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# Latest Urban Rail Demand Forecast Model System in the Tokyo Metropolitan Area

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## ABSTRACT

This paper reports on an urban rail travel demand forecast model system, which technically supported the formulation of the Tokyo Urban Rail Development Master-plan 2016. The model system was included in the forthcoming 15-year urban rail investment strategy for Tokyo. The model system was utilized to quantitatively assess urban rail projects including 24 new rail development projects, which had been proposed in response to expected changes in socio-demographic patterns, land-use market, and the government's latest transportation policy goals. The system covers the entire urban rail network within the Tokyo Metropolitan Area (TMA) of approximately 50-km radius with a population of over 34 million. The system must handle over 80 million trips per day. Three demand models are used to predict daily rail passenger link flows: the urban rail demand model, the airport rail access demand model, and the high-speed-rail rail access demand model. These practical models have unique characteristics such as incorporating differences in behavior between aged and non-aged travelers, reflecting expected influences of urban redevelopment on trip generation and distribution, highlighting urban rail access to airports or high-speed-rail stations, examining impacts of in-vehicle crowding on rail route choice, and deploying urban rail-station access/egress mode choice models for rail route choice. It is concluded that the model system would be well calibrated with observed data for reproducing travel patterns, identifying potential problems, assessing proposed projects, presenting results with high accuracy, and assisting decision-making of urban rail planners.


**Keywords.** Urban rail, demand forecast model system, Tokyo, Japan

# INTRODUCTION

A new long-term Tokyo Urban Rail Development Master-plan discussing the future development strategies for the urban rail network in TMA was established by the Council for Transport Policy in April 2016 (*1*). This is the latest master plan from the succession of plans that have been revised approximately every 15 years since 1956. This master plan aims at providing recommendations for the urban rail infrastructure development within TMA for the forthcoming 15 years by reflecting on the latest socio-demographic and socio-economic conditions. See Morichi et al. (*2*) for the outline of the previous master plan established in 2000. The latest master plan proposed the construction of additional 24 new rail lines and included proposed renovation or rehabilitation of the existing major rail stations.

For finalizing the proposals, the proposed projects were assessed separately using 46 performance indexes including a cost-benefit ratio, financial feasibility, and policy impacts as proposed through many discussions among the 13 committee members. The committee members are noted experts in transportation planning, traffic engineering, transportation economics, urban planning, and tourism research, which included three of the authors. Those indexes were quantified by using a large-scale travel demand forecast model system which predicted the future urban rail passenger demand in 2030 for both the with and without investment cases for each proposed project.

This paper outlines the practical travel demand forecast model system utilized in the Tokyo Urban Rail Development Master-plan in 2016. The proposed model basically follows the structure of prior model that was used for the last master plan, but it adds a rail-station access/egress model while it also takes accounts of rapid changes in socio-demographic patterns. It is not the intent to show the state-of-the-art methodologies in travel demand analysis, but to present practical applications of the travel demand forecast models to assess the proposed projects for the process of urban rail transportation planning in response to the latest policy goals.

The paper is organized as follows. The next section introduces unique characteristics of the urban rail travel demand forecast model for Tokyo, followed by model development including its estimation results. Then reproducibility of urban rail demand is presented. Finally, the findings are summarized with further research issues.

# CHARACTERISTICS OF URBAN RAIL TRAVEL DEMAND FORECAST MODEL IN TOKYO

The model system has five distinctive characteristics by considering the unique features of the urban rail services in Tokyo. First, the models incorporate the influences of rapid changes in socio-demographic patterns on travel demand since Tokyo is facing rapid aging and is predicted to experience a further aging society in the future. The population of 65 year-olds or over accounted for 14.5% of the overall population in 2000, which then increased to 21.0% in 2010 and is projected to be at 29% in 2030. Since senior individuals are generally expected to engage in less out-of-home activities than younger individuals, peoples' daily activity patterns may vary across the types of journeys, age levels, and gender. Furthermore, destination choice patterns, mode choice patterns, and route choice patterns of senior travelers could be different from those of younger travelers. Such differences are taken into account in the developed model system by segmenting the travelers by age subgroup.

Second, the expected changes in land-use patterns are incorporated into the models. As shown in Kato (*3*) and Suzuki et al. (*4*), urban redevelopment in the central district of Tokyo has grown since early 2000s. This growth was due to the Act on Special Measures Concerning Urban Regeneration introduced in 2002 in which the Building Standards Law was revised to relax the maximum floor area ratio constraint. This led to the sharp increase of high-rise buildings for residential, office, and mixed-use in the central ward areas of Tokyo. Such changes in land-use pattern in the central business district (CBD) influence not only the trip generation/attraction but also the trip distribution patterns because the types of trips to/from redeveloped zones may be changed.

Third, an airport rail access demand (ARAD) model and a high-speed-rail rail access demand (HSR-RAD) model have been developed in addition to the urban rail passenger demand (URD) model. The ARAD model reflects the recent government's transportation policy that highlights the improvement of accessibility to two international airports in Tokyo. The HSR-RAD model is intended for predicting urban passenger demand accessing the Chuo Shinkansen that employs the superconducting maglev system. A new Japanese maglev line has been planned to connect Tokyo with Chukyo and ultimately with Kinki (*5*). The introduction of new high-speed maglev should also influence the urban rail demand, particularly the one accessing to/generating from HSR stations in TMA.

Fourth, the rail-route choice submodel in the URD model explicitly considers the in-vehicle rail crowding since urban rail passengers are still suffering from serious in-vehicle congestion, particularly during morning peak hours (*6*, *7, 8*).

Finally, the rail route choice submodel in the URD model also incorporates an accessibility measure calibrated with the rail-station access/egress mode choice submodels. The urban rail network has been densely developed in TMA, where urban rail passengers have multiple options to access or egress rail stations. Particularly, urban bus services are operated connecting to and from the rail stations thereby affecting passenger rail route choice.

## GOAL AND SCOPE OF MODEL DEVELOPMENT

The developed model system is intended to assess the proposed urban rail investment projects using several performance indexes. To quantify these performance indexes, the link-based daily rail passenger flows need to be forecasted under given future conditions. The target area covers areas in a 50-km radius from the CBD in Tokyo, which is generally regarded as a commutable area in TMA. The area includes the five prefectures of Tokyo, Kanagawa, Saitama, Chiba, and Ibaraki and is divided into 2,907 Traffic Analysis Zones (TAZs) with an average area of 1.8 km$^2$.

The population-relevant numbers in the target area in 2010 were 37.24 million (nighttime population), 19.13 million (nighttime worker population), 19.19 million (daytime worker population), 4.70 million (nighttime student population), and 4.73 million (daytime student population). In addition to the urban rail network, the arterial/expressway road network is also employed from Digital Road Map data while the bus network is also prepared from the information provided by bus operators. Consequently, the target transport network has 18,178 links and 9,567 nodes.

The model system consists of the URD model, the ARAD model, and the HSR-RAD model with their submodels. The model system is in line with the traditional structure of a four-step model that includes trip generation/attraction, trip distribution, mode choice, and rail-route choice submodels where the output of upper-level submodels constrains the total input of the lower-level submodels.

The daily rail passenger link flows are computed as the final output of the model system. The URD model predicts the rail passenger demand for the given population while the ARAD/HSR-RAD models forecasts corresponding urban rail demand for the airports and station-based HSR demands as predetermined by the National Government. Thus, trip generation/attraction submodels are not included in the ARAD/HSR-RAD models.

# URBAN RAIL DEMAND (URD) MODEL

## Market Segmentation

Each submodel in the URD model forecasts travel demands by ten different trip purposes: home-to-workplace (H-W), home-to-school (H-S), home-to-private (H-P), out-of-home-to-private (OH-P), home-to-business (H-B), workplace-to-other business (W-B), workplace-to-home (W-H), school-to-home (S-H), private-to-home (P-H), and business-to-home (B-H). In the trip generation/attraction submodel and the trip distribution submodel, travelers are segmented by gender. Additionally, all submodels segment individuals into multiple age subgroups except for the H-S trips within the mode choice and the rail route choice submodels. The age subgroups are then defined into different categories depending on trip purposes, gender, and submodels.

## URD-Trip Generation/Attraction Submodels

These submodels estimate daily trip demand generated from and attracted to a zone. Simple trip rate models have been applied as

$$GU_i^{pag} = \alpha_G^{pag} \cdot Y_i^{pag} \tag{1}$$

$$AU_j^{pag} = \alpha_A^{pag} \cdot Y_j^{pag} \tag{2}$$

where $GU_i^{pag}$ is the number of daily trips with trip purpose $p$ for age subgroup $a$ and gender $g$ generating from zone $i$; $AU_j^{pag}$ is the number of daily trips attracted to zone $j$; $Y_i^{pag}$ represents the total number of individuals; and $\alpha_G^{pag}$ and $\alpha_A^{pag}$ are the constant trip rates (trips per day per individual) regarding the attraction and generation, respectively. Note that $Y_i^{pag}$ and $Y_j^{pag}$ are different across trip purposes, age groups, and gender.

## URD-Trip Distribution Submodel

This submodel predicts the daily trip distribution of the target area for the given zone-based generated and attracted trips obtained from the trip generation/attraction submodels. Two modeling approaches have been applied according to the classification of the Origin-Destination (O-D) pairs. First, for the zones where no significant change in future land-use patterns is expected, the growth factor method has been applied for predicting future trip distributions. The growth rates are adjusted with the Fratar method.

Second, for zones where large-scale urban (re-)developments would be implemented, the gravity model has been applied to estimate the trip distribution of population migrating into the (re-)developed zones. The zones to which the gravity model is applied include zones in the CBD of Tokyo, the Sagamihara area, along the Tsukuba Express Line, and around the Koshigaya Laketown area. By incorporating zone-specific dummy variables, the gravity models are formulated as follows:

$$TU_{Rj}^{ap} = \left(\kappa_0^{ap} + \sum_k \kappa_k^{ap}\delta_{Rj,k}\right)\cdot\left(\sum_g GU_R^{apg}\right)^{\gamma_G^{ap}}\cdot\left(\sum_g AU_j^{apg}\right)^{\gamma_A^{ap}}\cdot\left(gc_{Rj}^{ap}\right)^{\gamma_{gc}^{ap}+\sum_k \gamma_k^{ap}\delta_{Rj,k}} \tag{3}$$

$$TU_{iR}^{ap} = \left(\bar{\kappa}_0^{ap} + \sum_k \bar{\kappa}_k^{ap}\delta_{iR,k}\right)\cdot\left(\sum_g GU_i^{apg}\right)^{\bar{\gamma}_G^{ap}}\cdot\left(\sum_g AU_R^{apg}\right)^{\bar{\gamma}_A^{ap}}\cdot\left(gc_{iR}^{ap}\right)^{\bar{\gamma}_{gc}^{ap}+\sum_k \bar{\gamma}_k^{ap}\delta_{iR,k}} \tag{4}$$

where $TU_{Rj}^{ap}$ and $TU_{iR}^{ap}$ represent the daily trips with purpose $p$ and age subgroup $a$ from the (re-)developed zones $R$ to zone $j$ and the daily trips from zone $i$ to zone $R$, respectively. Additionally, $\delta_{ij,k}$ is the dummy variable of a band *k* for the direct distance between the O-D pair $i$ and $j$, $gc_{ij}^{ap}$ is the generalized cost estimated from the mode choice submodel for age subgroup $a$ with purpose $p$; and vectors of $\boldsymbol{\kappa}$ and $\boldsymbol{\gamma}$ represent the unknown coefficients. Six bands are defined for direct distances of less than 10 km, 10-20 km, 20-30 km, 30-40 km, 40-50 km, and 50-60 km.

**URD-Mode Choice Submodel**

This submodel predicts the daily trip demand by each travel mode for a given O-D matrix obtained from the URD-trip distribution submodel. Trips are predicted for each combination of trip purpose and age subgroup. The choice set includes walk/bicycle, bus, rail, and car. The modal share of walk/bicycle is assumed to be dependent on the travel distance but is not affected by the level of service of other transportation modes. This is formulated as

$$XU_{ij,w/b}^{ap} = s_{w/b}^{ap}\left(l_{ij}\right)\cdot TU_{ij}^{ap} \tag{5}$$

where $XU_{ij,w/b}^{ap}$ represents the daily walk/bicycle-use trips from zone $i$ to $j$ for purpose $p$ and age subgroup $a$; $s_{w/b}^{ap}(\cdot)$ is the distance-impedance function for walk/bicycle trips with respect to $l_{ij}$ (a direct distance from zone $i$ to $j$).

For the choice modeling of a bus, rail, and car, we employ multinomial logit (MNL). The travel demand for mode *m* is given by

$$XU_{ij,m}^{ap} = \frac{\left(TU_{ij}^{ap} - XU_{ij,w/b}^{ap}\right)\cdot\exp\left(VU_{ij,m}^{ap}\right)}{\exp\left(VU_{ij,bus}^{ap}\right)+\exp\left(VU_{ij,rail}^{ap}\right)+\exp\left(VU_{ij,car}^{ap}\right)} \tag{6}$$

where $XU_{ij,m}^{ap}$ represents the trips of mode $m(=bus, rail, car)$ from zone $i$ to $j$ with purpose $p$ for age subgroup $a$, and $VU_{ij,m}^{ap}$ is the systematic utility of mode $m$, which is assumed to be a linear function of explanatory variables such as travel time and travel cost.

**URD-Rail Route Choice Submodel**

The rail-route choice submodel has a nested structure of rail route choice (upper-level) and rail station access/egress mode choice (lower-level) submodels. The access trip means the trip from an origin zone to a boarding rail station while the egress trip means the trip from an alighting rail station to a destination zone. The rail-station access/egress mode choice is formulated as a MNL while the rail route choice is formulated as Multinomial Probit (MNP) model with structured covariance (*6*). It is important to note that the rail route consists of an access link connecting the origin zone to a rail station, rail line-haul links connecting the boarding rail station with the alighting rail station, waiting and transfer links at stations, and an egress link connecting the alighting rail station to the destination zone. The rail route flows are computed as

$$XU_{ij,r}^{ap} = XU_{ij,rail}^{ap} \cdot p_{ij,r}^{ap} \tag{7}$$

where $XU_{ij,r}^{ap}$ represents the daily trips of a rail route $r$ from zone $i$ to $j$ with purpose $p$ for age subgroup $a$, and $pu_{ij,r}^{ap}$ is the probability of choosing route $r$, which is formulated as

$$pu_{ij,r}^{ap} = \int_{\varepsilon_r=-\infty}^{+\infty} \int_{\varepsilon_1=-\infty}^{\varepsilon_r+v_{ij,r}^{ap}-v_{ij,1}^{ap}} \cdots \int_{\varepsilon_r=-\infty}^{+\infty} \cdots \int_{\varepsilon_R=-\infty}^{\varepsilon_r+v_{ij,r}^{ap}-v_{ij,R}^{ap}} \phi\left(\varepsilon_1^{ap}, \cdots \varepsilon_r^{ap}, \cdots, \varepsilon_R^{ap}\right) d\boldsymbol{\varepsilon} \tag{8}$$

where $\varepsilon_r^{ap}$ is the error component of utility function of rail route $r$ with purpose $p$ for age subgroup $a$, $v_{ij,r}^{ap}$ is the systematic utility of route $r$, and $\phi(\cdot)$ is a multivariate normal density function defined as

$$\phi(\boldsymbol{\varepsilon}) = (2\pi)^{-\frac{j}{2}} |\Sigma|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\boldsymbol{\varepsilon}\Sigma^{-1}\boldsymbol{\varepsilon}^T\right] \tag{9}$$

and

$$\Sigma = \sigma^2 \begin{pmatrix} L_{11} & L_{12} & \cdots & L_{1R} \\ L_{12} & L_{22} & & \vdots \\ \vdots & & \ddots & \\ L_{1R} & \cdots & & L_{RR} \end{pmatrix} + \sigma_0^2 I \tag{10}$$

where $\boldsymbol{\varepsilon} = (\varepsilon_1, \cdots \varepsilon_r, \cdots \varepsilon_R)$, $L_{rr'}$ is the overlapped length between routes $r$ and $r'$, $I$ is the identity matrix, and $\sigma^2$ and $\sigma_0^2$ are the variance parameters. The MNP model with structured covariance can incorporate correlations of overlapped routes through its error structure. The systematic utility $v_{ij,r}^{ap}$ is specified as a linear function of the explanatory variables such as the logsum variable computed from the rail-station access/egress submodel.

The rail-station access/egress mode choice submodel is formulated as the probability of choosing an access/egress mode:

$$qu_{am}^{ap} = \frac{\exp\left(VU_{am}^{ap}\right)}{\sum_{am'} \exp\left(VU_{am'}^{ap}\right)} \tag{11}$$

where $VU_{am}^{ap}$ is the systematic utility of travel mode $am$ for trip with purpose $p$ and for age subgroup $a$. The choice set of this submodel includes walk, bicycle, bus, and car. The logsum variable for the rail route choice submodel is then derived as

$$\Lambda U_r = \ln \sum_{am} \exp\left(VU_{r,am}^{ap}\right) \tag{12}$$

The rail link flows are then computed by summing up the rail route flows in a specific link across the age subgroups and the types of trips as

$$xu_l = \sum_a \sum_p \sum_{ij} \sum_r \delta_{ij,r,l} \cdot XU_{ij,r}^{ap} \tag{13}$$

where $xu_l$ is the passenger flows of rail link $l$ estimated from the URD model and $\delta_{ij,r,l}$ is the dummy variable if the rail link $l$ belongs to rail route $r$ from zone $i$ to $j$.

## AIRPORT RAIL ACCESS DEMAND (ARAD) MODEL

### Market Segmentation

The ARAD model system predicts the rail passenger demand to/from the Haneda and Narita airports in TMA. The airport demand consists of domestic and international air passengers. The domestic air passengers are categorized into eight subgroups by their trip purpose, residential area, and access/egress. The trip purposes are business or nonbusiness; the residential areas are TMA or other areas; and access/egress is the access to or the egress from an airport. The international air passengers are also categorized into six subgroups by their trip purpose, residential area, and access/egress. International air passengers residing in Japan are categorized into four subgroups: access to the airport for business, access to the airport for nonbusiness, egress from the airport for business, and egress from the airport for nonbusiness. International air passengers residing outside of Japan are categorized into two subgroups: access to and egress from the airport. A shortage of traveler data resulted in a lack of segmentation with respect to trip purpose for non-Japanese residents.

### ARAD-Trip Distribution Submodel

This submodel assumes the present pattern of O-D matrix of airport access/egress trips would be maintained in the future for both national and international air passengers. The air passenger demands of the two airports in 2030 are provided from other demand forecasting results by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (*7*). The forecasts include domestic and international air travel demand across regions in Japan and between Japan and other countries, which have been estimated using an inter-regional travel demand analysis system.

### ARAD-Mode choice Submodel

This submodel predicts the trip demand of each transport mode. Traveling from the two airports to other destination zones or origin zones to the two airports under the given O-D matrixes are estimated from the trip distribution submodel. The choice set includes bus, rail, and car. The trips are predicted using the MNL model as

$$XA_{ij,m}^{dphg} = \frac{TA_{ij}^{dphg} \cdot \exp\left(VA_{ij,m}^{dphg}\right)}{\exp\left(VA_{ij,bus}^{dphg}\right) + \exp\left(VA_{ij,rail}^{dphg}\right) + \exp\left(VA_{ij,car}^{dphg}\right)} \tag{14}$$

where $XA_{ij,m}^{dphg}$ represents the trips by mode $m(=bus, rail, car)$ from $i$ to $j$ by domestic or international passenger $d$ residing at residential zone $h$ with purpose $p$ and for access/egress to or from airport $g$. Additionally, $TA_{ij}^{dphg}$ represents the trips from $i$ to $j$ estimated from the trip distribution submodel, and $VA_{ij,m}^{dphg}$ is the systematic utility, which is assumed to be a linear function of explanatory variables including travel time and travel cost. It is noted that if $g = 0$, the trip is made for access to airport and the destination would be the airport whereas if $g = 1$, the trip is made for egress from airport and the origin would be the airport.

**ARAD-Rail Route Choice Submodel**

The rail-route choice submodel is formulated using MNL as

$$XA_{ij,r}^{dp} = \frac{\exp\left(VA_{ij,r}^{dp}\right)}{\sum_{r'} \exp\left(VA_{ij,r'}^{dp}\right)} \cdot \sum_{h} \sum_{g} XA_{ij,rail}^{dphg} \tag{15}$$

where $XA_{ij,r}^{dp}$ represents trips to/from airports by rail route $r$ from zone $i$ to $j$ by domestic or international passengers $d$ with purpose $p$, and $VA_{ij,r}^{dp}$ is the systematic utility of rail route $r$, which is assumed to be a linear function of then explanatory variables. It is assumed that (1) the Tokyo-Monorail and Keikyu-Kuko lines are available for all departing zones for Haneda Airport access; and (2) the Narita-express, Keisei-Skyliner, Keisei, and JR lines are available for all departing zones for Narita Airport access except some adjacent zones to the airport.

The rail link flows for airport access trips are computed by summing up the rail route flows in a specific link across all subgroups as

$$xa_l = \sum_{d} \sum_{p} \sum_{ij} \sum_{r} \delta_{ij,r,l} \cdot XA_{ij,r}^{dp} \tag{16}$$

where $xa_l$ is the passenger flows of rail link $l$ estimated from airport access rail demand and $\delta_{ij,r,l}$ is the dummy variable for rail link $l$, which belongs to rail route $r$ from zone $i$ to $j$ and 0 for otherwise.

## HIGH-SPEED-RAIL RAIL ACCESS DEMAND (HSR-RAD) MODEL

**Market Segmentation**

The HSR-RAD model system predicts the rail passenger demand to and from HSR stations in TMA. This reflects the fact that the HSR is well connected with the local urban rail network in Tokyo leading to multiple options of access/egress travel to and from HSR stations. HSR lines operating in the target area are the Tokaido-Shinkansen connecting with western part of Japan and the Tohoku/Jyoetsu-Shinkansen connecting with northern part of Japan. There are seven HSR stations in the target area.

The same demand models are shared for all HSR lines while the demand is predicted for each subgroup by their trip purpose (business, leisure, and private). Therefore, the model assumes that trip patterns are not affected by access/egress, residential locations, or nationalities. This is due to the poor data availability necessary for detailed analysis.

### HSR-RAD-Trip Distribution Submodel

This submodel predicts the daily trips to/from HSR stations as well as from/to each zone using MNL-based destination choice models. The passenger demands of the HSR stations including new maglev stations in 2030 are provided from another travel demand forecast conducted by MLIT, in which the inter-regional travel demand in Japan is estimated with a large-scale demand analysis system.

The HSR-RAD-trip distribution submodel is formulated as

$$TH_{Sj}^{p} = \frac{\exp\left(VH_{Sj}^{p}\right)}{\sum_{j'} \exp\left(VH_{Sj'}^{p}\right)} \cdot GH_{S}^{p} \quad \text{or} \quad TH_{iS}^{p} = \frac{\exp\left(VH_{iS}^{p}\right)}{\sum_{i'} \exp\left(VH_{i'S}^{p}\right)} \cdot GH_{S}^{p} \tag{17}$$

where $TH_{Sj}^{p}$ represents the trips from HSR station $S$ to zone $j$ with purpose $p$; $TH_{iS}^{p}$ represents the trips from zone $i$ to HSR station $S$ with purpose $p$; $VH_{Sj}^{p}$ and $VH_{iS}^{p}$ are the systematic utilities; and $GH_{S}^{p}$ is the generated/attracted trips to/from HSR station $S$ with purpose $p$. The individual-specific choice sets are constructed according to the HSR lines they would use.

### HSR-RAD-Mode Choice Submodel

This submodel estimates the daily trip demand of each transport mode from HSR stations to other destination zones (and vice-versa) under the given O-D matrixes estimated from the trip distribution submodels. The MNL model has been employed and the modes included in the universal choice set are bus, rail, car, and taxi. The demand for mode *m* is given by

$$XH_{ij,m}^{p} = \frac{TH_{ij}^{p} \cdot \exp\left(VH_{ij,m}^{p}\right)}{\exp\left(VH_{ij,bus}^{p}\right) + \exp\left(VH_{ij,rail}^{p}\right) + \exp\left(VH_{ij,car}^{p}\right) + \exp\left(VH_{ij,taxi}^{p}\right)} \tag{18}$$

where $XH_{ij,m}^{p}$ is the trips by mode $m\ (= bus, rail, car, taxi)$ from zone $i$ to $j$ (either $i$ or $j$ is a HSR station) with purpose $p$; $TH_{ij}^{p}$ represents the trips from zone $i$ to $j$; and $VH_{ij,m}^{p}$ is the systematic utility.

### HSR-RAD-Rail Route Choice Submodel

For the rail-route choice submodel, MNL model is employed as

$$XH_{ij,r}^{p} = \frac{\exp\left(VH_{ij,r}^{p}\right)}{\sum_{r'} \exp\left(VH_{ij,r'}^{p}\right)} \cdot XH_{ij,rail}^{p} \tag{19}$$

where $XH_{ij,r}^{p}$ represents the trips to/from HSR stations by rail route $r$ from zone $i$ to $j$ with purpose $p$ and $VH_{ij,r}^{p}$ is the systematic utility, which is assumed to be a linear function of the explanatory variables. The route choice set is constructed considering the frequently observed routes shown in dataset with the maximum size of five.

The rail link flows in the HSR rail access trips are computed by summing up the rail route flows in a specific link across all subgroups as

$$xh_l = \sum_{p}\sum_{ij}\sum_{r}\delta_{ij,r,l} \cdot XH_{ij,r}^{p} \tag{20}$$

where $xh_l$ is the passenger flows of rail link $l$ estimated from the HSR rail access demand; $\delta_{ij,r,l}$ is the dummy variable if rail link $l$ belongs to rail route $r$ from zone $i$ to $j$.

## TOTAL RAIL LINK FLOW

Finally, the total link passenger flows are computed by summing the rail link flows estimated in urban rail demand, those in airport rail access demand, and those in HSR rail access demand as

$$x_l = xu_l + xa_l + xh_l \tag{21}$$

## MODEL ESTIMATION

### Data

The model parameters are estimated with various travel-related survey data sources as summarized in TABLE 1. In addition, the level of service data of transportation services is collected from timetables and fare-tables of public transport.

**TABLE 1 Data Sources for Estimating Models**

| Models | Submodels | Sources mainly used as the demand data | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Domestic/ International | Name | Implementing Organization | Frequency | Data size | Scope | Data Collection Method |
| Urban Rail Demand (URD) | Trip Generation/ Attraction | | 2010 National Census | MIAC | Every five years | Approx. 52 mil. households | Entire nation in Japan | Household survey. Self-completion forms distributed and collected by enumerators. |
| | | | 2008 Person Trip (PT) Survey | MLIT | Every ten years | Approx. 1.4 mil. households | Tokyo metropolitan area | Household survey. Self-completion forms distributed and collected by post. |
| | Trip Distribution | | 2010 National Census | MIAC | Every five years | Approx. 52 mil. households | Entire nation in Japan | Household survey. Self-completion forms distributed and collected by enumerators. |
| | | | 2008 Person Trip (PT) Survey | MLIT | Every ten years | Approx. 1.4 mil. households | Tokyo metropolitan area | Household survey. Self-completion forms distributed and collected by post. |
| | Mode Choice | | 2008 Person Trip (PT) Survey | MLIT | Every ten years | Approx. 1.4 mil. households | Tokyo metropolitan area | Household survey. Self-completion forms distributed and collected by post. |
| | Rail Route Choice | | 2010 Metropolitan Public Transport Census | MLIT | Every five years | Approx. 1.25 mil. urban rail passengers | Tokyo metropolitan area | Individual survey. Self-completion forms distributed by surveyors and collected by post or through a web site. |
| Airport Rail Access Demand (ARAD) | Trip Distribution | Domestic: | 2013 Domestic Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 240,000 domestic air passengers | All domestic airline services on a single day | Intercept survey. Self-completion forms distributed and collected by flight attendants during flights. |
| | | International: | 2013 International Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 450,000 international air passengers | International airline services from Japan during a week | Intercept survey. Face-to-face interviews by surveyors at international airports in Japan. |
| | | | 2012 Overnight Stay Tourism Statistical Survey | MLIT | Quarterly | Approx. 350 mil. overnight-stay tourists | Entire nation in Japan | Regular reports from all accommodation operators with 10 or over employees to the Government. |
| | Mode Choice | Domestic: | 2013 Domestic Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 240,000 domestic air passengers | All domestic airline services on a single day | Intercept survey. Self-completion forms distributed and collected by flight attendants during flights. |
| | | International: | 2013 International Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 450,000 international air passengers | International airline services from Japan during a week | Intercept survey. Face-to-face interviews by surveyors at international airports in Japan. |
| | Rail Route Choice | Domestic: | 2013 Domestic Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 240,000 domestic air passengers | All domestic airline services on a single day | Intercept survey. Self-completion forms distributed and collected by flight attendants during flights. |
| | | International: | 2013 International Air Passenger Travel Demand Survey | MLIT | Every one/two years | Approx. 450,000 International air passengers | International airline services from Japan during a week | Intercept survey. Face-to-face interviews by surveyors at international airports in Japan. |
| HSR Rail Access Demand (HSR-RAD) | Trip Distribution | | 2010 Inter-regional Passenger Travel Survey | MLIT | Every five years | Approx. 129,000 inter-regional rail passengers | Inter-regional travelers in Japan | Intercept survey. Self-completion forms distributed and collected by surveyors during rail ride. |
| | Mode Choice | | 2010 Inter-regional Passenger Travel Survey | MLIT | Every five years | Approx. 129,000 inter-regional rail passengers | Inter-regional travelers in Japan | Intercept survey. Self-completion forms distributed and collected by surveyors during rail ride. |
| | Rail Route Choice | | 2010 Inter-regional Passenger Travel Survey | MLIT | Every five years | Approx. 129,000 inter-regional rail passengers | Inter-regional travelers in Japan | Intercept survey. Self-completion forms distributed and collected by surveyors during rail ride. |
| | | | 2010 Metropolitan Public Transport Census | MLIT | Every five years | Approx. 1.25 mil. urban rail passengers | Tokyo metropolitan area | Individual survey. Self-completion forms distributed by surveyors and collected by post or through a web site. |

Note: MLIT represents the Ministry of Land, Infrastructure, Transport and Tourism, Japan; and MIAC represents the Ministry of Internal Affairs and Communications.

**Model Estimation**

*URD Model.* The estimation results with nonlinear least squares method of the trip distribution models in the URD-Trip Distribution Submodel are summarized in TABLE 2. The distance-based modal shares of walk/bicycle in the URD-Mode Choice Submodel are estimated by assuming that the travel distance is categorized into trips of 0-3 km, 3-6 km, 6-9 km, 9-12 km, and 12 km or longer. Next, the MNL-based model in the URD-Mode choice Submodel is estimated with disaggregate data from the 2008 PT Survey. These results are summarized in TABLE 3. Model fitness and statistical significance of all variables are considered high.

TABLE 3 also summarizes the estimation results of the URD-Rail Route Choice Submodel. The MNL-based rail-station access/egress mode choice models are estimated with disaggregated data and shows that McFadden's Rho-squared values are all sufficiently high and all explanatory variables are statistically significant. The disaggregate MNP-based rail route choice models are estimated in which the in-vehicle congestion index (*2, 5, 6*) is defined as

$$Cong_{ij,r} = \sum_{l} \delta_{ij,r,l} \cdot t_l \cdot \left( \frac{x_l}{Cap_l} \right)^2 \tag{22}$$

where $Cong_{ij,r}$ is the in-vehicle congestion index for rail route $r$ from zone $i$ to zone $j$; $t_l$ is the travel time of rail link $l$; $x_l$ is the passenger flows of rail link $l$; $Cap_l$ is the capacity of passenger flows of rail link $l$; and $\delta_{ij,r,l}$ is the dummy variable for rail link $l$ that belongs to rail route $r$ from zone $i$ to zone $j$. The route choice set is formulated following a method proposed by Kato et al. (*8*). The level-of-service of each route (e.g. representative rail route travel time) is computed following the observed data in the model estimation process while it is computed following a concept of "hyperpath" (*9*, *10*) in the model verification and future forecast processes. Note that the concept of hyperpath is newly introduced into the proposed model system. The disaggregate data used for estimating the route choice model is resampled from the original entire dataset, reflecting the population distribution relative to trip distance. For each sample trip, four or less alternative routes are prepared. The estimation results show that model fitness is good and all explanatory variables are statistically significant.

**TABLE 2 Estimation Results of Urban Rail Demand (URD) Model- Trip Distribution Submodels**

| | | | Constant | | Gener. Trips | | Attract. Trips | | General. cost | | 0/1 (<10 km) | | 0/1 (10-20 km) | | 0/1 (20-30 km) | | 0/1 (30-40 km) | | 0/1 (40-50 km) | | 0/1 (50<km) | | 0/1 (CBD) | | R-sq. | # obs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | G/A | Age | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | | |
| Yamanote and Bay Area | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H-W | G | Age 1 | 0.624 | 30.1 | 1.14 | 155 | 0.940 | 170 | -2.41 | -110 | | | | | | | | | | | | | | | 0.848 | 18772 |
| | G | Age 2 | 0.067 | 23.7 | 1.36 | 124 | 0.888 | 111 | -3.49 | -114 | | | | | | | | | | | | | | | 0.803 | 18146 |
| | G | Age 3 | 0.324 | 18.0 | 1.44 | 86.6 | 0.860 | 63.6 | -3.16 | -78.1 | | | | | | | | | | | | | | | 0.598 | 17520 |
| | A | Age 1 | 0.300 | 11.1 | 1.18 | 76.6 | 0.952 | 54.5 | -0.71 | -11.3 | 0.197 | 6.51 | 0.082 | 5.53 | 0.04 | 3.24 | 0.063 | 2.97 | | | | | | | 0.794 | 2948 |
| | A | Age 2 | 0.603 | 12.1 | 1.15 | 65.4 | 0.925 | 41.9 | -1.07 | -14.6 | 0.875 | 7.33 | 0.451 | 7.46 | | | | | | | | | | | 0.756 | 2948 |
| | A | Age 3 | 1.77 | 18.6 | 1.22 | 85.7 | 1.180 | 53.5 | -1.20 | -24.8 | 0.376 | 6.01 | | | | | | | | | | | | | 0.835 | 2948 |
| H-S | G | All | 0.0222 | 1.22 | 1.83 | 8.92 | 1.560 | 9.33 | -1.32 | -6.31 | | | | | | | | | | | | | | | 0.187 | 2948 |
| H-P | G | All | 0.0001 | 2.28 | 1.52 | 21.4 | 0.804 | 26.9 | -4.13 | -25.2 | | | | | | | | | | | | | -0.0000671 | -2.41 | 0.608 | 1827 |
| | A | All | 0.094 | 4.25 | 0.892 | 31.7 | 0.707 | 20.1 | -1.09 | -10.1 | 0.301 | 3.13 | 0.094 | 3.07 | 0.019 | 1.38 | 0.043 | 2.27 | | | | | | | 0.497 | 2221 |
| OH-P | G | All | 0.011 | 5.07 | 0.628 | 20.1 | 0.854 | 28.7 | -2.41 | -46.2 | | | | | | | | | | | | | | | 0.454 | 1827 |
| | A | All | 0.0004 | 4.60 | 0.809 | 24.8 | 0.717 | 20.6 | -2.73 | -45.1 | | | | | | | | | | | | | | | 0.462 | 1827 |
| H-B | G | All | 0.0622 | 4.09 | 1.217 | 16.6 | 0.893 | 22.2 | -3.63 | -29.2 | | | | | | | | | | | | | | | 0.699 | 1827 |
| | A | All | 1.1 | 13.2 | 1.01 | 44.7 | 1.02 | 42.9 | -1.79 | -32.6 | -0.18 | -5.98 | | | | | | | | | | | | | 0.763 | 1861 |
| W-B | G | All | 0.189 | 6.23 | 0.866 | 50.8 | 0.921 | 49.1 | -1.44 | -29.9 | 0.325 | 6.82 | 0.206 | 5.58 | 0.000452 | 0.014 | 0.095 | 2.56 | | | | | | | 0.985 | 1890 |
| | A | All | 0.307 | 11.1 | 0.867 | 52.3 | 0.84 | 49.9 | -1.79 | -40.4 | 0.095 | 3.21 | 0.056 | 2.35 | -0.07 | -2.29 | | | | | | | | | 0.764 | 1890 |
| P-H | G | All | 0.0218 | 2.71 | 1.3 | 28.9 | 1.07 | 24.9 | -0.90 | -11.2 | 0.089 | 2.91 | 0.038 | 2.67 | 0.01 | 1.31 | 0.017 | 1.82 | 0.003 | 0.332 | -0.00359 | -0.40 | 0.093 | 3.62 | 0.799 | 1832 |
| | A | All | 0.0003 | 2.14 | 0.877 | 25.2 | 1.14 | 17.0 | -3.35 | -20.1 | 0.000775 | 1.86 | | | | | | | | | | | | | 0.423 | 1827 |
| B-H | G | All | 1.18 | 8.59 | 1.02 | 47.4 | 1.20 | 33.0 | -0.65 | -8.52 | 2.01 | 5.12 | 1.46 | 5.33 | 0.615 | 3.51 | 0.725 | 4.12 | 0.504 | 3.28 | 0.232 | 13.8 | 2.85 | 5.67 | 0.832 | 1832 |
| | A | All | 0.139 | 5.24 | 1.05 | 26.5 | 1.05 | 17.4 | -3.03 | -31.4 | | | | | | | | | | | | | | | 0.308 | 1827 |
| Areas along Tsukuba Express Line and Koshigaya Laketown Area | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H-W | G | Age 1 | 0.0174 | 1.60 | 1.26 | 50.8 | 0.952 | 52.4 | -1.87 | -15.4 | 0.592 | 5.42 | 0.238 | 6.16 | 0.08 | 4.8 | 0.098 | 5.68 | 0.107 | 6.18 | 0.039 | 2.43 | 0.029 | 3.99 | 0.95 | 2412 |
| | G | Age 2 | 0.0128 | 1.20 | 1.22 | 33.3 | 1.22 | 35.1 | -3.76 | -19.2 | 0.111 | 3.18 | 0.063 | 3.32 | 0.01 | 0.922 | 0.022 | 1.87 | 0.033 | 2.52 | | | 0.011 | 2.87 | 0.82 | 2412 |
| | G | Age 3 | 0.141 | 1.26 | 1.24 | 45.8 | 1.08 | 43.1 | -2.46 | -18.1 | 1.84 | 4.74 | 1.05 | 5.25 | 0.406 | 3.13 | 0.644 | 4.87 | 0.782 | 5.77 | 0.229 | 1.50 | 0.460 | 6.27 | 0.888 | 2412 |
| H-S | G | All | 0.0157 | 0.987 | 0.567 | 3.67 | 0.010 | 0.367 | -1.64 | -4.11 | | | | | | | | | | | | | | | 0.261 | 2412 |
| H-P | G | All | 0.0368 | 1.37 | 0.465 | 1.70 | 0.374 | 6.13 | -2.83 | -12.5 | | | | | | | | | | | | | | | 0.479 | 378 |
| H-B | G | All | 0.361 | 1.07 | 0.327 | 2.78 | 0.652 | 8.04 | -0.47 | -2.66 | 6.75 | 1.98 | 4.29 | 2.63 | 2.57 | 2.64 | 1.77 | 2.43 | 0.802 | 1.39 | 1.24 | 1.75 | 0.930 | 1.59 | 0.624 | 378 |
| P-H | A | All | 0.0005 | 1.16 | 0.464 | 7.54 | 0.713 | 2.74 | -3.94 | -13.3 | | | | | | | | | | | | | | | 0.53 | 378 |
| B-H | A | All | 0.445 | 1.65 | 0.815 | 10.1 | 0.400 | 3.61 | -0.74 | -3.56 | 3.67 | 1.69 | 2.19 | 2.10 | 1.28 | 2.10 | 1.57 | 2.43 | 0.39 | 1.00 | 0.653 | 1.25 | | | 0.412 | 378 |
| Sagamihara Area | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H-W | A | Age 1 | 0.0304 | 1.79 | 0.674 | 24.7 | 1.06 | 29.9 | -2.40 | -29.5 | 0.562 | 6.73 | 0.417 | 7.50 | 0.187 | 6.39 | 0.086 | 3.79 | 0.035 | 1.48 | | | | | 0.708 | 1876 |
| | A | Age 2 | 0.0459 | 1.49 | 0.495 | 15.5 | 0.906 | 21.1 | -2.58 | -27.2 | 1.11 | 6.77 | 0.702 | 7.86 | 0.235 | 5.14 | 0.105 | 2.47 | | | | | | | 0.596 | 1876 |
| | A | Age 3 | 0.0529 | 1.05 | 0.686 | 26.4 | 0.734 | 21.1 | -2.30 | -30.2 | 1.33 | 8.24 | 1.15 | 10.1 | 0.516 | 7.41 | 0.246 | 3.95 | 0.112 | 1.56 | | | | | 0.661 | 1876 |
| H-P | A | All | 0.0008 | 0.097 | 0.629 | 14.3 | 2.16 | 9.38 | -1.06 | -7.99 | 0.085 | 1.24 | 0.057 | 1.36 | | | | | | | | | | | 0.938 | 484 |
| OH-P | G | All | 0.001 | 2.07 | 0.579 | 10.3 | 0.702 | 17.0 | -4.35 | -24.4 | | | | | | | | | | | | | | | 0.582 | 484 |
| | A | All | 0.0028 | 1.25 | 0.689 | 15.4 | 1.05 | 12.1 | -3.29 | -9.08 | | | | | | | | | | | | | | | 0.498 | 484 |
| H-W | A | All | 1.41 | 3.60 | 0.808 | 19.2 | 2.37 | 10.5 | -0.94 | -4.84 | 14.9 | 3.28 | 8.85 | 3.76 | 1.89 | 2.63 | | | | | | | | | 0.601 | 484 |
| P-H | G | All | 7E-05 | 1.75 | 1.19 | 17.2 | 0.838 | 23.5 | -5.05 | -23.7 | | | | | | | | | | | | | | | 0.826 | 484 |
| B-H | G | All | 0.366 | 1.92 | 0.927 | 10.9 | 0.742 | 19.2 | -1.65 | -11.0 | 0.688 | 1.76 | 1.043 | 2.63 | 0.903 | 2.94 | 0.698 | 2.45 | | | | | | | 0.55 | 484 |

Note 1: G denotes trip generation and A denotes trip attraction

Note 2: Age 1 denotes an age subgroup of 15-64 yrs. male and 15-34 yrs. female; Age 2 denotes an age subgroup of 35-64 yrs. female; and Age 3 denotes an age subgroup of 65 yrs. or older male and female.

Note 3: Units of Generated and Attracted trips are 10,000 trips; units of generalized cost are 10,000 JPY.

1 **TABLE 3 Estimation Results of Urban Rail Demand (URD) Model- Mode Choice and Rail Route Choice Submodels**

| Purpose | H-W + W-H | | | | H-S + S-H | | H-P | | | | | | OH-P | | | | | | H-B + W-B | | | | P-H | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age group | 15-64 | | 65< | | All | | 15-64 | | 65-74 | | 74< | | 15-64 | | 65-74 | | 74< | | 15-64 | | 65< | | 15-64 | | 65-74 | | 74< | |
| | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. |
| URD-Mode choice Submodel | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Travel Cost | -0.001 | -10.4 | -0.0009 | -7.3 | -0.006 | -13.1 | -0.002 | -6.2 | -0.002 | -9.2 | -0.003 | -9.7 | -0.002 | -7.8 | -0.002 | -8.2 | -0.001 | -3.2 | -0.0004 | -2.9 | -0.002 | -8.2 | -0.002 | -9.0 | -0.003 | -12.2 | -0.003 | -12.4 |
| Railride time | -0.048 | -18.2 | -0.0389 | -13.8 | -0.01 | -2.1 | -0.026 | -6.6 | -0.035 | -8.8 | -0.041 | -11.0 | -0.025 | -6.1 | -0.022 | -7.1 | -0.03 | -5.5 | -0.0178 | -5.3 | -0.031 | -8.2 | -0.035 | -8.7 | -0.026 | -9.4 | -0.036 | -10.6 |
| Car own. (car) | 1.13 | 7.2 | 2.45 | 12.9 | 0.972 | 3.4 | 2.22 | 10.2 | 5.64 | 21.8 | 6.85 | 25.7 | | | | | | | | | | | 4.14 | 18.7 | 4.91 | 22.3 | 5.63 | 24.6 |
| 0/1 CBD (car) | -1.72 | -21.3 | -0.847 | -8.6 | -0.571 | -2.1 | -1.18 | -10.9 | -1.2 | -11.0 | -1.28 | -10.7 | -1.06 | -9.9 | -1.38 | -15.4 | -1.78 | -11.1 | -0.647 | -5.4 | -0.96 | -8.3 | -0.638 | -5.5 | -0.565 | -5.5 | -0.712 | -6.3 |
| Logsum of route choice (rail) | 0.446 | 33.6 | 0.504 | 24.0 | 0.148 | 4.9 | 0.341 | 13.7 | 0.367 | 13.9 | 0.361 | 13.6 | 0.405 | 15.9 | 0.413 | 19.7 | 0.372 | 9.4 | 0.404 | 19.6 | 0.38 | 16.6 | 0.465 | 15.5 | 0.314 | 14.5 | 0.402 | 14.0 |
| 0/1 short distance (car) | 0.665 | 6.1 | 0.53 | 4.3 | 2.18 | 6.9 | 1.63 | 15.0 | 1.22 | 10.8 | 1.04 | 8.4 | 1.48 | 13.3 | 0.951 | 10.5 | 0.867 | 5.4 | 1.13 | 9.8 | 0.916 | 8.3 | 1.64 | 13.3 | 1.07 | 10.4 | 1.16 | 9.8 |
| Const. (bus) | -0.773 | -7.7 | 0.248 | 2.0 | 4.28 | 14.0 | 0.0288 | 0.2 | 2.67 | 15.2 | 3.84 | 21.2 | -0.793 | -5.3 | -0.805 | -7.1 | 0.122 | 0.6 | -2.78 | -14.7 | -1.1 | -7.5 | 2.15 | 11.8 | 2.62 | 17.2 | 4.06 | 24.1 |
| Const. (rail) | 2.82 | 21.8 | 2.73 | 17.0 | 4.8 | 14.8 | 1.91 | 11.4 | 3.67 | 18.3 | 3.85 | 19.2 | 2.17 | 14.4 | 1.43 | 11.3 | 0.875 | 4.0 | 1.37 | 8.3 | 0.721 | 4.4 | 3.99 | 19.5 | 3.64 | 20.8 | 3.8 | 19.9 |
| Initial log-likelihood | | -10,710 | | -42,99 | | -22,773 | | -3,270 | | -3,675 | | -3,625 | | -3,483 | | -3,865 | | -1,304 | | -3.331 | | -3,204 | | -3,354 | | -3,532 | | -3,537 |
| Final log-likelihood | | -2,785 | | -19,52 | | -553 | | -1,507 | | -1,611 | | -1,730 | | -1,508 | | -2,118 | | -812 | | -1.515 | | -1,528 | | -1,344 | | -1,905 | | -1.796 |
| Rho2 | | 0.74 | | 0.55 | | 0.98 | | 0.54 | | 0.56 | | 0.52 | | 0.57 | | 0.45 | | 0.38 | | 0.54 | | 0.52 | | 0.60 | | 0.46 | | 0.49 |
| # obs. | | 9,763 | | 3,689 | | 2,786 | | 2,608 | | 3,037 | | 3,047 | | 2,894 | | 3,521 | | 1,018 | | 2,780 | | 2,604 | | 2,774 | | 3,219 | | 2,932 |
| Access/egress mode choice model in URD-Rail Route Choice Submodel | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Travel time (walk/bike) | -0.22 | -26.7 | -0.127 | -12.6 | -0.159 | -12.7 | -0.131 | -11.7 | -0.118 | -12.1 | | | | | | | | | -0.155 | -13.7 | -0.118 | -8.7 | | | | | | |
| Travel time (bus) | -0.091 | -7.5 | -0.0449 | -2.7 | -0.072 | -4.9 | -0.049 | -2.8 | -0.029 | -2.0 | | | | | | | | | -0.0865 | -4.3 | -0.064 | -3.0 | | | | | | |
| Travel cost | -0.006 | -9.6 | -0.0037 | -4.2 | -0.007 | -5.3 | -0.004 | -3.9 | -0.004 | -4.7 | | | | | | | | | -0.0039 | -4.1 | -0.003 | -2.5 | | | | | | |
| Height gap (walk/bike) | -0.011 | -4.1 | -0.0089 | -2.6 | -0.013 | -3.5 | -0.008 | -3.3 | -0.014 | -3.7 | | | | | | | | | -0.0103 | -2.4 | -0.012 | -2.8 | | | | | | |
| ln (serv. freq.) | 0.287 | 6.2 | 0.236 | 3.5 | 0.19 | 2.4 | 0.313 | 4.4 | 0.354 | 5.5 | | | | | | | | | 0.381 | 5.2 | 0.265 | 3.1 | | | | | | |
| Const. (bike) | -3.02 | -32.9 | -2.24 | -16.6 | -1.91 | -14.6 | -2.39 | -16.8 | -2.7 | -18.3 | | | | | | | | | -2.79 | -19.8 | -2.72 | -13.2 | | | | | | |
| Const. (car) | -6.78 | -33.6 | -5.16 | -17.7 | -4.98 | -17.5 | -4.75 | -17.2 | -5.12 | -17.7 | | | | | | | | | -4.67 | -18.1 | -4.96 | -12.5 | | | | | | |
| Const. (bus) | -4.58 | -17.9 | -3.44 | -9.2 | -3.22 | -9.3 | -4.05 | -9.2 | -4.13 | -9.8 | | | | | | | | | -4.19 | -9.9 | -3.45 | -6.1 | | | | | | |
| Initial log-likelihood | | -4,086 | | -1,345 | | -1,355 | | -1,359 | | -1,340 | | | | | | | | | | -1,358 | | -668 | | | | | | |
| Final log-likelihood | | -2,549 | | -983 | | -988 | | -1,008 | | -923 | | | | | | | | | | -962 | | -465 | | | | | | |
| Rho2 | | 0.38 | | 0.27 | | 0.27 | | 0.26 | | 0.31 | | | | | | | | | | 0.29 | | 0.30 | | | | | | |
| # obs. | | 3,000 | | 1,000 | | 1,000 | | 1,000 | | 1,000 | | | | | | | | | | 1,000 | | 500 | | | | | | |
| URD-Rail Route Choice Submodel | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Travel cost | -0.004 | -3.9 | -0.0033 | -3.1 | -0.004 | -3.9 | -0.004 | -3.6 | -0.004 | -2.8 | | | | | | | | | -0.0031 | -2.7 | | | | | | | | |
| Railride time | -0.151 | -7.4 | -0.0974 | -5.6 | -0.08 | -5.4 | -0.091 | -5.2 | -0.102 | -3.1 | | | | | | | | | -0.136 | -7.4 | | | | | | | | |
| Flat transfer walking time | -0.242 | -6.5 | -0.139 | -4.2 | -0.133 | -3.5 | -0.205 | -3.9 | -0.183 | -2.6 | | | | | | | | | -0.14 | -2.8 | | | | | | | | |
| Up/down transfer time | -0.313 | -4.8 | -0.329 | -4.9 | -0.137 | -2.0 | -0.221 | -2.9 | -0.261 | -2.1 | | | | | | | | | -0.376 | -4.3 | | | | | | | | |
| Waiting time | -0.145 | -4.2 | -0.112 | -3.6 | -0.078 | -3.4 | -0.105 | -3.7 | -0.12 | -2.5 | | | | | | | | | -0.132 | -4.1 | | | | | | | | |
| Congestion | -0.012 | -2.5 | -0.0335 | -5.4 | -0.01 | -1.9 | | | | | | | | | | | | | | | | | | | | | | |
| Logsum of access/egress | 0.883 | 12.7 | 0.991 | 10.6 | 0.908 | 12.6 | 0.752 | 11.4 | 0.975 | 5.0 | | | | | | | | | 0.888 | 12.2 | | | | | | | | |
| Cov. ratio | 0.128 | 2.9 | 0.022 | 1.2 | 0.019 | 1.1 | 0.033 | 1.2 | 0.253 | 1.4 | | | | | | | | | 0.035 | 1.3 | | | | | | | | |
| Initial log-likelihood | | -1,585 | | -773 | | -777 | | -791 | | -734 | | | | | | | | | | -770 | | | | | | | | |
| Final log-likelihood | | -887 | | -472 | | -441 | | -512 | | -491 | | | | | | | | | | -392 | | | | | | | | |
| Rho2 | | 0.44 | | 0.39 | | 0.43 | | 0.35 | | 0.33 | | | | | | | | | | 0.49 | | | | | | | | |
| # obs. | | 1,000 | | 500 | | 500 | | 500 | | 500 | | | | | | | | | | 500 | | | | | | | | |

2 Note 1: Models for OH-P and P-H in URD-Rail Route Choice Submodel are assumed to be the same as those for H-P in URD-Rail Route Choice Submodel.

3 Note 2: Models for the age subgroup of 65-74 for H-P in URD-Rail Route Choice Submodel are assumed to be the same as those for the age subgroup of 75< for H-P in URD-Rail Route Choice Submodel.

4 Note 3: Units of all time related variables, travel cost, and car own in mode choice models and route choice models are min., JPY, and # per person, respectively.

*ARAD Model.* The growth factor method has been applied to estimate trip distribution of domestic air passengers in the ARAD-Trip Distribution Submodel per the following the two steps. (1) Allocating the trips under the assumption that the future trip distribution pattern would be the same as the current distribution pattern by large-scale (L) zone level. Note the area of L zones is approximately equivalent to municipal administrative area and there are 333 L zones in the target area. (2) Allocating the L-zone-based O-D trips into TAZ-based O-D trips in proportion to their population size. The population sizes are assumed to be nighttime population for the nonbusiness trips of domestic air passengers; the daytime worker population for the business trips made by domestic air passengers who reside in other areas than TMA; and average of the nighttime population and daytime worker population for the business trips made by domestic air passengers who reside in TMA.

TABLE 4 shows the estimation results of the ARAD model where the MNL-based mode choice model is estimated for domestic air passengers. The results show that all models have high McFadden's Rho-squared values while all explanatory variables are statistically significant. One of the unique aspects of this model is that the travel time reliability measured as the standard deviation of travel times for car trips has been incorporated as one of the car-mode specific variables. The reliability data were obtained from the probe database of motor vehicle companies (*11*). As for the routes without such observed data, the following formula estimated from the route-level regression has been applied to obtain the interpolated numbers (*12*):

$$SD_{ij,r} = \underset{(32.6)}{28.805\,CI_{ij,r}} + \underset{(45.5)}{0.092\,D_{ij,r,\exp}} + \underset{(9.7)}{0.130\,D_{ij,r,multi-lane}} + \underset{(15.3)}{0.145\,D_{ij,r,two-lane}} - \underset{(-31.8)}{34.416} \quad (23)$$

$$N = 1{,}559 \quad R^2 = 0.73$$

where $SD_{ij,r}$ is the standard deviation of travel times (min.) for route $r$ from zone $i$ to zone $j$; $CI_{ij,r}$ is the congestion index (average travel time divided by free-flow travel time); $D_{ij,r,\exp}$ is the length (km) of expressway section in route $r$; $D_{ij,r,multi-lane}$ is the length (km) of non-expressway section with three or more lanes in route $r$; and $D_{ij,two-lane}$ is the length (km) of non-expressway section with two lanes in route $r$.

The MNL-based rail route choice submodel is estimated for domestic air passengers in the ARAD-Rail Route Choice Submodel as shown in TABLE 4. The explanatory variables are the total travel time of non-express rail service; rail-ride travel time of express rail service; travel cost; and time of transfers from rail to rail. Level-of-service data is computed using the hyperpath algorithm (9) for each L-zone level. All models have high McFadden's Rho-squared values and all parameters are statistically significant.

The growth factor method is applied to the estimation of trip distribution of international air passengers in the ARAD-Trip Distribution Submodel, thereby following the same process as domestic air passengers. The 2013 International Air Passenger Travel Demand Survey cannot capture the origin to access the airports while it can capture the L-zone-based destination. The locations of foreign individuals who stayed overnight are assumed to represent their origins to access the airports using the data of the 2012 Overnight Stay Tourism Statistical Survey. We note this assumption may lead to biased results because they may not directly travel from their accommodation to airports or vice versa.

The MNL-based mode choice model is estimated for international air passengers in the ARAD-Mode choice Submodel in TABLE 4. The results show that the goodness-of-fit of the leisure purpose model is slightly weaker than for other models. The travel time reliability is weakly significant for

**TABLE 4 Estimation Results of Airport Rail Access Demand (ARAD) Model: Mode choice and Rail Route Choice Submodels (Domestic/International)**

| | Business (Japanese Passengers) | | | | | | | | Nonbusiness (Japanese Passengers) | | | | | | | | Foreigners | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Tokyo/Access | | Tokyo/Egress | | OutTokyo/Access | | OutTokyo/Egress | | Tokyo/Access | | Tokyo/Egress | | OutTokyo/Access | | OutTokyo/Egress | | | |
| | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. |
| ARAD-Mode choice Submmodel (Domestic) | | | | | | | | | | | | | | | | | | |
| Total travel time (car/bus) | -0.0263 | -16.5 | -0.0197 | -11.6 | -0.0241 | -5.96 | -0.0228 | -7.18 | -0.0205 | -12.7 | -0.0205 | -12.7 | -0.0363 | -9.49 | -0.0278 | -8.44 | | |
| Total travel cost (car/bus) | -0.0003 | -6.76 | -0.0003 | -5.49 | -0.0004 | -1.56 | -0.0003 | -1.57 | -0.0004 | -9.80 | -0.0003 | -8.1 | -0.0008 | -4.31 | -0.001 | -5.93 | | |
| Transfer time (bus) | -1.17 | -16.0 | -1.07 | -13.7 | -0.626 | -3.40 | -1.52 | -9.93 | -1.16 | -14.3 | -1.09 | -13.7 | -1.22 | -7.99 | -1.94 | -13.5 | | |
| Ln (Serv. Freq.) (bus) | 0.603 | 18.7 | 0.538 | 15.7 | 0.906 | 10.7 | 1.17 | 16.3 | 0.333 | 9.08 | 0.265 | 7.61 | 0.754 | 9.65 | 0.816 | 11.0 | | |
| Travel time reliability (car/bus) | -0.0141 | -1.11 | | | | | | | -0.0439 | -3.02 | | | | | | | | |
| Logsum of rail route choice (rail) | 0.303 | 23.9 | 0.311 | 20.8 | 0.346 | 10.1 | 0.338 | 11.9 | 0.467 | 20.6 | 0.484 | 20.8 | 0.844 | 13.9 | 0.722 | 13.8 | | |
| Const. (bus) | -2.61 | -19.5 | -2.75 | -18.7 | | | | | | | | | | | | | | |
| Const. (car) | -3.06 | -38.6 | -3.46 | -36.3 | | | | | | | | | | | | | | |
| Const. (Narita_bus) | | | | | -2.21 | -3.26 | -1 | -2.00 | 0.234 | 1.18 | -2.14 | -1.05 | 0.766 | 1.77 | 1.47 | 3.84 | | |
| Const. (CBD-Haneda_bus) | | | | | -5.39 | -16.4 | -6.31 | -23.4 | | | | | | | | | | |
| Const. (Other-Haneda_bus) | | | | | -4.81 | -13.7 | -5.24 | -18.1 | | | | | | | | | | |
| Const. (Haneda_bus) | | | | | | | | | -1.35 | -8.54 | -1.33 | -8.26 | -3.16 | -9.94 | -2.58 | -8.85 | | |
| Const. (Haneda_car) | | | | | | | | | -2.06 | -21.8 | -2.39 | -24.1 | | | | | | |
| Const. (Narita_car) | | | | | | | | | -0.29 | -1.87 | -2.00 | -1.33 | | | | | | |
| Initial log-likelihood | | -15,205 | | -10,455 | | -3,057 | | -5,489 | | -8,610 | | -7,950 | | -2,096 | | -2,489 | | |
| Final log-likelihood | | -9,387 | | -7,359 | | -1,218 | | -1,686 | | -6,892 | | -6,693 | | -1,530 | | -1,764 | | |
| Rho2 | | 0.383 | | 0.296 | | 0.600 | | 0.692 | | 0.200 | | 0.158 | | 0.27 | | 0.291 | | |
| # obs. | | 13,840 | | 9,517 | | 4,410 | | 7,919 | | 7,837 | | 7,236 | | 3,024 | | 3,591 | | |
| ARAD-Rail Route Choice Submodel (Domestic) | | | | | | | | | | | | | | | | | | |
| Total travel time of non-express | -0.106 | -53.9 | | | | | | | -0.06 | -25.1 | | | | | | | | |
| Rail-ride travel time of express | -0.0177 | -1.90 | | | | | | | -0.0098 | -1.59 | | | | | | | | |
| Total travel cost | -0.0014 | -11.0 | | | | | | | -0.001 | -7.25 | | | | | | | | |
| Transfer time | -0.292 | -13.6 | | | | | | | -0.364 | -13.2 | | | | | | | | |
| 0/1 (Narita_Keisei Line) | 6.79 | 13.9 | | | | | | | 4.05 | 13.7 | | | | | | | | |
| 0/1 (Narita_JR Line) | 8.29 | 16.0 | | | | | | | 4.86 | 14.6 | | | | | | | | |
| Initial log-likelihood | | -19,143 | | | | | | | | -9,283 | | | | | | | | |
| Final log-likelihood | | -16,109 | | | | | | | | -7,462 | | | | | | | | |
| Rho2 | | 0.158 | | | | | | | | 0.196 | | | | | | | | |
| # obs. | | 27,090 | | | | | | | | 11,870 | | | | | | | | |
| ARAD-Mode choice Submodel (International) | | | | | | | | | | | | | | | | | | |
| Total travel time (car/bus) | -0.0193 | -8.07 | | | | | | | -0.0157 | -7.65 | | | | | | | -0.0177 | -9.70 |
| Total travel cost (car/bus) | -0.0002 | -4.44 | | | | | | | -0.0003 | -7.22 | | | | | | | -0.0003 | -10.0 |
| Transfer time (bus) | -0.942 | -8.58 | | | | | | | -0.853 | -8.18 | | | | | | | -0.935 | -9.86 |
| Ln (Serv. Freq.) (bus) | 0.312 | 5.80 | | | | | | | 0.252 | 5.15 | | | | | | | 0.811 | 16.5 |
| Travel time reliability (car/bus) | -0.046 | -2.02 | | | | | | | -0.0323 | -1.60 | | | | | | | -0.0665 | -3.64 |
| Logsum of rail route choice (rail) | 0.459 | 12.2 | | | | | | | 0.526 | 13.8 | | | | | | | 0.533 | 18.9 |
| Const. (Haneda_bus) | -1.25 | -5.24 | | | | | | | -1.49 | -7.04 | | | | | | | -2.96 | -15.1 |
| Const. (Haneda_car) | -1.81 | -11.5 | | | | | | | -1.27 | -10.2 | | | | | | | -1.23 | -10.7 |
| Const. (Narita_bus) | -0.489 | -1.93 | | | | | | | -1.06 | -4.73 | | | | | | | -2.06 | -10.7 |
| Const. (Narita_car) | -1.57 | -7.04 | | | | | | | -1.05 | -5.98 | | | | | | | -0.913 | -6.31 |
| Initial log-likelihood | | -3,576 | | | | | | | | -4,501 | | | | | | | | -8,064 |
| Final log-likelihood | | -2,898 | | | | | | | | -4,047 | | | | | | | | -5,706 |
| Rho2 | | 0.19 | | | | | | | | 0.101 | | | | | | | | 0.292 |
| # obs. | | 3,255 | | | | | | | | 4,085 | | | | | | | | 7,340 |
| ARAD-Rail Route Choice Submodel (International) | | | | | | | | | | | | | | | | | | |
| Total travel time of non-express | -0.0624 | -15.7 | | | | | | | -0.0498 | -13.2 | | | | | | | -0.0551 | -23.9 |
| Rail-ride travel time of express | -0.0132 | -2.36 | | | | | | | -0.0054 | -1.10 | | | | | | | -0.0124 | -3.42 |
| Total travel cost | -0.0006 | -3.67 | | | | | | | -0.0011 | -6.71 | | | | | | | -0.0008 | -7.03 |
| Transfer time | -0.391 | -7.00 | | | | | | | -0.309 | -5.86 | | | | | | | -0.338 | -8.91 |
| 0/1 (Narita_Keisei Line) | 2.07 | 7.35 | | | | | | | 1.57 | 5.65 | | | | | | | 1.74 | 9.86 |
| 0/1 (Narita_JR Line) | 2.43 | 6.28 | | | | | | | 1.74 | 4.58 | | | | | | | 2.01 | 8.40 |
| Initial log-likelihood | | -2,240 | | | | | | | | -2,267 | | | | | | | | -4,506 |
| Final log-likelihood | | -1,447 | | | | | | | | -1,634 | | | | | | | | -4,002 |
| Rho2 | | 0.354 | | | | | | | | 0.279 | | | | | | | | 0.112 |
| # obs. | | 1,975 | | | | | | | | 2,011 | | | | | | | | 3,986 |

Note: Units of all time related variables and travel cost are min. and JPY, respectively.

Japanese business passengers accessing airports while it is fairly significant for non-business Japanese passengers accessing airports. For international passenger accessing an airport, the opposite held true.

Finally, the MNL-based rail route choice model is estimated for international air passengers in the ARAD-Rail Route Choice Submodel. Level-of-service data is also computed using the hyperpath algorithm (*9*) at the L-zone level. The model fitness is high while all variables are statistically significant.

*HSR-RAD Model.* TABLE 5 summarizes the estimation results of the HSR-RAD Model. First, the MNL-based model is estimated in the HSR-RAD Trip Distribution Submodel. The explanatory variables are generalized travel cost to access/egress from/to HSR stations; daily passengers of HSR stations; HSR travel time from HSR station to destination or from origin to HSR station; and HSR travel cost from HSR station to destination or from origin to HSR station. The final destinations/origins of inter-city trips by HSR are assumed to be Nagoya for Tokaido Shinkansen passengers; Sendai for Tohoku Shinkansen passengers; and Takasaki for Jyoetsu Shinkansen passengers. The results indicate the model fitness is sufficiently high.

The MNL-based model is estimated in the HSR-RAD-Mode Choice Submodel. McFadden's Rho-squared value is high and all variables are statistically significant. Finally, the MNL-based model is estimated in the HSR-RAD-Rail Route Choice Submodel. The model fitness is satisfactory and all variables are statistically significant.

**TABLE 5 Estimation Results of HSR Rail Access Demand (HSR-RAD) Model**

| | Business | | Leisure | | Private | |
|---|---|---|---|---|---|---|
| | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. |
| HSR-RAD-Trip Distribution Submodel | | | | | | |
| Generalized cost to access/egress to HSR stations (thousand JPY) | -1.86 | -105.0 | -1.85 | -81.2 | -2.79 | -95.1 |
| Daily pax. of HSR stations (thousand pax. per day) | 0.0105 | 48.6 | 0.0122 | 39.6 | 0.0114 | 42.2 |
| HSR travel time (min.) | -0.0508 | -36.9 | -0.0271 | -19.0 | -0.0321 | -24.7 |
| HSR travel cost (thousand JPY) | -0.882 | -25.5 | -0.881 | -23.1 | -1.33 | -36.7 |
| Initial log-likelihood | | -49,234 | | -27,446 | | -37,470 |
| Final log-likelihood | | -20,418 | | -10,724 | | -14,432 |
| Rho2 | | 0.585 | | 0.609 | | 0.615 |
| # obs. | | 35,515 | | 19,798 | | 27,029 |
| HSR-RAD-Mode choice Submodel | | | | | | |
| Total travel time (min.) | -0.0202 | -8.70 | -0.0288 | -8.50 | -0.0249 | -10.7 |
| Total travel cost (JPY) | -0.000333 | -13.1 | -0.000491 | -9.30 | -0.000605 | -15.5 |
| 0/1 (bus) | -3.53 | -41.4 | -3.17 | -28.9 | -2.97 | -34.3 |
| 0/1 of trips between HSR stations in CBD and their nearest zones (car) | -1.70 | -34.8 | -1.78 | -22.2 | -1.55 | -21.9 |
| 0/1 of trips between HSR stations in CBD and other zones than their nearest zones (car) | -3.44 | -56.0 | -3.72 | -44.3 | -3.01 | -54.6 |
| 0/1 of trips between HSR stations in non-CBD and their nearest zones | -2.28 | -15.7 | -2.15 | -13.1 | -2.06 | -16.7 |
| 0/1 of trips between HSR stations in non-CBD and other zones than their nearest zones | -4.20 | -22.7 | -4.14 | -21.4 | -3.78 | -25.4 |
| 0/1 of trips between the Tokyo Station and zones in CBD (taxi) | -0.836 | -13.4 | -1.29 | -12.8 | -0.423 | -4.80 |
| 0/1 of trips between the Shinagawa Station and zones in CBD (taxi) | -1.40 | -12.0 | -2.01 | -13.7 | -1.45 | -11.4 |
| 0/1 of trips between the Ueno Station and 23-ward area (taxi) | -1.71 | -8.7 | -1.36 | -6.40 | -1.15 | -6.50 |
| 0/1 of trips to/from other stations than Tokyo, Shinagawa, or Ueno (taxi) | -2.49 | -27.7 | -3.15 | -25.2 | -2.29 | -21.0 |
| Initial log-likelihood | | -22,775 | | -12,924 | | -17,603 |
| Final log-likelihood | | -7,320 | | -3,526 | | -5,426 |
| Rho2 | | 0.678 | | 0.726 | | 0.691 |
| # obs. | | 16,429 | | 9,323 | | 12,698 |
| HSR-RAD-Rail Route Choice Submodel | | | | | | |
| Access/egress travel time between zone and its nearest rail station (min.) | -0.502 | -52.1 | -0.437 | -39.2 | -0.456 | -43.3 |
| Rail travel time excluding transfer minutes (min.) | -0.148 | -26.9 | -0.125 | -18.1 | -0.141 | -23.5 |
| Total travel cost (JPY) | -0.0023 | -9.2 | -0.0029 | -8.50 | -0.0029 | -10.2 |
| Transfer time (min.) | -2.62 | -48.8 | -2.58 | -37.3 | -2.66 | -43.3 |
| Initial log-likelihood | | -12,939 | | -6,409 | | -8,856 |
| Final log-likelihood | | -4,614 | | -2,526 | | -3,382 |
| Rho2 | | 0.643 | | 0.605 | | 0.618 |
| # obs. | | 9,094 | | 4,594 | | 6,475 |

# VALIDATION OF MODEL SYSTEM

FIGURE 1 shows daily passengers observed from 2014 versus those estimated with the developed model system which used the observed socio-demographic and level of service in 2014 in terms of rail link flows and in station-use passengers as inputs. The R values are 0.995 and 0.983 for the rail link flows and for station-use passengers, while the RMS errors are 33.7 and 33.2 thousand passengers per day for rail link flows and for station-use passengers. Hence, forecasting with the estimated model allow for reproduction of the observed rail-related passenger flows without large biases or dispersions.

FIGURE 2 illustrates the model reproducibility in the rail link flows in which the rates of the estimated rail link flows with respect to the observed flows in all links are categorized into eight colors from 0-0.5 to over 2.0. The link flows in suburban areas tend to be overestimated whereas those in

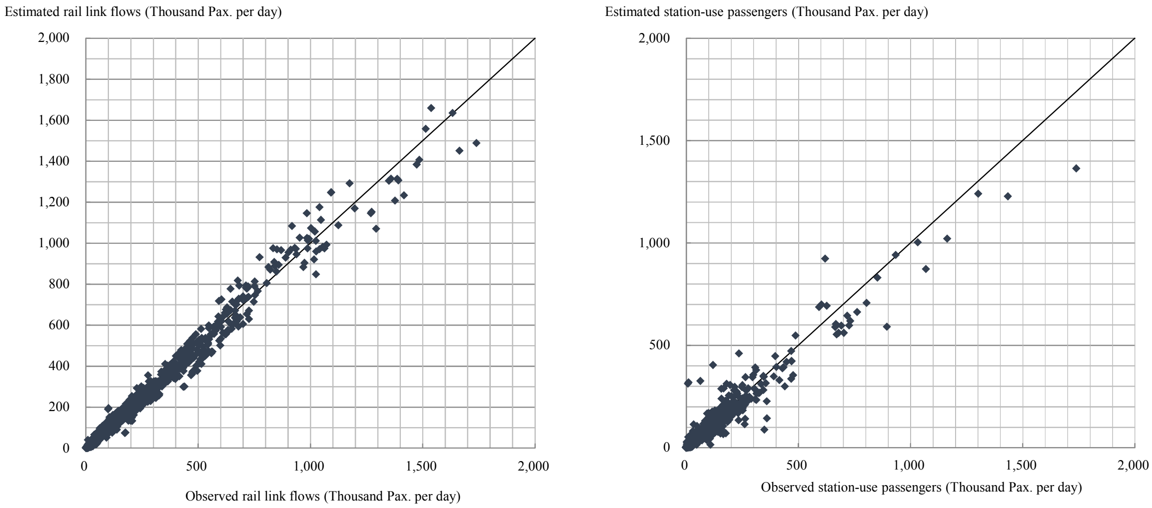


**FIGURE 1 Correlation between Observed and Estimated Passengers (Left: Rail Link Flows; Right: Station-use Passengers)**

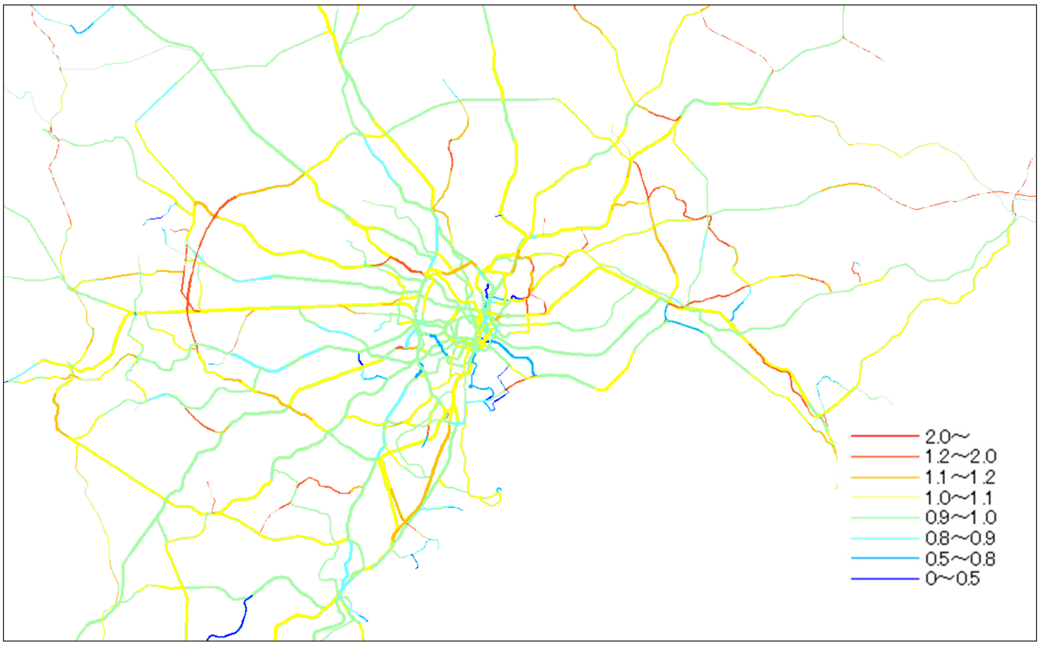


**FIGURE 2 Comparison of Estimated and Observed Rail Link Flows in the Urban Rail Network (>1.0: Overestimation; <1.0: Underestimation)**

urban areas tend to be underestimated. One of the possible reasons is that the data used in our estimation process does not include the urban rail passengers who originally come from regions other than the target area. For example, those who visit Tokyo from other parts of Japan for business or leisure may use urban rail services, they are not covered by our model. Such visitors are expected to use urban rail services rather than suburban rail services. Note that the observed rail link flows were reported by rail operators based on their direct observation.

## CONCLUSIONS

This paper reported on the travel demand forecasting methods developed for evaluating the long-term master plan for urban rail investment in TMA. One of the advantages of the proposed model is that many of the submodels are estimated using discrete choice modeling so that consistent economic analysis is made possible. At the project assessment stage, the logsum variable was used for estimating the net social benefit for the proposed projects (*13*). Following the government's guideline, the cost-benefit analysis was performed using the results of travel demand analysis with our developed model (*14*).

Although the study has successfully developed the foundation of urban rail demand analysis in TMA, there are many further issues to consider. First, our model only covers weekdays. Although the travel patterns on weekends are significantly different from those on weekdays, they are not captured in the existing survey data. This is because the surveys in TMA have been implemented primarily for understanding the extent to which the traffic capacity should be expanded in response to the passenger demand during peak hours. As more leisure-based activities using urban rail services are expected including international visitors' activities, additional modeling for weekends using other data sources is strongly recommended. Second, the developed model follows the traditional four-step modeling framework although recent transportation modeling has explored an activity-based approach (*15*). One of our challenges is the lack of activity episode data, which could be used for the activity-based analysis. An introduction of large-scale activity diary surveys should be examined for TMA. Third, model accuracy should be further improved. Although the best efforts have been made for model estimation, its accuracy is highly dependent on the quality and availability of the data. Supplementary data such as tracking data collected from mobile phones with GPS could enable improvements in the model estimations. Additionally, we checked the model accuracy through the model calibration and adjustments, but we should further examine its predictive power, for example, through a transferability analysis of the developed model to the past travel demand. Fourth, the user friendliness of the model system is considered an important practical issue. Since bulk data sources are required, the operability may be challenging. The computation time for analyzing a single scenario is over 1.5 hours using parallel computing with high-performance computers. For orderly policy discussions, a higher performance model is strongly required (*16*). Finally, potential impacts of advanced transportation technology such as autonomous cars on urban travel demand should be also examined. Our master plan assumed that the current transportation technology does not change in the target year of 2030. This is because many experts in Japan predict that an introduction of innovative transportation technology is limited by 2030 while its impact is also quite smaller in TMA where the public transportation demand is dominant. The expected impact of emerging transportation technology on future travel demand could be discussed under multiple technology development scenarios.

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