DEMAND AND SOCIO-ECONOMIC ANALYSES OF DIRECT-THROUGH OPERATION OF SHINKANSEN SERVICE TO EXISTING NETWORK

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Abstract: This paper focuses on a project for a direct-through operation of inter-city high-speed railway service, by which passengers can move between large city and local city without any transfer. For analyses of the project, we developed an original transport demand forecasting model, which consists of four sub-models. Since the sub-models are connected each other by inclusive variables, we can examine that a change of the railway service impacts on not only the railway route choice, but also the modal choice, the destination choice and the generation of transport. After estimating coefficients of the models, we applied it to the Yamagata Shinkansen Project to evaluate the socio-economic impact.

Key Words: Direct-through Operation, Inter-city High-speed Railway, Demand Analysis, Socio-economic Analysis, Shinkansen Line

1. INTRODUCTION

In the past thirty years, the so-called "Full Shinkansen" service has been developed to connect highly density areas in Japan. The FS (Full Shinkansen) network has reached to more than 2,000 km by the year 2000 and the FS trains can run at more than 260 km/h on the FS network. Its fast and safe service attracts many inter-city travelers. More than 850,000 passengers use it per day in 1999. The FS can provide high-speed service because its line uses highly developed structures and it is independent from other local railway lines and highways. This means that a level of geometric features is very high and the network consists only of elevated structures, tunnels and bridges with no sections at-grade. Even though time savings to be benefited by constructing a new FS line is very significant, its cost is very expensive. Therefore, the FS can be only constructed between cities with high demand.

The government of Japan (Ministry of Transport, 2000) insists on the necessity of a wider high-speed transport network including construction of inter-city railway, airports and inter-city expressways. In regards to the high-speed railway network, three new Full Shinkansen lines are under construction at the year 2000. However, even after completing those new lines, we cannot judge that we have completed the high-speed railway network of Japan. We need to pursue more mobility for a coming aged society, and actually there are many claims for more high-speed network. However, we are facing difficulty to provide the FS service immediately due to financial problems.

Recently, a new kind of railway service has started between Tokyo and Yamagata, and between Tokyo and Akita. Those service enables the FS trains to run directly on local railway lines through improved connecting stations. In addition to that, the local railway lines were also partly improved for running at a higher speed. This improved the feasibility of constructing the new FS facilities. The new service also provides added benefits as travelers can reach the destination without any transfer. Many people expect that we can apply the same kind of service to other places where the travel demand is not high enough to construct a new FS line.

As far as demand and socio-economic analyses are concerned, it is easier to predict the effect of an FS project, because it impacts clearly on population patterns and industrial structures. On the contrary, as for the direct-through operation project, it is not so easy to analyze its effect by the same analysis tool as the FS project, because its impact is less clear than the FS project and its range is quite local. Moreover, its effect stems mainly from reducing transfer. Therefore, we need to make a new numerical tool for forecasting the impact of the direct-through operation projects. This paper aims to develop a transport demand model, by which we can estimate the impact of the direct-through operation of the FS service and evaluate socio-economic effects. After completion of the model, we applied it to an example case to examine the model's transferability.

2. BASIC CONCEPT OF THE MODEL

2.1 Basic Structure of the Model

The direct travel service of inter-city high-speed railway will reduce passenger's burden of transfer at connecting stations. Without the direct travel service, a railway passenger who would like to visit cities outside the FS service area needs to get off at the connecting station and change to another train. He/she needs to walk from one platform to another in the station with heavy bags and may have to wait for the appropriate train. If the train goes to the destination directly, he/she does not experience such transfer at all. This may impact on railway route choice when there are more than one route from origin to destination. In addition, travelers of air transport may change to high-speed railway. If a terminal is a resort city, people may change their leisure place and if the terminal is a business city, business people may change their business destination as well.

As mentioned above, the direct-through operation of high-speed railway service causes a chain-reaction of travel demand. This means that we cannot evaluate its impact independently. Therefore, we introduce an integrated four-step demand model to this problem. The integrated model consists of four sub-models: Generation Sub-model; Destination Choice Sub-model; Modal Choice Sub-model; and Railway Route Choice Sub-model. The calculation flow of the integrated model is depicted in Fig.1. Because all sub-models are inter-connected by inclusive values, we can evaluate an impact of the project on all sub-choices of travelers. The inclusive

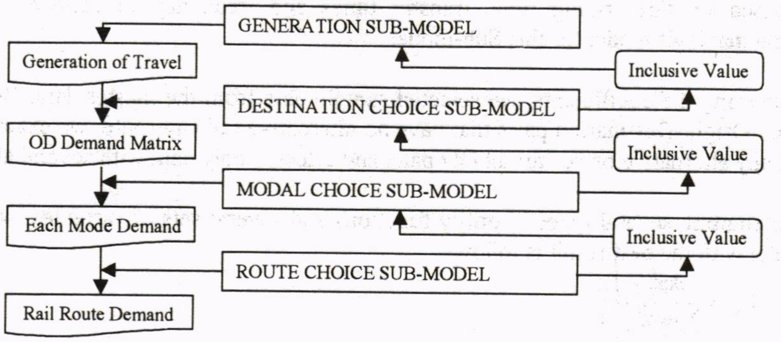

Fig.1: Flow Chart of the Integrated Model for High-speed Inter-city Railway Demand

value is a measure of benefit of a certain choice item in the model.
The improvement of high-speed inter-city railway service impacts on many types of travels, such as business travel and leisure travel, and its features are different as well. Therefore, we grouped the travel data into three categories according to traveler's purposes: business travel, leisure travel and the private travel. The private travel includes such as a visit to relatives, a visit for ceremony, etc. Then we estimated the coefficients of the sub-models for the three types of travel purposes separately.

2.2 Travel Data

We used the National Survey on Inter-city Passenger Travel of Japan in 1995 as data, but we arranged it from the viewpoint of traveler's attribute. When we see a data in which a traveler moves from a certain city (we say city O) to an other city (city D), we recognize whether the traveler inhabits in the city O or the city D. If he/she lives in the city O, the travel from O to D means visiting the city D, while if he/she lives in the city D, the travel means returning to city D. In this paper, we regard traveling from a city of residence and returning travel to the city of residence separately. Of course, we can find some travel data of people living neither in the origin city nor in the destination city, this means that the travelers move around several cities. However, those travels are much less than the go-and-return type of travels, we ignored such travel data.

The integrated model covers the whole nation of Japan except some isolated islands. We divided the nation into 207 zones and we aggregate the personal travel data into zonal data.

3. MODEL ESTIMATION

We estimated coefficients of the four sub-models step by step. Because an upper sub-model has an inclusive variable which is calculated based on a lower sub-model, we needed to start the estimation from the lowest sub-model, the Railway Route Choice Sub-model.

3.1 Railway Route Choice Sub-model

The Railway Route Choice Sub-model calculates the number of passengers who select a railway route among several alternatives from an origin zone to a destination zone, when the number of railway passengers is given by the Modal Choice Sub-model. A traveler chooses a route based on fare, riding time, transfer times and frequency of service. We apply a multi-nominal logit model for this Sub-model.

For estimating the coefficients, we selected sample data from the master data. Because there are many Origin-Destination pairs that have no alternative railway route, we examine whether there is any alternative or not for all OD pairs and selected only data with several alternatives.

After attempting several types of utility functions and several sets of variables, we found that the model with the best result is follows:

$$P_{R_i} = \frac{\exp(V_{R_i})}{\sum_j \exp(V_{R_j})} \quad (1)$$

$$V_{R_i} = a_1 T_i + a_2 C_i + a_3 N_i + a_4 \ln(K_i) \quad (2)$$

where

P_{R_i} : Probability of choosing a railway route i of an OD pair

V_{R_i} : Utility of choosing a railway route i of an OD pair

T_i : Total riding time of a railway route i of an OD pair

C_i : Total fare of a railway route i of an OD pair

N_i : Total transfer times of a railway route i of an OD pair

K_i : Frequency of service of a railway route i of an OD pair

a_j : Coefficient of the j-th variables of the utility function.

Here we omit subscripts of origin zone and destination zone in equation (1) and (2).

The result of estimation is shown in table 1. We find a ratio of cost to a riding hour, that is, the value of time to be about 3,400 yen/hour for business purpose; 2,500 yen/hour for leisure purpose; and 3,900 yen/hour for private purpose. Because an average wage of workers in Japan is about 2,500 yen/hour in 1998, we can feel that the values of time of these results are quite appropriate. Also we can find that the ratio of riding minutes to transfer times to be about 40.

Table1: Estimation Results of Railway Route Choice Sub-model

		Business		Leisure		Private	
Variable name	unit	Coefficient estimated	t statistic	Coefficient estimated	t statistic	Coefficient estimated	t statistic
Riding time(T)	minute	-0.01872	-12.1	-0.01780	-6.5	-0.01697	-7.7
Fare(C)	yen	-0.03276	-5.2	-0.04236	-6.1	-0.02571	-2.5
transfer times(N)	time	-0.0006772	-5.7	-0.0006552	-3.7	-0.0007171	-3.5
Frequency(K)	per day	-0.9841	-5.7	0.3487	1.4	0.4886	1.9
Basic statistics							
Number of samples		1,498		553		414	
hit raio	%	86.5		87.0		82.9	
ρ^2		0.5511		0.5269		0.4516	

3.2 Modal Choice Sub-model

By the Modal Choice Sub-model, we can calculate the number of railway passengers for all OD pairs. Because air transport, railway, bus and private automobile are affected by the direct-through operation of high-speed railway service, we regard these four transport modes as alternatives in the Modal Choice Sub-model. If a traveler uses several transport modes from origin to destination, we choose a primary mode from the four travel alternatives. Its priority is as follows; the first is air transport; the second is railway; the third is bus; and the fourth is automobile.

We divided the sub-model into two models; one is a choice model between automobile and public transport: the other is a choice model of public transport among railway, air transport and bus. The structure of choosing travel mode is depicted in Fig.2. We formulated the model as a NL (Nested Logit) model. This is because we consider that a market of automobile users is different from the one of public transport users since a trip length via automobile is much shorter than the trip length via public transport.

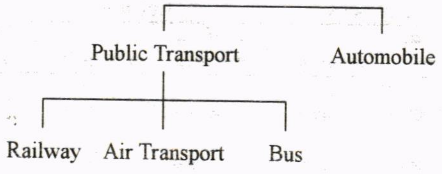

Fig.2: Structure of modal choice sub-model

Public Transport Choice

We apply a MNL model for the choice of public transport, shown as

$$P_m = \frac{\exp(V_m)}{\exp(V_R)+\exp(V_A)+\exp(V_B)} \tag{3}$$

$$V_m = b_1 T_m + b_2\ C_m + b_3 \ln(K_m) + b_4 LS_R + b_5 \delta_A + b_6 \delta_B \tag{4}$$

where

P_m : Probability of choosing public transport m

V_m : Utility of choosing public transport m

T_m, C_m, K_m : Riding time, cost and frequency of service of public tranport m except railway

LS_R : Inclusive value of railway, which is expressed as

$$LS_R = \ln\left(\sum_{i=1} \exp(V_{R_i})\right) \tag{5}$$

in which V_{R_i} is the utility of railway route i, which is used in the Railway Route Choice Sub-model

δ_A : Dummy variable for air transport

δ_B : Dummy variable for bus

b_k : Coefficient of the k-th variables of the utility function.

The estimation results are shown in Table 2. The value of time is about 5,200 yen/hour for the business travels; 3,700 yen/hour for the leisure travels; and 3,500 yen/hour for the private

Table2: Estimation results of Public Transport Choice model

		Business		Leisure		Private	
Variable name	unit	Coefficient estimated	t statistic	Coefficient estimated	t statistic	Coefficient estimated	t statistic
Riding time(T)	minute	-0.009759	-29.4	-0.005798	-6.5	-0.007501	-17.1
Cost(C)	yen	-0.0001138	-14.7	-0.00009490	-6.1	-0.0001298	-8.5
Frequency(K)	per day	0.4394	8.0	0.3210	3.0	0.2882	2.7
Inclusive value(LS)	time	0.4546	42.0	0.3168	19.5	0.3421	18.6
Specific dummy for air	1,0	0.1194	3.4	-0.5731	-1.2	0.4578	4.4
Specific dummy for bus	1,0	-0.1294	-8.2	-1.446	-5.8	-1.419	-5.7
Basic statistics							
Number of samples		13,194		3,081		1,976	
hit raio	%	78.5		75.8		67.7	
ρ^2		0.2184		0.2223		0.2701	

Table3: Estimation results of the modal choice model between public transport and automobile

		Business		Leisure		Private	
Variable name	unit	Coefficient estimated	t statistic	Coefficient estimated	t statistic	Coefficient estimated	t statistic
Travel time of automobile(T)	minute	-0.00876	-49.7	-0.008252	-27.5	-0.01153	-18.7
Inclusive value of public transport(LS)		0.8654	38.2	0.8839	15.6	0.9765	10.4
Specific dummy for automobile	1,0	-0.1830	-20.7	1.827	17.1	-2.429	-18.5
Basic statistics							
Number of samples		13,529		4,701		1,997	
hit raio	%	79.5		76.0		76.1	
ρ^2		0.2116		0.2289		0.2680	

travels.

Modal Choice between Public Transport and Automobile

We apply a BNL model for the choice between public transport and automobile shown as

$$P_M = \frac{\exp(V_M)}{\exp(V_C)+\exp(V_P)} \quad (6)$$

$$V_M = d_1 T_C + d_2 LS_P + d_3 \delta_C \quad (7)$$

where

P_M : Probability of choosing mode M

V_M : Utility of choosing mode M

T_C : Travel time of automobile

LS_P : Inclusive value expressed as

$$LS_P = \ln(\exp(V_R)+\exp(V_A)+\exp(V_B)) \quad (8)$$

in which V_R is the utility of railway; V_A is the utility of air transport; and V_B is the utility of bus, which are used in the public transport modal choice model

d_l : Coefficient of l-th variable in equation (7).

The result of estimation is shown in Table 3. Here, we did not use travel cost of automobile as a variable in the utility function, because it has very high correlation with travel time.

3.3 Destination Choice Sub-model

The Destination Choice Sub-model expresses that a traveler from an origin zone chooses a destination zone among alternatives. As the alternatives we used fifty zones of the nation, which nearly correspond to prefectures of Japan. This is because there would be too many alternatives if we used the 207 zones as well as other sub-models. In this model, we neglect travelers whose origin zone is the same as the destination zone.

Because we expected that a traveler considers not only the utility of transportation but an attractiveness of the destination city, we attempt several variables for the attractiveness of zones: working population and average yield of industrial product for the business travels; the number of hotels and area of national nature park for the leisure travels; and night population and average income for the private travels.

The model is expressed as

$$P_{rs} = \frac{\exp(V_{rs})}{\sum_{n=1}^{N} \exp(V_{rn})} \tag{9}$$

$$V_{rs} = g_1 Y_s + g_2 LS_{rs} \tag{10}$$

where

P_{rs} : Probability of choosing destination zone s from an origin zone r

V_{rs} : Utility of chooosing destination zone s from an origin zone r

Y_s : Total income of resident in zone s

LS_{rs} : Inclusive value of travel expressed as

$$LS_{rs} = \ln\left(\exp(V_{C,rs}) + \exp(V_{P,rs})\right) \tag{11}$$

in which $V_{M,rs}$ is the utility of choosing travel mode M from zone r to zone s, which is used in the modal choice model

g_p : Coefficietns of p-th variable in the utility function.

Estimation results of coefficients are shown in Table 4.

Table4: Estimation results of the Destination Choice Sub-model

		Business		Leisure		Private	
Variable name	unit	Coefficient estimated	t statistic	Coefficient estimated	t statistic	Coefficient estimated	t statistic
Resident income of destination zone(Y)	hundred billion yen	0.005762	2.4	0.002870	1.3	0.004479	2.0
Inclusive value of transportation(LS)		0.4356	1.6	0.3841	2.9	0.5300	2.6
Basic statistics							
Number of samples		1,355		1,139		1,121	
ρ^2		0.2287		0.1621		0.2293	

3.4 Generation Sub-model

We finally developed the Generation Sub-model. By this model, we can calculate the number of travelers generating at each zone. We expected that the generation of travelers depends on socio-economic activity and mobility of the zone.

Therefore, we applied such a function as

$$\ln(G_r) = h_1 \ln(Y_r) + h_2 \ln(LS_r) + h_3 \tag{12}$$

where

G_r : Number of travelers generating at zone r

Y_r : Total income of resident in zone r

LS_r : Inclusive value of destination from zone r

$$LS_r = \ln\left(\sum_s \exp(V_{rs})\right) \tag{13}$$

h_q : Coefficient of q-th variable in the equation (12).

A result of the estimation is shown in Table 5.

Table5: Estimation results of the Generation Sub-model

		Business		Leisure		Private	
Variable name	unit	Coefficient estimated	t statistic	Coefficient estimated	t statistic	Coefficient estimated	t statistic
Resident income of destination zone(Y)	billion yen	0.7405	9.3	0.4471	5.1	0.5764	6.4
Inclusive value of transportation(LS)		0.3297	2.1	0.9185	3.6	0.3397	2.3
constant		1.834	3.4	1.443	1.7	0.2088	3.4
Basic statistics							
Number of samples		50		50		50	
Correration Coefficient		0.8472		0.7096		0.7319	

4. APPLICATION OF THE MODEL

We applied the model to a project for the direct-through service of the Full Shinkansen, called the Yamagata Shinkansen project, to evaluate the socio-economic impact of the project. First of all, we will show an outline of the project and the application, and then, discuss the effect of the project.

4.1 Outline of the Yamagata Shinkansen project

The Yamagata Shinkansen runs between Fukushima and Yamagata, which is about 87 km long. Map of the line is depicted in Fig. 3. Both Fukushima and Yamagata are located at the northern part of Japan about 300 km from Tokyo. Although Fukushima is not a large city compared to other neighboring cities, it is on the way from Tokyo to Sendai, one of the largest cities in Japan, therefore, it is a station of the Tohoku Shinkansen line, one of the FS lines. On the other hand, Yamagata is a prefectural capital with 255,000 population in Yamagata City

Fig.3: Map of Yamagata Shinkansen Line

(1999). It is popular as one of major resort cities in Japan. However, the FS does not reach Yamagata, because it locates beyond a mountain ridge apart from the Tohoku Shinakansen line.

Before the start of the Yamagata Shinkansen service, railway travelers from Tokyo to Yamagata had to select a railway route among two alternatives: one is to ride the Tohoku Shinkansen to Fukushima and to change at Fukushima to another train bound for Yamagata; the other is to ride the Tohoku Shinkansen to Sendai and to change it at Sendai to another train bound for Yamagata (the Senzan line). As far as travelers used railway, they needed to transfer once at a connecting station. Many people appealed to improve accessibility to Yamagata. Moreover the government has announced the "Development for a Balanced Nation" as a national policy. As a result, a survey was started to study the feasibility of the project. Because the Senzan line runs through mountain areas, engineers judged it is impossible to improve the Senzan line immediately. Consequently, it was determined to push through the Yamagata Shinkansen project. The direct train service started between Tokyo and Yamagata in 1992. This service enabled travel time between Tokyo and Yamagata to decrease from 189 minutes to 147 minutes.

4.2 Demand and benefit analyses by an application of the model

By using the developed model, we analyzed the demand and socio-economic impact of the Yamagata Shinkansen project. After we define alternative cases, we applied the model into these cases and we examine the socio-economic effect by cost-benefit analysis.

Alternative cases

In order to analyze an effect of the project, we need to define alternative cases in advance. We consider the following two cases: one is "with case" and the other is "without case". The "with case" means a situation in which the project has been completed and the new service is started, whereas the "without case" means a situation in which the project is not conducted.

In fact, we can observe not only the change of railway service but also other changes caused by other projects, such as a start of new expressway service near Yamagata or a decline of air transport service between Tokyo and Yamagata. However, we could not predict those actions by other transport operators due to the railway project just by our demand forecasting model. If we would like to consider them, we might need to develop an additional model, which may include the behavior of transport operators. Such model is out of the scope of this paper, therefore, we assumed that only the Yamagata Shinkansen service is started and the other elements remain constant in the "with case".

The two cases are shown in Table 6. We applied our model to these two cases and compared the results each other to analyze the effect of the project.

Table 6: Alternative Cases in Yamagata Shinkansen Project

	unit	without case	with case
Travel time(Fukushima-Yamagata)	minute	78	61
Frequency of service	per day	12	14
Transfer time at Fukushima Sta.		1	0
Other service level of transport		Equal to LOS in 1989	Equal to LOS in 1995

Demand analysis

The results of demand analyses are shown in Fig.4a to Fig.4d. We can discuss the impacts on the transportation demand quantitatively. First, Fig.4a shows us that business travelers from Yamagata prefecture increases by 2 %, while leisure and private travelers do not increase so much. Second, Fig.4b illustrates that travelers between Tokyo and Yamagata increases by around 5 % due to the project, most of which are business travelers. Third, Fig.4c displays that railway demand increases by about 5 % while other transport modes lose their shares of demand. Especially, the air transport demand decreases by about 15%. This result coincides with the real situation that airline operators decreased the number of flights between Tokyo and Yamagata from 1993 to 1999. Finally, Fig.4d shows that a route via Fukushima becomes much more attractive than the route via Sendai in all travel purposes.

Socio-economic Analysis

We analyzed benefit stemming from the project based on the demand analysis. We calculated the user's net surplus and the railway operator's net profit as the benefit. The user's net surplus consists of time saving, cost saving and other change of level of service such as decreasing transfer times and a change of frequency. It is calculated by the inclusive value of transport, which can be determined by equation (8). The railway operator's profit is calculated by the marginal running cost and the marginal earning, that is the sum of the product of fare and number of passengers for all OD pairs.

As a consequence, we could find that the user's net surplus is about 7.04 billion yen per year and the railway operator's net profit is about 1.28 billion yen per year in 1995.

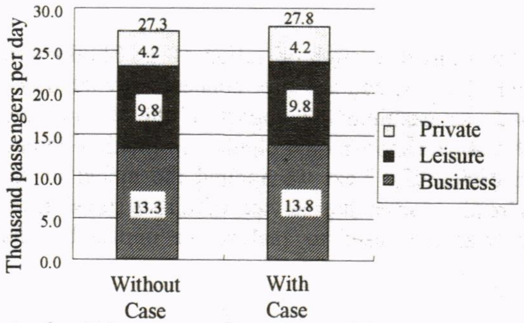

Fig.4a: Result of generation analysis

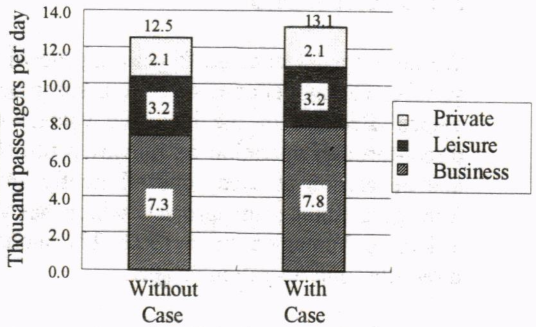

Fig.4b: Result of destination choice analysis

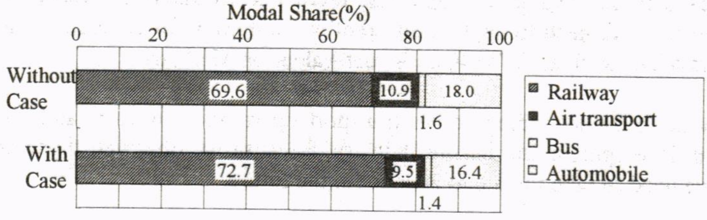

Fig.4c: Result of modal choice analysis between Tokyo and Yamagata

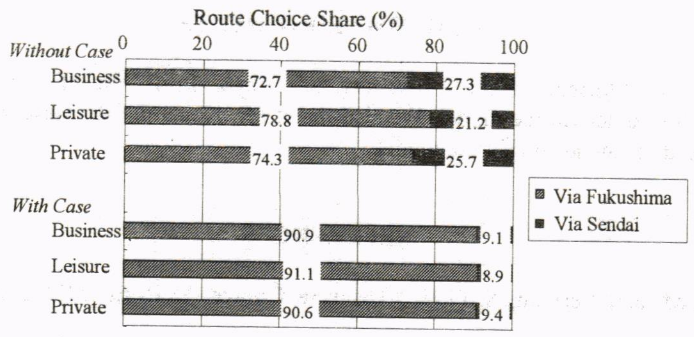

Fig.4d: Result of railway route choice analysis between Tokyo and Yamagata

Based on the calculated benefit per year, we summed it up to total benefit in fifty years. As the data used in the model were observed in 1995, that is, just three years after the start of service, we judged that although it is possible to analyze the demand of a year of 1995, it seems too difficult to analyze the change of the future demand. Therefore, we assumed that the travel demand will be constant from 1995 to the end of analysis period. In addition to that, we assumed four percent as the social discount rate and the calculating base year as 1999. Next, we calculated the construction cost, maintenance cost and re-construction cost in fifty years as well. In this calculation, we excluded taxes in the costs and assumed that train vehicles are changed every thirteen years.

Then we determined that the ratio of the benefit to cost is 1.98 and the economic internal rate of return is 12.3%. This means that this project is very efficient from a socio-economic point of view.

5. CONCLUSIONS

We developed a demand forecasting model for a direct-through operation of the Shinkansen service. The model consists of four sub-models, all of which are inter-connected by inclusive values. Because of the inclusive values, we can examine the impact of the starting the direct-through operation on railway route choice, transport modal choice, destination choice and generation at each zone efficiently and effectively. Next we applied the model to the Yamagata Shinkansen project, which has already started the service of direct travel from Tokyo to Yamagata since 1992. The model was then used to analyze the impact by this direct-through operation project.

Although the suggested model covers only time saving, cost saving and transfer reduction as benefit factors, a direct travel service may impact on not only a physical side but also on the psychological side. For example, people may recognize a value of existence of the direct train service. However, we need to apply a different methodology for evaluating the psychological impact on travelers, such as CVM (Contingent Valuation Method).

And this model does not include other transport operators' behaviors and the other markets such as land development and leisure industry. Because we observed those change in actual examples, we need to take them into account in the future.

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