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Inter-Regional Travel Demand Analysis Using Integrated Model For Practical Travel Demand Forecast

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Abstract: This paper presents a latest inter-urban travel demand model for Japan. It intends the travel demand analysis for private business planning rather than government-based transportation planning. Cross-sectional data from the 2005 Interregional Travel Survey, Japan, is used for the model estimations. The model consists of three sub-models: a trip modal choice sub-model, trip distribution sub-model, and tip generation/attraction sub-model. The trip modal choice sub-model is a nested logit model including an upper tree choice of automobile and public transportation and a lower tree choice of rail, bus, and air transportation; the trip distribution sub-model is an aggregated logit model; and the trip generation/attraction sub-model is a log-linear regression model. The models are verified by comparing the estimated results with the observed data. The proposed model successfully reproduces the current travel demand.

Key Words: *inter-urban travel demand model, passenger travel, integrated model, Japan*

1. INTRODUCTION

The inter-urban travel demand forecast plays an important role in formulating a national transportation policy, including high-speed rail, airport, and expressway network planning. A number of researchers have developed models to forecast future travel demand, particularly in the context of the inter-urban transportation market. These include demand models for air transportation, such as those developed by Grosche *et al.* (2007), Marazzo *et al.* (2010), and Carson *et al.* (2010); demand models for inter-urban rail transportation, such as those developed by Bel (1997), Wardman (1997, 2006), and Marlborough House (2004); demand models for road transportation, such as those proposed by DETR (1997), the Department for Transport (2005), and Mori *et al.* (2010); modal choice models for inter-urban transportation, such as those developed by Ortuzar and Iacobelli (1998), Monzón and Rodríguez-Dapena (2006), and Ahern and Tapley (2008); and integrated demand models for inter-urban passenger transportation, such as those proposed by Van Vuren *et al.* (2001) and WSP (2006). In Europe, multiple travel demand models for passenger transportation have been developed, including SCENES (SCENES consortium, 2001), VACLAV-VIA (Shoch, 2000), and EXPEDITE (de Jong *et al.* 2004). Some of these studies are developed in the framework of a national model. These national models are generally developed by national planning authorities, such as ministries of transportation (Daly, 2000). This is also the case in Japan. Two national travel demand models have been recently developed in Japan. The Institute for Transport Policy Studies (2000) developed one for the long-term domestic travel demand forecast, under the organization of the Ministry of Transport, and the other was developed by the Ministry of Land, Infrastructure, Transport and Tourism (2003), for the domestic air transportation demand forecast in Japan.

This paper adds a latest model to the body of research related to inter-urban travel demand analysis in the context of Japan. Rather than push the state of the art in travel demand modeling, this paper contributes to the discussions on the practical national travel demand forecast. Particularly, it intends the travel demand analysis for private business planning rather than government-based transportation planning. Thus, the proposed models are estimated with public and regularly published data. An inter-urban travel demand model is proposed on the basis of integrated three step models. The cross-sectional data of transportation demand and socio-demographic data were used to develop the models. The model is characterized by its integrated structure in which the inclusive value estimated from a trip distribution sub-model is incorporated into a trip generation/attraction sub-model, while the inclusive value estimated from a modal choice model is incorporated into the trip distribution sub-model. This model structure follows the approach proposed by Kato *et al.* (2001) and Yao and Morikawa (2005). The paper is organized as follows. First, the motivation and goals of this study are discussed. Next, the overview of the model is presented. Then, the three sub-models, including the trip generation/attraction sub-model, trip distribution sub-model, and modal choice sub-model, are formulated. Model verifications are also presented. Finally, achievements are summarized and further research issues are presented.

2. MODEL

2.1 Overview of the Model System

Our model covers the entire nation of Japan. The zoning system follows the current prefectural boundaries, except Hokkaido Prefecture, where it is divided into four zones. In total, 50 zones are used. As inter-zone travel within the metropolitan area is regarded as urban travel rather than inter-urban travel, inter-zone travel is out of our scope within the three metropolitan areas, including Tokyo, Chukyo, and Kinki. The Tokyo Metropolitan Area includes Tokyo, Saitama, Chiba, and Kanagawa Prefectures; the Chukyo Metropolitan Area includes Aichi, Gifu, and Mie Prefectures; and the Kinki Metropolitan Area includes Kyoto, Osaka, Hyogo, and Nara Prefectures. The model includes three sub-models: the trip generation/attraction sub-model, trip distribution sub-model, and modal choice sub-model. The structure of the model is shown in Figure 1. The sub-models are interacted via inclusive values because it is assumed that individuals' decision-making processes, in the context of interurban travel, are interrelated with each other (Koppelman, 1989). The trip generation sub-model is estimated with a log-linear regression model, while the trip distribution sub-model and the modal choice sub-model are estimated with a multinomial logit (MNL) model. The distribution sub-model and modal choice sub-model have a nested structure, using a nested MNL model. In the trip generation/attraction sub-model, the travel demand is categorized into the three types, by travel purpose: business, leisure, and other. In the trip generation sub-model and the trip distribution sub-model, the trips in each category are further divided into two subgroups: home-to-destination and destination-to-home. This leads to six subgroups, including home-to-business, home-to-leisure, home-to-others, business-to-home, leisure-to-home, and others-to-home travels.

2.2 Modal Choice Sub-model

2.2.1 Model formulation

This sub-model estimates the travel demand from an origin zone to a destination zone, by travel mode and by travel purpose. The sub-model is formulated as the nested MNL model of a two-step tree structure. An upper tree includes the options of public transportation and automobile, while a lower tree includes the options of air, inter-urban bus, and inter-urban rail. The probability of choosing a public transportation mode in the lower tree is shown as

$$p_{m1} = \frac{\exp(u_{m1})}{\sum_{m1' \in M1} \exp(u_{m1'})}, \tag{1}$$

where p_{m1} is the probability of choosing a mode, $m1$, u_{m1} is the indirect utility function under the condition that mode $m1$ is chosen, and $M1$ is a choice set consisting of public transportation, including air, inter-urban bus, and inter-urban rail. The systematic portion of the conditional indirect utility function is formulated as

$$u_{m1} = \sum_k \beta_{km1} \cdot X_{km1}, \tag{2}$$

where X_{km1} is the kth explanatory variable of the mode, $m1$, and β_{km1} is its kth coefficient. The probability of choosing an option in the upper tree is determined as

$$p_{m2} = \frac{\exp(u_{m2})}{\sum_{m2' \in M2} \exp(u_{m2'})}, \tag{3}$$

where p_{m2} is the probability of choosing a mode, $m2$, u_{m2} is the indirect utility function under the condition that mode $m2$ is chosen, and $M2$ is a choice set consisting of automobile

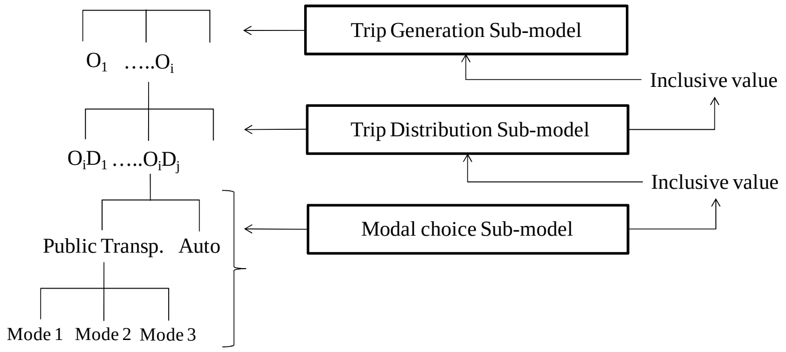


Figure 1 Structure of integrated inter-urban travel demand model

and public transportation. The systematic portion of the conditional indirect utility function is formulated as

$$u_{auto} = \sum_{k'} \beta_{k'auto} \cdot X_{k'auto} \,, \tag{4a}$$

$$u_{pub} = \sum_{k'} \beta_{k'pub} \cdot X_{k'pub} + \beta_{M1} \Lambda_{M1} \,, \tag{4b}$$

where $X_{k'auto}$ is the k' th explanatory variable of automobile, $\beta_{k'auto}$ is the k' th coefficient of automobile, $X_{k'pub}$ is the k' th explanatory variable of public transportation, $\beta_{k'pub}$ is the k' th coefficient of public transportation, Λ_{M1} is the inclusive value, or the logsum variable, derived from the lower tree model, and β_{M1} is the coefficient corresponding to the logsum variable. The logsum variable is defined as

$$\Lambda_{M1} = \ln \sum_{m1 \in M1} \exp(u_{m1}) \tag{5}$$

2.2.2 Data and model estimation

The travel demand data used for the parameter estimation is selected from the database of the 2005 Interregional Travel Survey (Ministry of Land, Infrastructure, Transport and Tourism, 2005). This dataset includes single-day-based individuals' travel episodes, including an origin zone, a destination zone, a chosen travel mode, and a chosen travel route. The database uses a 207-zone system covering the entire nation. As some origin-destination (O-D) pairs include unreliable data due to too low sampling rate in the original dataset, the travel data of the O-D pairs with over 0.6 of standard error are eliminated from the original dataset for the model estimation. As for the explanatory variables used in the indirect utility function, travel time, travel cost, travel distance, and service frequency by travel mode are prepared by the authors. The details of the level-of-service data are shown in Table 1. The total travel time, the total travel cost, the transfer time, and the service frequency are used in the indirect utility function. The total travel time is defined as the travel time from an origin zone to a destination zone, including the access travel time, the in-vehicle travel time, the transfer travel time, and the egress travel time. The total travel cost is defined as the travel expense paid by an individual from the origin zone to the destination zone, including the access travel cost, the in-vehicle travel cost, the fare, and the egress travel cost. The transfer time and the service frequency are defined by the dataset shown in Table 1.

Then, the model parameters are estimated by maximizing the weighted likelihood function in the framework of the Weighted Exogenous Sample Maximum Likelihood estimation, expressed as

$$\max_{\boldsymbol{\beta}} L(\boldsymbol{\beta}) = \sum_{n} \sum_{m} \delta_{nm} \cdot w_n \cdot \ln p_{nm}(\boldsymbol{\beta}), \tag{6}$$

where w_n is the weight parameter corresponding to an individual n, δ_{nm} is equal to 1 if the individual n chose option m and 0 if not, $p_{nm}(\cdot)$ is the probability of choosing option m for individual n, $L(\cdot)$ is the log-likelihood function, and $\boldsymbol{\beta}$ is a vector of coefficients. The weight parameter is introduced to remove the bias between the sample data and population data. It is defined as follows:

$$w_n = \frac{H_n}{Q_n} \,, \tag{7}$$

where H_n is the population proportion for individual n and Q_n is the sample proportion. It should be noted that this could be rewritten as

Table 1 Definitions of level-of-service data used in analysis

Data		Definitions	Assumptions
Rail	Access travel time	Travel time from an origin zone to an origin rail station	It is assumed that an individual uses the bus to access the rail station if the individual travels from an origin zone where no rail station is located. It is also assumed that the individual accesses the rail station by a 15-minute walk from the origin station, where the rail station is located.
	Access travel cost	Travel cost from an origin zone to an origin rail station	
	Egress travel time	Travel time from a destination station to a final destination zone	
	Egress travel cost	Travel cost from a destination station to a final destination zone	
	In-vehicle travel time	Travel time riding the train	
	Transfer travel time	Transfer travel time at station from one train to another train	It is assumed that the transfer travel time is 10 minutes per transfer.
	In-vehicle travel cost	Travel cost paid for the rail service	This includes the additional charge of using the express service or seat reservation.
	Transfer times	Number of transfers at stations	
	Service frequency	Service frequency of express rail service	The service frequency of all directions starting at the origin station
Auto	Total travel time	In-vehicle travel time, rest time, and in-ferry travel time	It is assumed that an individual takes a rest for ten minutes for every two-hours of driving.
	In-vehicle travel time	Travel time by automobile	It is assumed that the travel speed is 35 km/h on an ordinary road and 80 km/h on an expressway.
	Travel distance (ordinary road)	Travel distance running along the ordinary road network	
	Travel distance (expressway)	Travel distance running along the expressway network	
	Travel cost	Fuel cost, engine oil cost, tire/tube cost, maintenance cost, and vehicle depreciation cost	It is assumed that the travel cost is 11.42 yen/km for ordinary road. This is estimated from the average travel cost when a car is running on a flat ordinary road. It is also assumed that the travel cost is 6.50 yen/km for expressways. This is estimated from the average travel cost when a car is running on the expressway at 80 km/h.
	Toll charge	Toll charge including expressway charge	
	Ferry charge	Charge for using ferry service	
Air	Access travel time	Travel time from an origin zone to an origin airport	It is assumed that an individual uses rail to access an airport if the rail service connects the origin zone with the origin airport. It no rail service is available for access to the airport, it is assumed that the individual uses the bus.
	Access travel cost	Travel cost from an origin zone to an origin airport	
	Egress travel time	Travel time from a destination airport to a final destination zone	
	Egress travel cost	Travel cost from a destination airport to a final destination zone	
	Total travel time	Travel time in a airplane	
	Transfer travel time and wait time	Transfer travel time and wait time at airports	It is assumed that the transfer travel time at an airport is 30 minutes while the wait time at the transfer airport is 15 minutes.
	Air travel cost	Air fare	The discounted airfare is used. It is assumed that the discount rate is 20 percent in any airline.
	Service frequency	Service frequency	
Inter-urban bus	Access travel time	Travel time from an origin zone to an origin bus stop	It is assumed that an individual chooses the mode providing the shortest travel time, from rail or city-bus, to access an inter-urban bus stop, if no inter-urban bus stop is located in an origin/destination zone. It is also assumed that the access/egress travel time is 30 minutes if the inter-urban bus stop is located in an origin/destination zone.
	Access travel cost	Travel cost from an origin zone to an origin bus stop	
	Egress travel time	Travel time from a destination bus top to a destination zone	
	Egress travel cost	Travel cost from a destination bus stop to a destination zone	
	In-vehicle time	Travel time riding a bus	
	Transfer travel time and wait time	Transfer travel time and wait time at bus stops	
	Bus travel cost	Bus fare	
	Transfer times	Number of transfer from one bus to another bus	
	Service frequency	Service frequency of inter-urban bus	

Table 2 Estimation results of modal choice sub-models

Lower-tree model		Business		Leisure		Others	
Variable	Unit	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
Total travel time (rail, bus, air)	Minute	-0.02	-150.3**	-0.01	-116.4**	-0.01	-162.8**
Total travel cost (rail, bus)	1000 yen	-0.16	-53.8**	-0.22	-71.7**	-0.20	-78.2**
Total travel cost (air)	1000 yen	-0.02	-11.8**	-0.03	-14.2**	-0.03	-13.5**
Transfer time (rail)		-0.24	-26.8**	-0.03	-3.7**	-0.02	-2.5*
1/frequency (rail)		-2.26	-30.0**	-1.90	-20.4**	-2.09	-31.3**
Constant (bus)		-0.94	-42.8**	-1.29	-53.9**	-0.46	-29.3**
Constant (air)		-4.03	-81.8**	-4.30	-79.5**	-4.64	-89.3**
Rho-squared		0.68		0.59		0.50	
Initial log-likelihood		-202837.1		-125690.7		-171968.8	
Final log-likelihood		-64456.8		-50962.7		-86526.0	
Number of observation		219711		154505		192785	
Upper-tree model		Business		Leisure		Others	
Variable	Unit	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
Total travel time (auto)	Minute	-0.02	-183.9**	-0.01	-118.0**	-0.01	-135.1**
Total travel cost (auto)	1000 yen	-0.04	-64.1**	-0.12	-93.6**	-0.09	-108.4**
Log-sum (public transportation)		0.33	75.9**	0.06	9.3**	0.07	11.4**
Constant (public transportation)		-2.06	-186.5**	-4.70	-288.8**	-3.98	-349.1**
Rho-squared		0.43		0.66		0.55	
Initial log-likelihood		-260255.2		-252548.8		-300331.0	
Final log-likelihood		-148439.9		-85782.5		-134240.6	
Number of observation		375491		364358		433291	

Note: * and ** represent the significance at 95% confidence level and 99% confidence level, respectively.

$$w_n = \frac{N \cdot \gamma_n}{\sum_{n'} \gamma_{n'}}, \tag{8}$$

where N represents the number of observations in the sample dataset and γ_n represents the magnification coefficient corresponding to individual n. As the magnification coefficient is defined as an inverse of a sampling rate in a zone, $\sum_n \gamma_n$ is the total number of individuals in the population. Note that eq. (8) is derived from $H_n = \gamma_n / \sum \gamma_{n'}$ and $Q_n = 1/N$. The variables whose t-statistics are equal to or greater than two are selected from the candidate explanatory variables. The coefficient of total travel time is estimated generically among rail, bus, and air whereas the coefficients of total travel cost are estimated independently for rail/bus and for air. This is because the air fare is often discounted while the fare of other modes is not. The estimation results of the models are shown in Table 2. The results of the tests for all coefficients indicate that they are highly significant. The likelihood ratios are also sufficiently high, and the signs of all the coefficients are reasonable.

2.3 Trip Distribution Sub-model

2.3.1 Model formulation

The trip distribution sub-model estimates the travel demand from an origin zone to a destination zone, by travel purpose. The sub-model is formulated via two types of aggregated choice models: a destination share model for home-to-business, home-to-leisure, and home-to-others; and an origin share model for business-to-home, leisure-to-home, and other-to-home. The dependent variable is the zonal share of destinations/origins while the independent variables are the zonal socio-demographic data. As the zone size varies, it may influence an individual's choice of destination/origin. The following destination share model is then used to incorporate the zone-size effect into the destination/origin choice:

$$p_{ij} = \frac{\exp(v_{ij} + \ln L_{ij})}{\sum_j \exp(v_{ij} + \ln L_{ij})} = \frac{L_{ij} \exp(v_{ij})}{\sum_j L_{ij} \exp(v_{ij})}, \tag{9}$$

where p_{ij} is the probability of choosing zone j for an individual in zone i, v_{ij} is the conditional indirect utility function of zone j for the individual in zone i, L_{ij} is the number of potential destinations/origins in zone j that the individual in zone i recognizes. It is assumed that the recognized number of potential destinations/origins is expressed by

$$L_{ij} = \alpha_1 S_j \exp\left(\alpha_2 \Lambda_{mode,ij}\right), \tag{10}$$

where S_j represents the area in which it is physically possible to reside in zone j, $\Lambda_{mode,ij}$ represents the logsum variables derived from the modal choice sub-model, and α_1, α_2 represent unknown parameters. This means that the number of potential destinations/origins recognized by an individual increases as the accessibility increases while it increases as the area of the destinations/origins is greater. The logsum variable, $\Lambda_{mode,ij}$, is defined as

$$\Lambda_{mode,ij} = \ln\left[\exp\left(u_{auto,ij}\right) + \exp\left(u_{pub,ij}\right)\right], \tag{11}$$

where $u_{auto,ij}$ represents the systematic portion of the indirect utility function of auto, from zone i to zone j, and $u_{pub,ij}$ represents the systematic portion of the indirect utility function of public transportation, from zone i to zone j. Next, it is assumed that the systematic portion of the indirect utility function of zone j, for an individual in zone i, is specified as follows:

$$v_{ij} = \sum_k \gamma_k \ln Y_{kj} + \gamma_{mode} \Lambda_{mode,ij}, \tag{12}$$

where Y_{kj} is the k th explanatory variable related to the socio-demographic in zone j and γ_k is the coefficient corresponding to the k th explanatory variable related to the socio-demographic in zone j.

By substituting eqs. (10) and (12) into eq. (9), the probability of choosing zone j for the individual in zone i can be rewritten as

$$p_{ij} = \frac{\exp\left[\sum_k \gamma_k \ln Y_{kj} + \left(\alpha_2 + \gamma_{mode}\right)\Lambda_{mode,ij} + \ln S_j\right]}{\sum_j \exp\left[\sum_k \gamma_k \ln Y_{kj} + \left(\alpha_2 + \gamma_{mode}\right)\Lambda_{mode,ij} + \ln S_j\right]}. \tag{13}$$

This indicates that the coefficient corresponding to the logsum variable is equal to $\alpha_2 + \gamma_{mode}$. As α_2 cannot be estimated independently of γ_{mode}, $\alpha_2 + \gamma_{mode}$ could be greater than 1, although γ_{mode} should be equal to or less than 1 (Ben-Akiva and Lerman, 1985). Note that α_1 is not included in eq.(13). This is because α_1 is canceled out since it is a generic variable among alternative zones. The origin share model is formulated by substituting zone i to zone j in the destination share model. In the same way as eq.(13), the probability of choosing zone i for an individual in zone j is expressed as

$$p'_{ij} = \frac{\exp\left[\sum_k \gamma'_k \ln Y'_{ki} + \left(\alpha'_2 + \gamma'_{mode}\right)\Lambda'_{mode,ij} + \ln S_i\right]}{\sum_i \exp\left[\sum_k \gamma'_k \ln Y'_{ki} + \left(\alpha'_2 + \gamma'_{mode}\right)\Lambda'_{mode,ij} + \ln S_i\right]}. \quad (14).$$

2.3.2 Data and model estimation

The travel demand data is again selected from the 2005 Interregional Travel Survey. The O-D travel demand data across 50 zones are used for the model estimation. The data across 50 zones rather than that across 207 zones is used first because the 50-zone-based output is mainly required from the practical business for the travel demand forecast in the context of Japan, second because few socio-demographic data is available on the basis of 207 zones, and third because the 207-zone-based data includes unreliable information due to too low sampling rate in the original dataset. The level-of-service data are used on the basis of Table 1. The destination share model is estimated maximizing the following weighted log-likelihood function:

$$L(\boldsymbol{\alpha}, \boldsymbol{\gamma}) = \sum_i \sum_j q_{ij} \cdot \omega_i \cdot \ln p_{ij}(\boldsymbol{\alpha}, \boldsymbol{\gamma}), \quad (15)$$

where ω_i is the weight parameter corresponding to zone i, q_{ij} is the ratio of observed travel demand, from zone i to zone j, to the total observed travel demand generated from zone i, p_{ij} is the probability of choosing zone j for the individual in zone i, ω_i is defined as $\omega_i = 50 G_i \big/ \sum G_i$, where G_i is the travel demand generated from zone i, and q_{ij} is defined as $q_{ij} = Z_{ij} \Big/ \sum_j Z_{ij} = Z_{ij} / G_i$, where Z_{ij} is the travel demand from zone i to zone j. The log-likelihood function of the origin share model is expressed as

$$L'(\boldsymbol{\alpha}', \boldsymbol{\gamma}') = \sum_j \sum_i q'_{ij} \cdot \omega'_j \cdot \ln p'_{ij}(\boldsymbol{\alpha}', \boldsymbol{\gamma}'), \quad (16)$$

where ω'_j is the weight parameter corresponding to zone j and q'_{ij} is the ratio of observed travel demand, from zone i to zone j, to the observed travel demand attracted to zone j, ω'_j is defined as $\omega'_j = 50 A_j \big/ \sum A_j$, where A_j is the travel demand attracted to zone j, and q'_{ij} is defined as $q'_{ij} = Z_{ij} \Big/ \sum_i Z_{ij} = Z_{ij} / A_j$. The reason for estimating the origin share model and the destination share model independently is that the destination choice of originating from home is expectedly different from that of returning home. The estimation results are shown in Table 3. The results of the tests for all coefficients indicate that they are highly significant. The likelihood ratios are also sufficiently high, and the signs of all the coefficients are reasonable. The R-squared, defined for the observed O-D travel demand versus the estimated O-D travel demand, is also high.

2.4 Trip Generation/attraction Sub-model

2.4.1 Model formulation

The trip generation sub-model estimates the travel demand generated from an origin zone by home-to-business, home-to-leisure and home-to-others, while the trip attraction sub-model estimates the travel demand terminating at home by business-to-home, leisure-to-home, and others-to-home. The models are formulated on the basis of a simple log-linear regression model, expressed as follows:

Table 3 Estimation results of trip destination sub-models

		Destination share model				Origin share model			
		Home-to-business		Home-to-leisure /others		Business-to-home		Leisure/others- to-home	
		Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
Average annual production per labor force	Million yen	3.70	2.4*			4.21	2.8**		
Ratio of labor force in service industries to total labor force		5.84	2.7**	2.87	2.1*	6.39	3.0**	3.70	2.7**
Average number of hotels per area	/1000ha			1.05	4.2**			1.12	4.5**
Quasi-logsum from zone i to zone j		1.47	8.0**	1.50	11.7**	1.40	7.5**	1.48	11.6**
Dummy of specific pairs of O-D		1.17	2.2*	1.32	3.4**	1.27	2.4*	1.36	3.5**
Initial log-likelihood		-201.3		-400.9		-199.9		-400.1	
Final log-likelihood		-114.9		-210.1		-116.6		-208.5	
Likelihood ratio		0.43		0.48		0.42		0.48	
Number of observations		50		100		50		100	
R-squared		0.67		Home-to-leisure: 0.61 Home-to-others: 0.69		0.71		Leisure-to-home: 0.68 Others-to-home: 0.68	

Note 1: Dummy of specific pairs of O-D is equal to 1 if the O-D pairs are Ibaraki-Tochigi, Ibaraki-Chiba, Ibaraki-Saitama, Tochigi-Gunma, or Tochigi-Saitama; and 0 if not.
Note 2: * and ** represent the significance at 95% confidence level and at 99% confidence level respectively.

$$\ln G_i = \sum_k \theta_k \ln W_{ki} + \theta_{dist} \Lambda_{dist,i} + \theta_{const} + \varepsilon_i , \tag{17}$$

$$\ln A_j = \sum_k \theta'_k \ln W'_{kj} + \theta'_{dist} \Lambda'_{dist,j} + \theta'_{const} + \varepsilon'_j , \tag{18}$$

where G_i is the travel demand generated from zone i, A_j is the travel demand attracted to zone j, W_{ki} and W'_{kj} are the k th explanatory variables relating to zone i and zone j, respectively, $\Lambda_{dist,i}$ and $\Lambda'_{dist,j}$ are the logsum variables derived from the trip distribution sub-model, ε_i and ε'_j are the error components, following the normal distribution, with a mean of 0, and θ_k, θ_{dist}, θ_{const}, θ'_k, θ'_{dist}, θ'_{const} are unknown coefficients. The logsum variables are defined as

$$\Lambda_{dist,i} = \ln \sum_j \exp\left(\sum_k \gamma_k \ln Y_{kj} + (\alpha_2 + \gamma_{mode}) \Lambda_{mode,ij} + \ln S_j \right), \tag{19}$$

$$\Lambda_{dist,j} = \ln \sum_i \exp\left(\sum_k \gamma'_k \ln Y'_{ki} + (\alpha'_2 + \gamma'_{mode}) \Lambda'_{mode,ij} + \ln S_i \right). \tag{20}$$

2.4.2 Data and model estimation

The travel demand data is again selected from the 2005 Interregional Travel Survey. The O-D travel demand data across 50 zones are used for the model estimation. The data across 50 zones rather than that across 207 zones is used first because the 50-zone-based output is mainly required from the practical business for the travel demand forecast in the context of Japan and second because few socio-demographic data is available on the basis of 207 zones. The level-of-service data are used on the basis of Table 1. The estimation results are shown in Table 4. The results of the tests for all coefficients indicate that they are highly significant. The model fitness of the R-squared is also high.

3. MODEL VERIFICATION

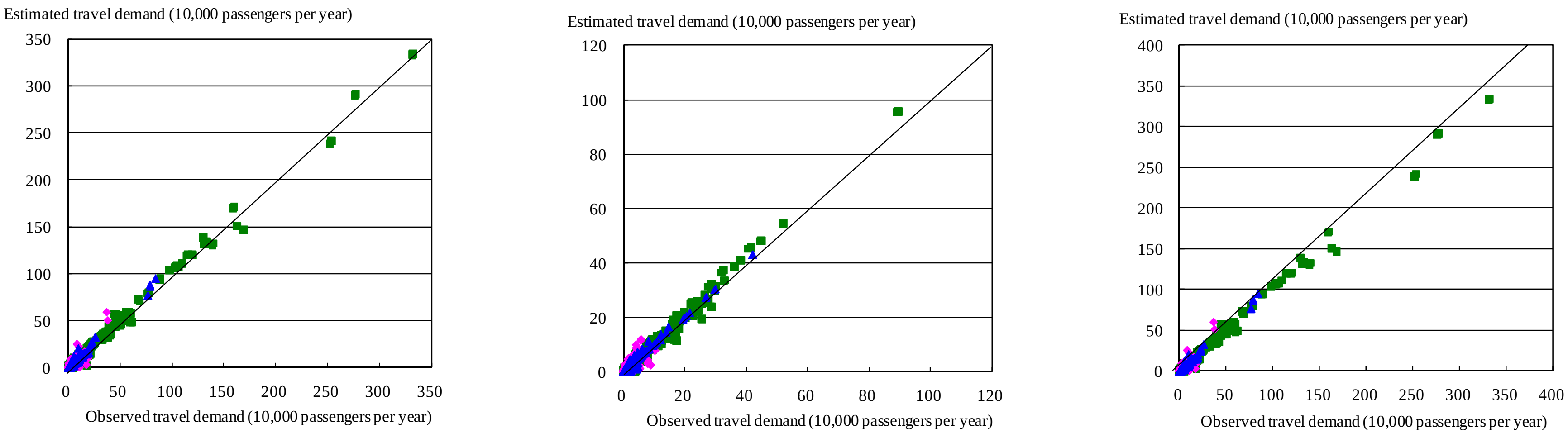
The estimated models are verified by comparing the estimated travel demand with the observed travel demand. Figure 2 shows the comparisons of the observed travel demand by O-D pair, by travel mode, versus that estimated with the lower tree model in the mode choice sub-model; Figure 3 shows the comparisons of the observed travel demand by O-D pair, by travel mode, versus that estimated with the upper tree model in the mode choice sub-model; Figure 4 shows the comparisons of the observed travel demand by O-D pair versus that estimated with the trip distribution sub-model; Figure 5 shows the comparisons of the observed travel demand by O-D distance versus that estimated with the trip distribution sub-model; and Figure 6 shows the comparisons of the observed travel demand by zone versus that estimated with the trip generation/attraction sub-model. These comparisons show that the fitness of all sub-models is very high.

Figure 4 shows that the O-D travel demand between Gunma and Tochigi is underestimated in home-to-business, home-to-leisure, home-to-others, and others-to-home trips, whereas the O-D travel demand between Saitama and Tochigi is overestimated for all trip purposes. Figure 6 also indicates that the travel demand generation of home-to-business trips in Fukuoka, the travel demand generation of home-to-leisure trip in Tochigi and Ibaraki, the travel demand generation of home-to-others trip in Gunma, Ibaraki, and Saitama, the travel demand attraction of leisure-to-home in Ibaraki and Saitama, and the travel demand attraction of others-to-home in Ibaraki, Gunma, and Saitama, are all underestimated. It should be noted that Ibaraki, Gunma, Tochigi, and Saitama are all located in or near the Tokyo Metropolitan Area. The underestimation in these zones probably occurred because the inter-zone travel to and from them may be regarded as urban travel rather than inter-urban travel. As for the overestimation of O-D travel demand between Saitama and Ibaraki, there are two possible reasons. The first possible reason is the unbalanced distribution patterns of population in Saitama Prefecture. The majority of the population resides in the southern part of Saitama

Table 4 Estimation results of trip generation/attraction sub-models

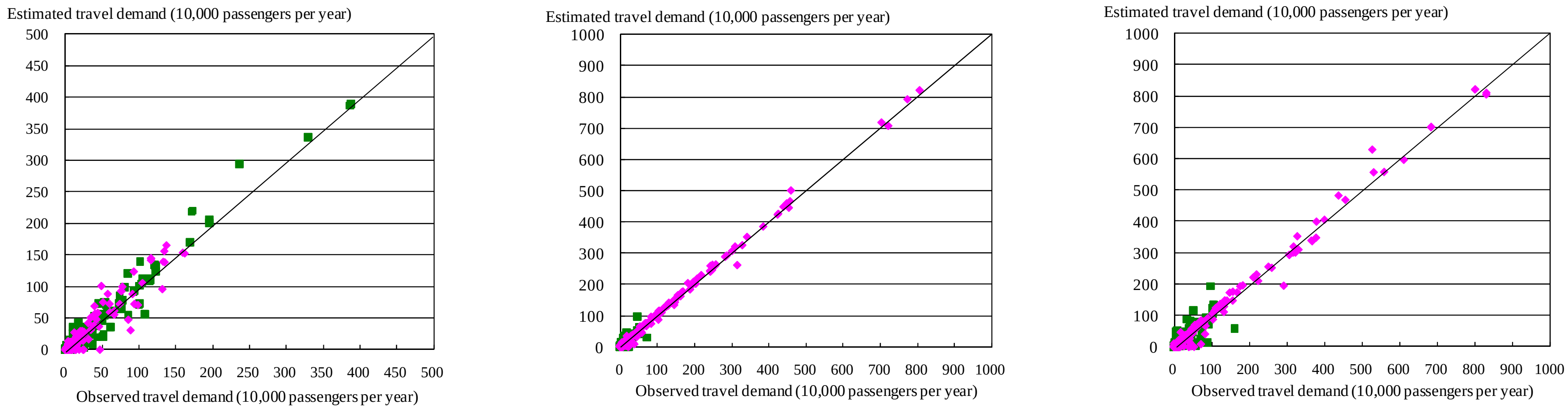
		Trip generation model			Trip attraction model		
		Home-to-business	Home-to-leisure	Home-to-others	Business-to-home	Leisure-to-home	Others-to-home
ln (Population)	x1000	-	0.57	0.46	-	0.68	0.54
		-	(6.5**)	(4.3**)	-	(6.7**)	(4.6**)
ln (Population	x1000	0.78	-	-	0.97	-	-
+Working population)		(9.8**)	-	-	(11.4**)	-	-
Log-sum		0.44	0.36	0.43	0.44	0.28	0.55
		(6.4**)	(5.1**)	(4.4**)	(5.7**)	(3.4**)	(5.0**)
Dummy of Hokkaido		-1.86	-2.27	-2.64	-1.63	-2.38	-2.55
		(-8.6**)	(-9.1**)	(-8.7**)	(-6.9**)	(-8.2**)	(-7.5**)
Dummy of Okinawa		-1.14	-1.15	-2.19	-0.92	-1.59	-1.81
		(-2.7**)	(-2.4*)	(-3.8**)	(-2.0*)	(-2.8**)	(-2.8**)
Constant		0.22	5.06	5.73	-2.34	4.39	4.24
		(0.3)	(7.3**)	(6.6**)	(-2.4*)	(5.5**)	(4.4**)
R-squared		0.88	0.85	0.81	0.87	0.82	0.79
Number of observations		50	50	50	50	50	50

Note 1: The value in the parenthesis represents a t-statistic related to the corresponding coefficient.
Note 2: * and ** represent the significance at 95% confidence level and at 99% confidence level respectively.



a. Business trip b. Leisure trip c. Others trip

Figure 2 Observed travel demand vs. estimated travel demand in modal choice sub-models (Lower tree model)



a. Business trip b. Leisure trip c. Others trip

Figure 3 Observed travel demand vs. estimated travel demand in modal choice sub-models (Upper tree model)

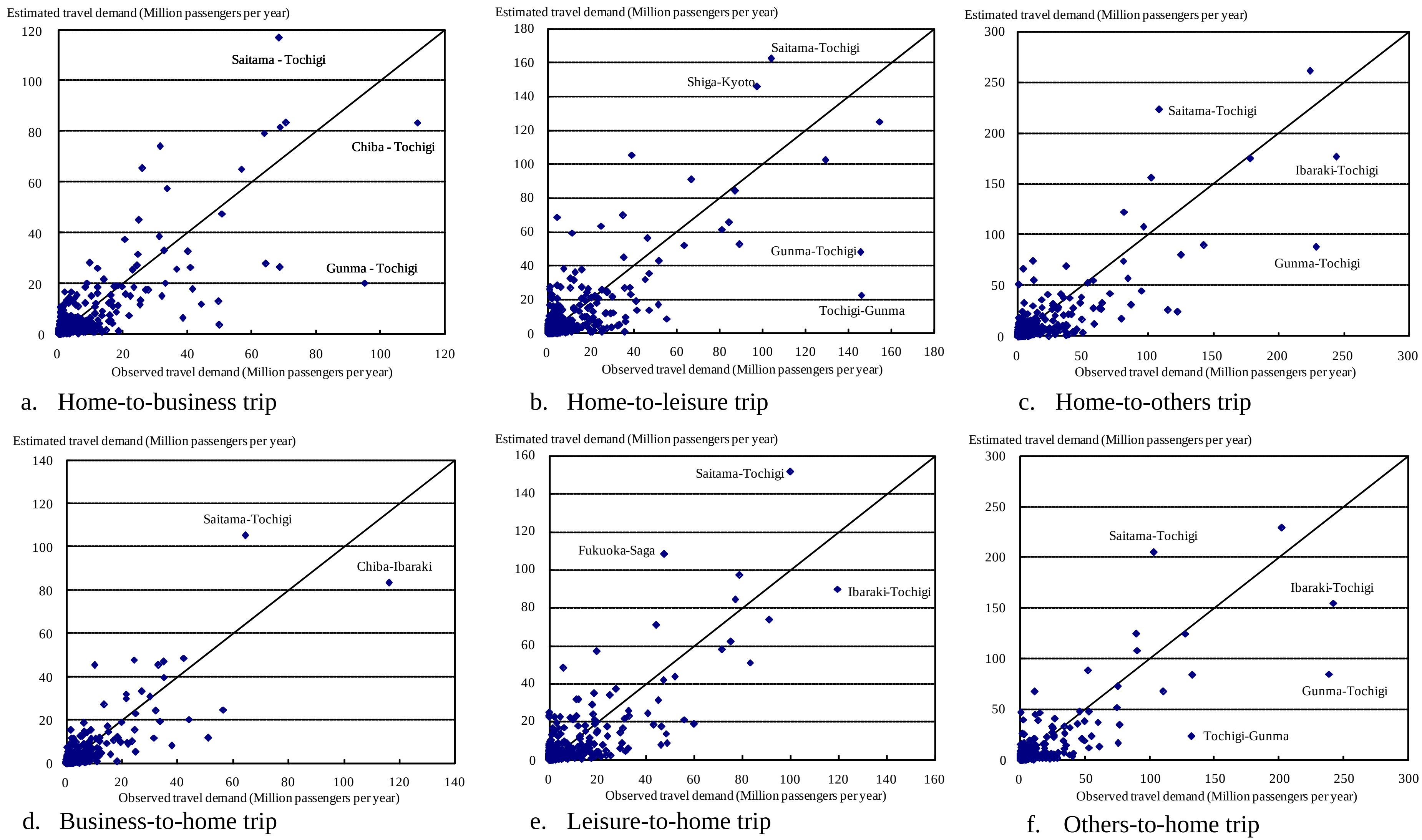


Figure 4 Observed travel demand vs. estimated travel demand in trip distribution sub-models by O-D pair

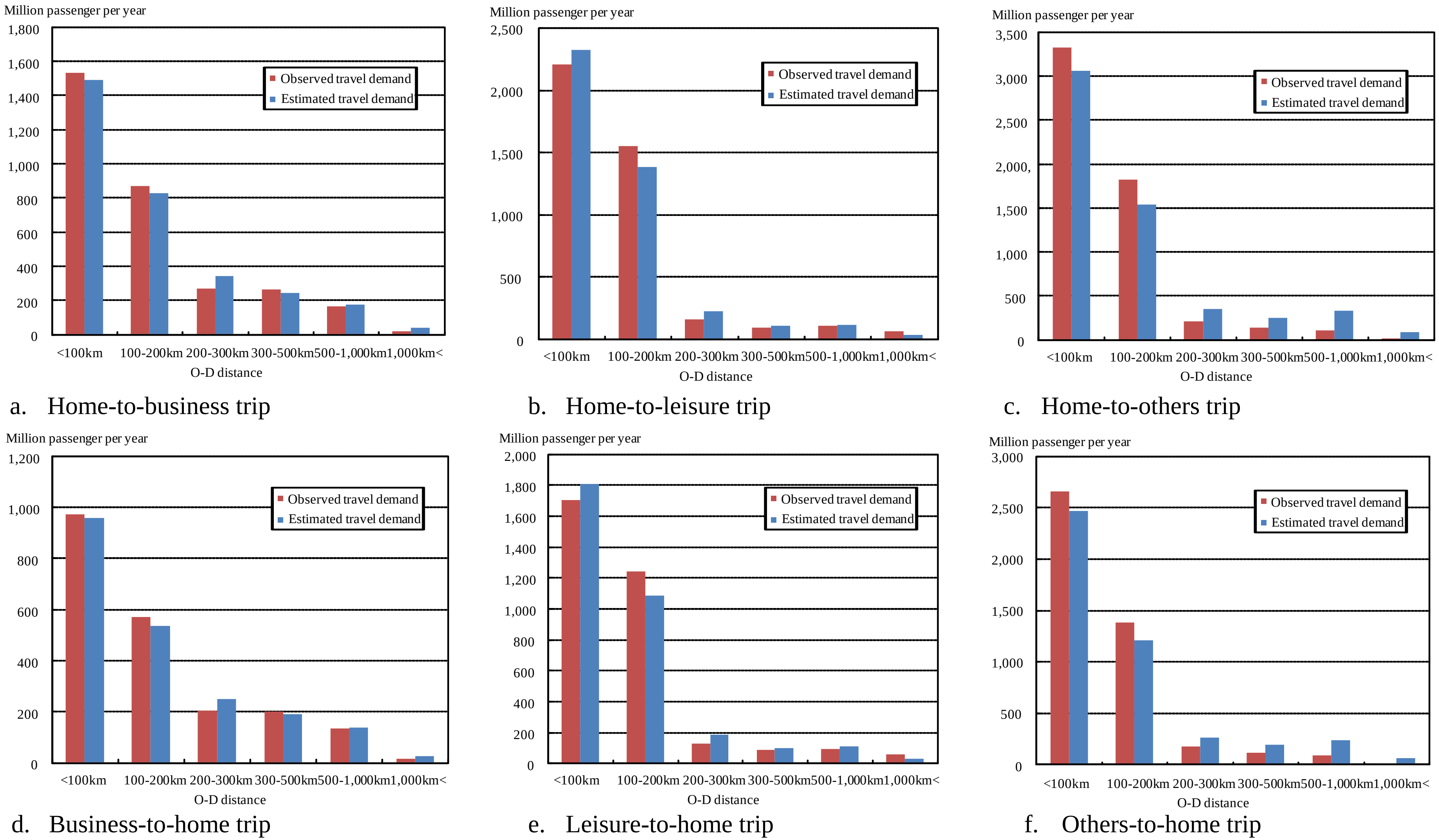
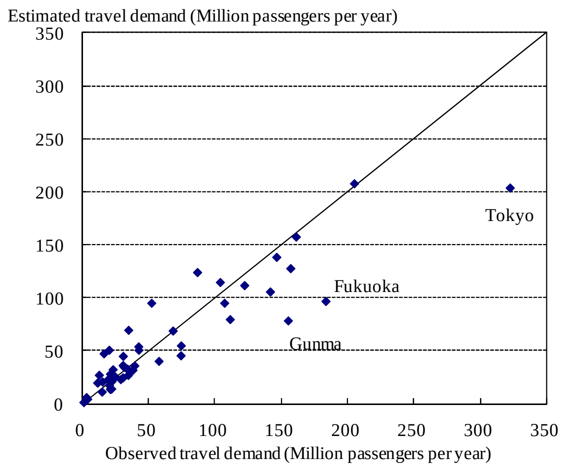
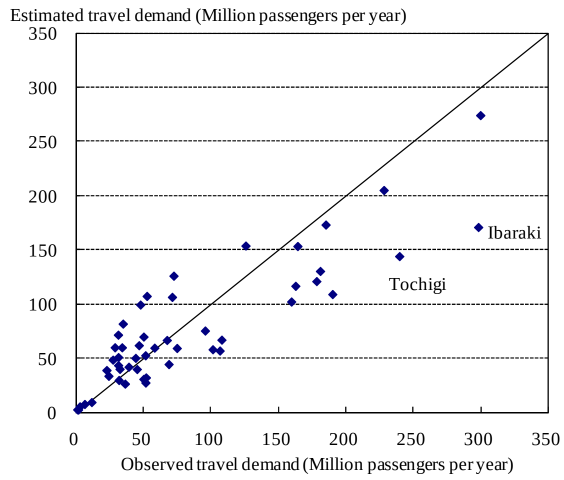


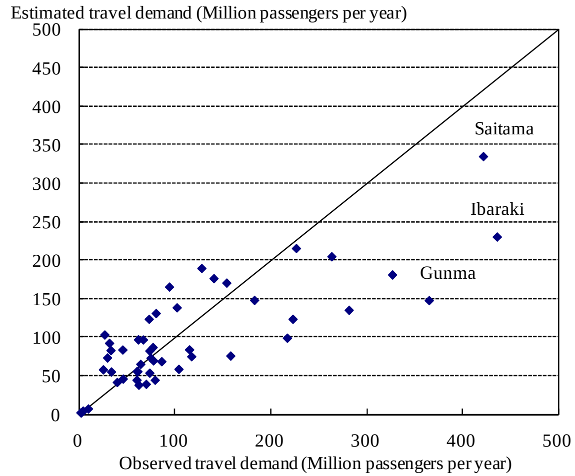
Figure 5 Observed travel demand vs. estimated travel demand in trip distribution sub-models by O-D distance



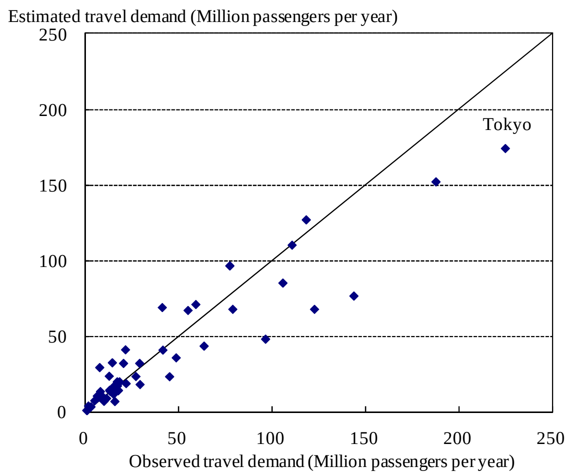
a. Home-to-business trip



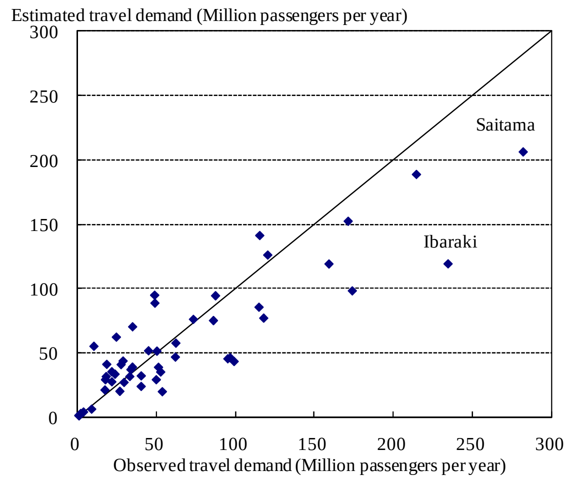
b. Home-to-leisure trip



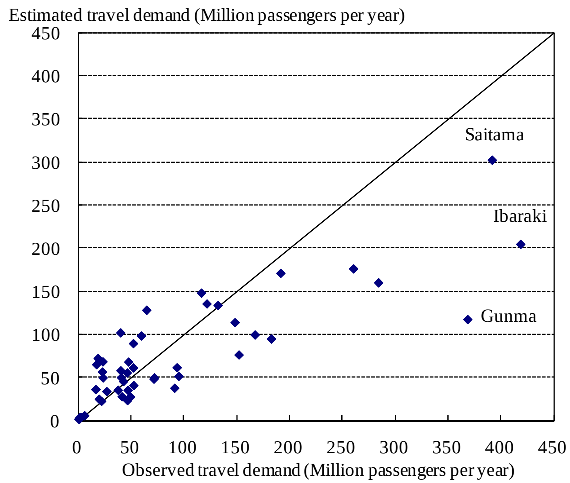
c. Home-to-others trip



d. Business-to-home trip



e. Leisure-to-home trip



f. Others-to-home trip

Figure 6 Observed travel demand vs. estimated travel demand in trip generation/attraction sub-models

Prefecture, which is on the opposite side of the border from Tochigi Prefecture. This causes more travel demand to manifest towards the direction opposite to Tochigi. The second possible reason is the strong attractiveness of Tokyo. As Saitama Prefecture is located next to Tokyo, more travel demand is generated between Saitama and Tokyo than that between Saitama and Tochigi. Although a specific dummy variable is introduced to the O-D pairs, including the trips between Saitama and Tochigi in the trip distribution sub-model, it may not work well in reproducing the current travel demand between them.

4. CONCLUSION

This paper presented the practical inter-urban travel demand model for Japan. As the model uses only public and regularly published data, it will permit us to update the travel demand forecast regularly. This is expected to contribute to the travel demand forecast for private business. This is because the private business planning needs more up-to-date travel demand forecast than the government-based long-term transportation planning. The paper also unveiled that the model is successfully estimated with the quite simple method of data treatment. This may enable the analysts to estimate the future travel demand in an easy manner. Additionally, as the sub-models are integrated by incorporating the inclusive variables, they enable us to estimate the travel demand in a systematic and consistent way.

Further research issues are summarized as follows. First, the model may be improved by using a more sophisticated modeling approach, such as a mixed logit model (Train, 2003). Additionally, the individual-based trip-generation/attraction models should be also explored for the theoretical consistency in the model. Second, the estimated models should be verified further with other data, including time-series travel demand data. The model parameters may vary with time because of changes in the market conditions and individuals' preferences. This is important particularly for the private business planning because the dynamic changes are often its main concerns. Third, the travel demand models for urban travel should be explored, in addition to the inter-urban travel. Then, the total national travel demand can be forecast using these models. It may be necessary to examine the interaction between inter-urban and urban travel to formulate such models. Finally, travel demand forecast and policy evaluation could be carried out using the estimated data from the private business viewpoints. For example, a free-of-charge policy for expressway service, a restructuring policy for local airports, and a new investment in a high-speed rail network may be included in the list of private business concerns.

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