the environment. Because the costs of air pollution and noise emission from cars are not priced at the market, automobile users are assumed to pay less than what they cost anywhere in the society. In this study, we estimated how much the costs of cars were covered directly by users and how much were not. We also investigated what types of urban transport policies could correct those biased cost allocation and make the efficient use of existent urban transport infrastructure.

First, we categorized the costs of urban transport into three main elements, time, money and indirect costs. Time cost is completely covered by users of cars and public transport, though some of it is considered to be produced by the externality discussed later. Money cost is also paid directly by users in the form of transport fare, but often the balance is covered by users and non-users in the form of tax. Whether the coverage of money cost is limited to users is dependent on a tax scheme and sometimes becomes a focus of discussion on public transport subsidy.

The third element of the costs of urban transport, indirect costs are not paid by users but paid by the society as a whole. The definition of "indirect cost" is different from that of "external cost". Indirect cost in this study is measured based on the current point of urban transport demand and supply, while external cost is measured based on the social optimal point of them. Although we should investigate "external cost" in order to describe the exact scheme to reach the social optimal point, it is not easy work. Before doing so, we could find the desirable direction of urban transport policy by studying the current situation and the status of the societal costs of urban transport including time, money and indirect costs shared by users and non-users. The term "indirect cost" often includes tax and subsidy in the literature, though they are counted in this study as a part of money cost.

In spite of different views toward the costs of urban transport, the cost items cited in the literature are very similar. Verhoef E.(1994) used the term "external costs" of vehicles and divided them into social, ecological and intra-sectral categories. Moffet J.(1993) estimated the costs of transport in USA at the current situation. Maddison D. *et al.*(1996) contained a thorough review of "external costs" of transport and the empirical results of estimation in UK based on the theory of externality as much as possible. In addition, dozens of work on this issue are recently published and some of them are listed in Table 1. Air pollution, CO2 emission, noise, traffic accident and congestion are big five items mostly stated in those studies, but some of them need careful investigation. The cost of traffic accident is a focal point of argument because the cost is assumed to be covered by insurance system. The cost of a series of systems for road safety such as the police and emergency hospitals as well as insurance companies could be examples against that view. Due to technological deficiency, road transport system inevitably generates external cost imposed on road users as a group in the form of congestion. Although the cost is external, it is perfectly paid by users as a group. In this study, we selected as indirect cost items air pollution, CO2 emission, noise and traffic accident. Congestion cost is covered in time cost and the other items are omitted.

So far, we reviewed the societal costs of urban transport from users' point of view, but there are other costs paid or traded by transport companies and government. Transport companies generally receive transport fare from users instead of supplying transport service. They pay a certain amount of money to other sectors for maintaining their transport service, and to the government as tax. The government collects money from transport companies and users of cars and public transport. It is often spent on public transport service and other transport related expense.

TABLE 1. Examples of the Societal Costs of Transport

Moffet J.(1993:USA)	Air/Noise/Accident/Congestion /Energy/Parking and etc.
Maddison D. (1996:UK)	Air/Noise/Accident/Congestion /CO2/Road Damage
Austroads (1994:Australia)	Air/Noise/Accident/Congestion /Energy/Water
Morisugi H. (1995:Japan)	Air/Noise/Accident/Congestion

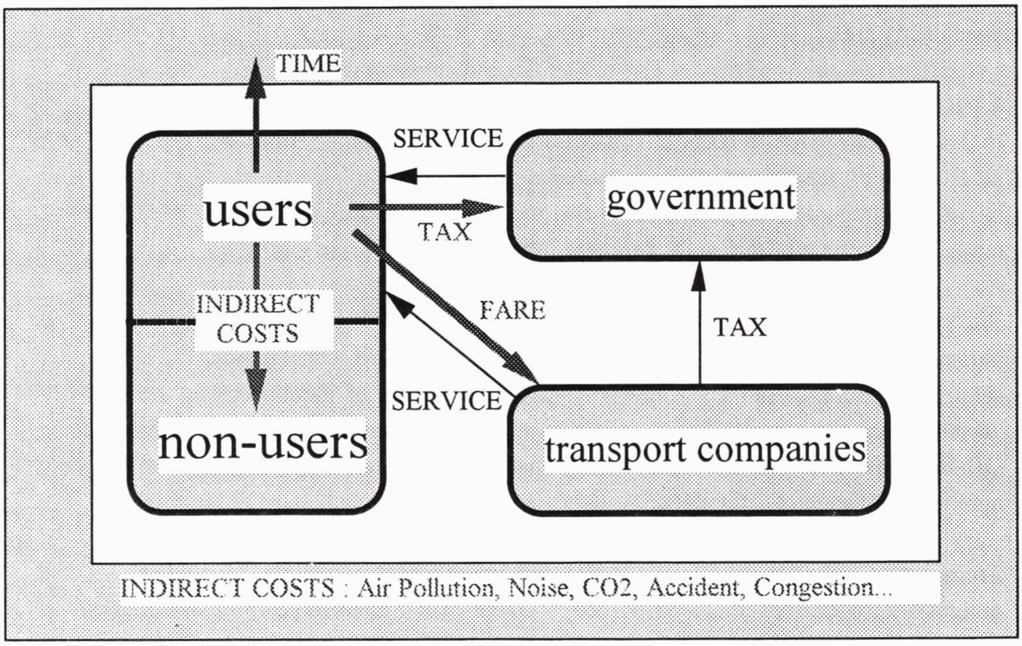

FIGURE 1. The Elements of the Societal Costs of Urban Transport

Although transport companies and the government also play important roles in sharing the costs of urban transport, they are neglected in this study and left to further research. The elements of the societal costs of urban transport and the interrelationship among them are summarized in Figure 1.

2. STUDY AREA AND RESEARCH FRAME

2.1. Study Area

As a study area, we selected Sendai City, a Japanese city located in 350km north of Tokyo. The population of Sendai City was about one million and that of metropolitan area was about 1.5 million. Because Sendai City was large enough to sustain various sorts of public transport system such as suburban commuter rail, subway and bus, we could compare the costs of urban transport by public transport modes. Person Trip Survey of Sendai City in 1992 and Traffic Census of 1994 allowed us to analyze the trip distribution pattern in Sendai City geographically. We could also compare the costs of urban transport by the time of day. The location of Sendai City within Sendai Metropolitan Area is shown in Figure 2 with its road network system.

Inhabited areas in Sendai City is classified into four groups according to population density as shown in Figure 3. The roads are also segmented by the number of lanes which is assumed to vary the number of traffic accidents per traffic volume. We estimated the indirect costs of urban transport first by each group and later aggregated them in total Sendai City area.

2.2 Research Frame

In order to estimate the costs of urban transport by area, mode, time and item, we built urban transport demand model. The model is divided into three parts, transport modal split model, assignment model and indirect cost model. The structure of urban transport demand model and the relationship among three sub-models are shown in Figure 4.

Transport modal split model is a conventional multinomial logit model whose estimated parameters are listed in Table 2. The alternative modes are car, bus and rail (including suburban commuter rail and subway) and the three sets of parameters for peak (7:00-10:00) commuting, peak non-commuting and off peak are estimated, given hourly fixed OD flow matrices. The time and money costs of rail mode are pre-determined and only applied for this modal split stage.

Transport assignment model targets car and bus alternatives of modal split model and assigns transport demand to each road segment. Typical BPR performance function is adopted and equilibrium assignment technique is applied repeatedly for one hour term from 7:00 to 10:00. The modified time and money costs are feedbacked into modal split model until the equilibrium conditions are satisfied.

FIGURE 2. Sendai City and its Road Network

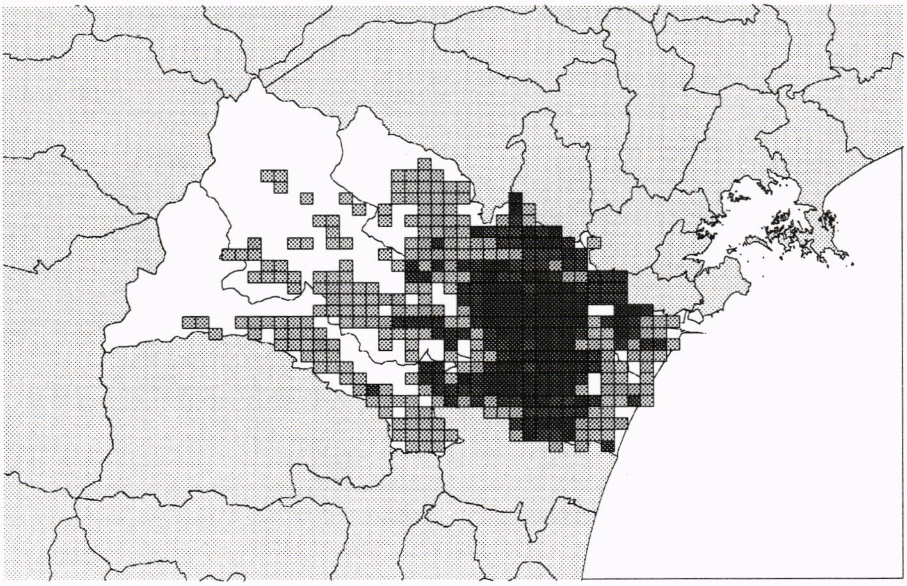

FIGURE 3. Population Density of Sendai City (4000/800/300/0km2)

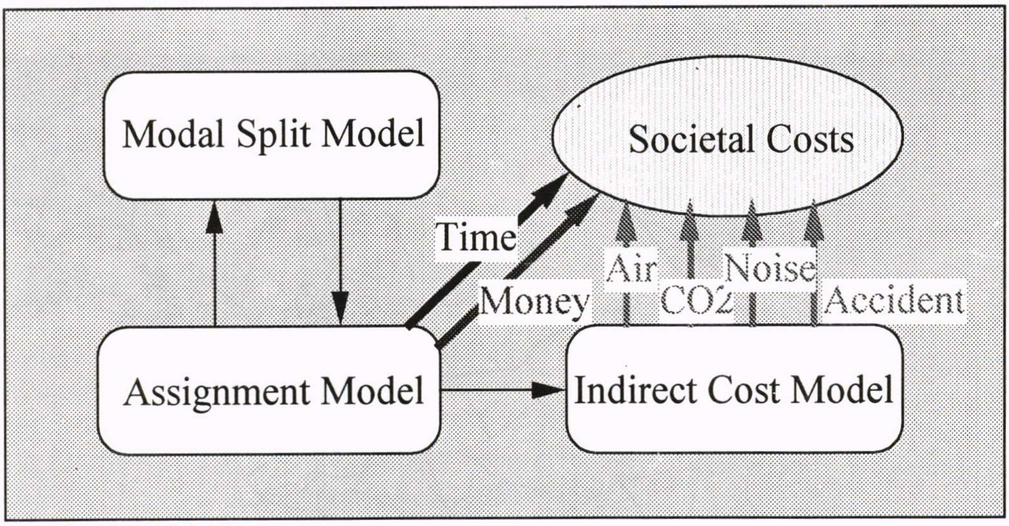

FIGURE 4. The Structure of Urban Transport Demand Model

TABLE 2. The Parameters of Modal Split Model

	Peak	Commuting	Peak	Others	Off Peak	
		(t-value)		(t-value)		(t-value)
Car Time(min)	-0.0632	-72.90	-0.0543	-58.68	-0.0565	-74.80
Bus Time(min)	-0.0819	-56.74	-0.0412	-26.77	-0.0491	-40.61
Rail Time(min)	-0.1698	-97.81	-0.0864	-51.72	-0.1061	-75.75
Out of Vehicle Time	-7.3792	-163.38	-4.7001	-94.52	-5.4642	-147.12
Cost(1000yen)	-1.8132	-24.44	-2.2205	-28.65	-2.4596	-39.19
Bus Dummy	-0.3594	-16.35	-1.2751	-47.15	-1.1352	-63.62
Rail Dummy	4.1990	124.62	1.8593	51.57	2.0459	77.28
L(0)	0.2047		0.1212		0.2553	
L(B)	0.1482		0.0901		0.1751	
RHO2	0.2758		0.2567		0.3144	
Sample	13372		7511		15764	

Indirect cost model is straight forward. The unit costs of each indirect costs are multiplied by the intensity of activity such as traffic volume. Traffic volume and other indices for unit categorization are given by the previous two models. A series of unit costs and equations are summarized in Table3 and emission factors of NOx and CO2 are in Figure 5.

3. THE SOCIETAL COSTS OF TRANSPORT

3.1 Time and Money

First, unit costs of time and money by each mode are compared. Time cost of bus users and railroad users are composed of in-vehicle time and out-of-vehicle time. Although the parameters of transport modal split model in Table 2 implied the different value of time for in-vehicle time and out-of-vehicle time, here a common value of time, 30 (yen/minute) is used for the simplicity. Time cost of car users is directly given by assignment model and transformed into monetary term by multiplying the same VOT.

As money cost of car users, the costs of parking, registration, maintenance and depreciation in addition to a car itself are generally covered by users, but in this study all of those items were omitted because of the lack of information. Only the cost of fuel is taken into account. Money cost of bus users and railroad users is just transport fare paid directly to transport companies.

Figure 5 shows the different unit costs (per person-km) of each transport mode for peak hours (7:00-10:00). The costs of car and rail modes are much cheaper than that of bus, which is reflected in the modal share of each mode. To look into the category of direct costs, the dominance of time cost is common among three modes. Time cost of bus mode is mostly incurred by out-of-vehicle time. This implies that the share of bus mode is small not only because of fare and speed, but because of difficulty of access.

3.2. Air Pollution

The costs of indirect items, air pollution, CO2, noise and traffic accident are only estimated for car mode, because the indirect costs of other modes are mostly negligible. The unit costs used in this study follow the guidelines (1998) with slight modification.

As air pollutants, we only estimated the total emission of NOx. Because SPM is mainly emitted by trucks not considered in this study and the monitoring values of other substances such as SOx and CO are generally within the acceptable level in Japan. A shown in Table 3, the unit costs of NOx emission are given according to the location classified by population density. The total emission from a certain road segment is estimated by multiplying the emission factor of the speed of that segment by the traffic volume of that segment, both of which are given by assignment model in chapter 2.

3.3. CO2

The cost of emitting CO2 from cars is estimated also by multiplying the unit cost of

TABLE 3. The Methods of Indirect Costs Estimation

Air Pollution(NOx): A*2920000yen/t+B*580000yen/t +C*200000yen/t+D*10000yen/t
CO2:2300yen/t-C
Noise:A*270yen/km*(Leq-55)+B*54yen/km*(Leq-55) +C*19yen/km*(Leq-55)+D*0.82yen/km*(Leq-55)
Accident:A&2lanes*6438000yen*Rate/vkm +B&2lanes*7169000yen*Rate/vkm+...
A/B/C/D-if located in the area whose population density is over 4000/#800/#300/0 persons/km2 (#:estimated by the author)

(Quoted from the committee for guidelines for road investment assessment(1998))

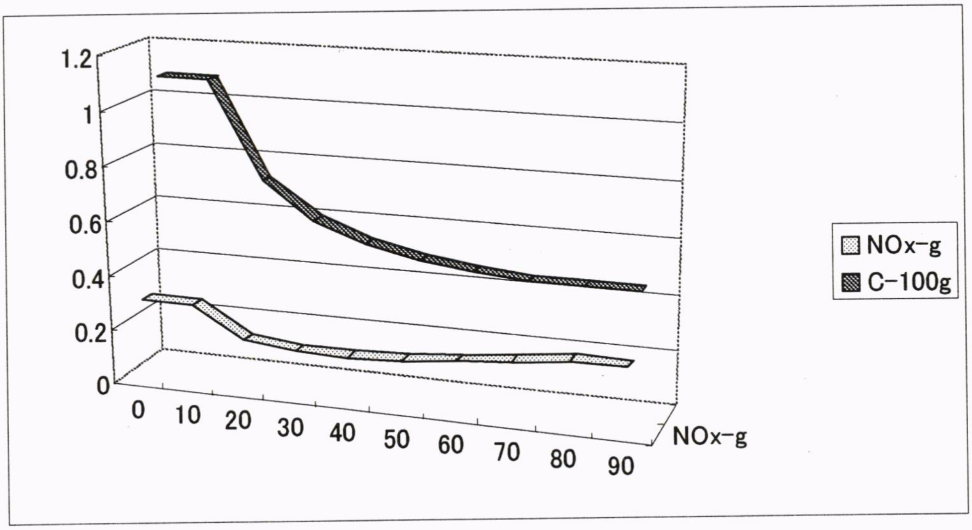

FIGURE 5. Emission Factors of NOx and CO2
(Quoted from Tokyo Metropolitan Government(1996))

emission (2300yen/ton) by the total emission. The unit cost was quoted from foreign studies.

3.4. Noise

The unit costs of traffic noise is shown in Table 3. Those values are a summary of preceding domestic studies on the effects of traffic noise on the value of land nearby. They were also calculated under the assumption that the effects were limited to 60% of the areas within 20m of the centerline of road and 12 hours per day. The unit is categorized by population density and noise level(Leq-dB(A)) . The equations for predicting the noise level from traffic volume and speed of each road segment are also shown in Table 3. The effects of sound barriers and high buildings were not counted because of the lack of information.

3.5. Traffic Accident

The unit costs of traffic accidents are also given in Table 3. The values are classified by the number of lanes as well as population density. The cost of traffic accident is assumed to be composed of three parts, the cost of human life and injury, the cost of infrastructure damage and the cost of traffic congestion caused by traffic accident. Roughly , the first category shares a half of the cost, while the second and the third share a quarter respectively. To estimate the total cost, we multiplied the traffic volume outputted from transport model by those unit costs according to the categorization .

3.6. Indirect Items

The estimation of indirect costs is summarized in Figure 6. As compared with preceding studies on the cost of transport listed in Table 1, the share of noise cost is relatively high in Sendai City. Considering the structure of Sendai City with the central area being densely inhabited, the result is quite understandable. The ratio of indirect costs of car users to direct costs was estimated to be about ten percent. This also shows fuel tax only cannot cover those indirect costs of car modes and we need further research on comparison between the total tax payment of car users and indirect costs of car mode imposed on the society as a whole. Although the relative weight of the costs of indirect items was similar to other studies, it is noted again that we did not include the cost of goods movement, which explains the most part of NOx and SPM emissions as well as noise pollution.

4. SCENARIO ANALYSIS AND POLICY IMPLICATIONS

Finally, scenario analysis was carried out for investigating the sensitivity of urban transport demand model and each category of the societal costs of urban transport. Two basic scenarios were adopted, one for the policy of increasing fuel tax and another for the policy of implementing cordon pricing whose cordon lines are pictured in Figure 2. The various levels of fuel tax and cordon fee were tested as shown in Table 4. The share of car, bus and rail mode and the generated direct and indirect costs were investigated.

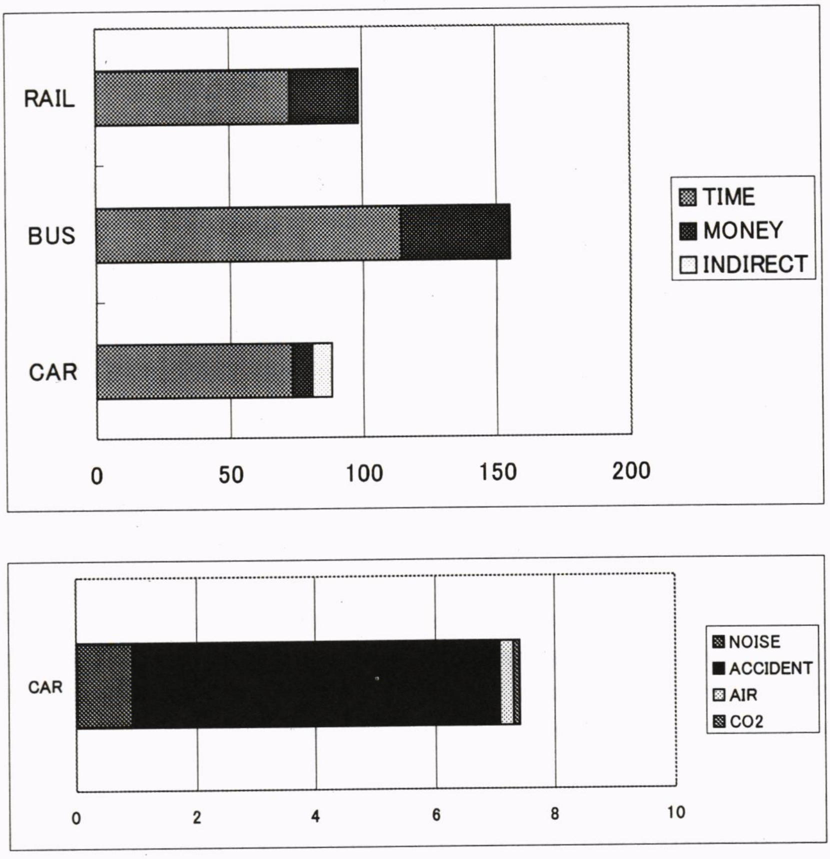

FIGURE 6. The Unit Costs of Direct and Indirect Items (per person-km)

TABLE 4. Policy Scenarios

	Fuel Tax(53.8 yen/l)	Cordon Pricing
Cordon Pricing 1000yen	53.8*1	1000 yen
Cordon Pricing 500yen	53.8*1	500yen
Base	53.8*1	0 yen
Fuel Tax *2	53.8*2	0 yen
Fuel Tax *3	53.8*3	0 yen

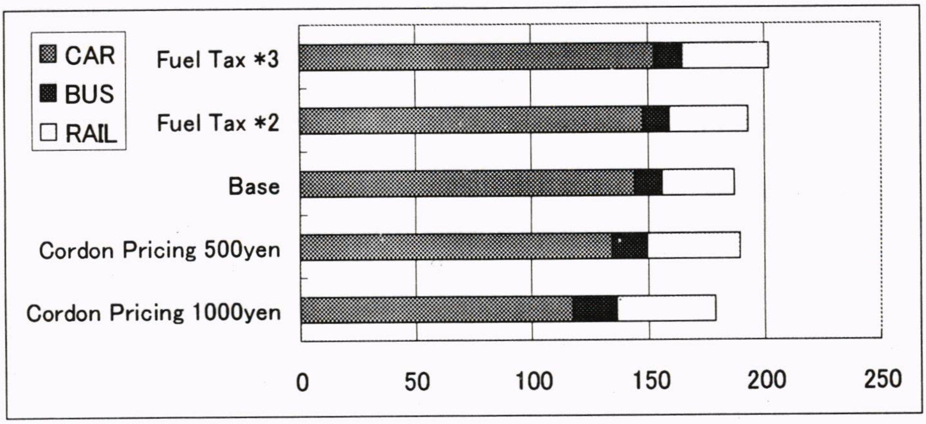

FIGURE 7. Direct Costs of Scenario Analysis (1M.yen)

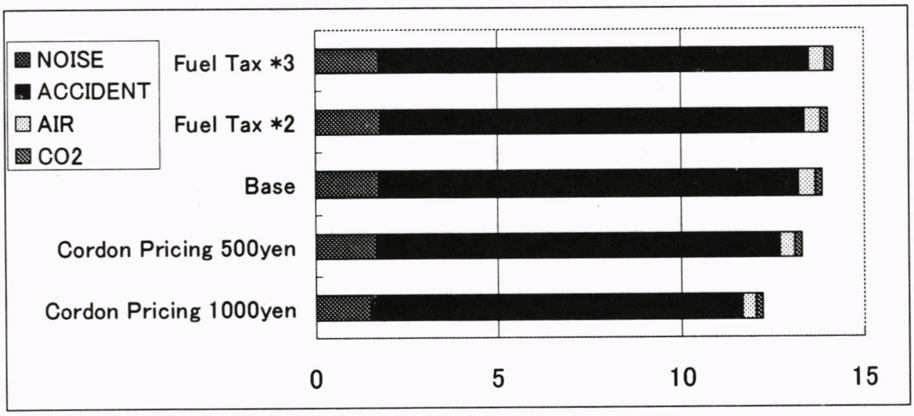

FIGURE 8. Indirect Costs of Scenario Analysis (1M.yen)

Figure 7 shows the result of direct cost estimation. As indicated in Figure 6, the time cost of public transport was high enough to make a small amount of increase in money cost of car mode negligible except a radical scenario "cordon pricing 1000 yen". The modal share were almost the same between two policies, but the revenue of fuel tax was higher than that of cordon pricing according to the scale of area affected by those policies.

Figure 8 shows the result of indirect cost estimation for car mode. Cordon pricing policy decreased indirect costs, while fuel tax policy somewhat increased them unexpectedly. As to the indirect costs generated in the center of Sendai City, cordon pricing is more sensitive to reduce the indirect costs, because cordon pricing is more geographically discriminated and more responsive to the structure of Sendai City with relatively strong city center. On the other hand, fuel tax hike may cause more costly trips in the areas where attractive alternative to car mode is not available.

5. CONCLUSION

In this study, we categorized the societal costs of urban transport into three, time, money and indirect costs. In Sendai City case study, we built urban transport demand model and estimated each category of the societal costs of transport. Finally, the sensitivity of each cost item to pricing policy such as increase in fuel tax and cordon pricing was investigated.

In conclusion, first, the dominance of time cost of public transport was clear, which implied the problem of low modal share of public transport was not only the problem of fare, money cost, but the problem of access system. Second, by calculating indirect costs of car modes in Sendai City, we indicated the cost of traffic noise was relatively higher than the value estimated in preceding studies. This was explained by the high population density of central area in Sendai City. Third, though apparent from the second conclusion, in order to reduce indirect costs of car mode, cordon pricing was advantageous because it was more geographically discriminate policy.

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