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Article / Book Information

1 **Latest Urban Rail Demand Forecast Model System in the Tokyo**

2 **Metropolitan Area**

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1 **ABSTRACT**

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3 This paper reports on an urban rail travel demand forecast model system, which technically
4 supported the formulation of the Tokyo Urban Rail Development Master-plan 2016. The model
5 system was included in the forthcoming 15-year urban rail investment strategy for Tokyo. The
6 model system was utilized to quantitatively assess urban rail projects including 24 new rail
7 development projects, which had been proposed in response to expected changes in socio-
8 demographic patterns, land-use market, and the government's latest transportation policy goals.
9 The system covers the entire urban rail network within the Tokyo Metropolitan Area (TMA) of
10 approximately 50-km radius with a population of over 34 million. The system must handle over
11 80 million trips per day. Three demand models are used to predict daily rail passenger link flows:
12 the urban rail demand model, the airport rail access demand model, and the high-speed-rail rail
13 access demand model. These practical models have unique characteristics such as incorporating
14 differences in behavior between aged and non-aged travelers, reflecting expected influences of
15 urban redevelopment on trip generation and distribution, highlighting urban rail access to
16 airports or high-speed-rail stations, examining impacts of in-vehicle crowding on rail route
17 choice, and deploying urban rail-station access/egress mode choice models for rail route choice.
18 It is concluded that the model system would be well calibrated with observed data for
19 reproducing travel patterns, identifying potential problems, assessing proposed projects,
20 presenting results with high accuracy, and assisting decision-making of urban rail planners.

21

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

23

1 **INTRODUCTION**
2
3 A new long-term Tokyo Urban Rail Development Master-plan discussing the future development
4 strategies for the urban rail network in TMA was established by the Council for Transport Policy in
5 April 2016 (*1*). This is the latest master plan from the succession of plans that have been revised
6 approximately every 15 years since 1956. This master plan aims at providing recommendations for
7 the urban rail infrastructure development within TMA for the forthcoming 15 years by reflecting on
8 the latest socio-demographic and socio-economic conditions. See Morichi et al. (*2*) for the outline of
9 the previous master plan established in 2000. The latest master plan proposed the construction of
10 additional 24 new rail lines and included proposed renovation or rehabilitation of the existing major
11 rail stations.
12   For finalizing the proposals, the proposed projects were assessed separately using 46 performance
13 indexes including a cost-benefit ratio, financial feasibility, and policy impacts as proposed through
14 many discussions among the 13 committee members. The committee members are noted experts in
15 transportation planning, traffic engineering, transportation economics, urban planning, and tourism
16 research, which included three of the authors. Those indexes were quantified by using a large-scale
17 travel demand forecast model system which predicted the future urban rail passenger demand in 2030
18 for both the with and without investment cases for each proposed project.
19   This paper outlines the practical travel demand forecast model system utilized in the Tokyo Urban
20 Rail Development Master-plan in 2016. The proposed model basically follows the structure of prior
21 model that was used for the last master plan, but it adds a rail-station access/egress model while it also
22 takes accounts of rapid changes in socio-demographic patterns. It is not the intent to show the state-of-
23 the-art methodologies in travel demand analysis, but to present practical applications of the travel
24 demand forecast models to assess the proposed projects for the process of urban rail transportation
25 planning in response to the latest policy goals.
26   The paper is organized as follows. The next section introduces unique characteristics of the urban
27 rail travel demand forecast model for Tokyo, followed by model development including its estimation
28 results. Then reproducibility of urban rail demand is presented. Finally, the findings are summarized
29 with further research issues.
30
31
32 **CHARACTERISTICS OF URBAN RAIL TRAVEL DEMAND FORECAST MODEL IN**
33 **TOKYO**
34
35 The model system has five distinctive characteristics by considering the unique features of the urban
36 rail services in Tokyo. First, the models incorporate the influences of rapid changes in socio-
37 demographic patterns on travel demand since Tokyo is facing rapid aging and is predicted to
38 experience a further aging society in the future. The population of 65 year-olds or over accounted for
39 14.5% of the overall population in 2000, which then increased to 21.0% in 2010 and is projected to be
40 at 29% in 2030. Since senior individuals are generally expected to engage in less out-of-home activities
41 than younger individuals, peoples' daily activity patterns may vary across the types of journeys, age
42 levels, and gender. Furthermore, destination choice patterns, mode choice patterns, and route choice
43 patterns of senior travelers could be different from those of younger travelers. Such differences are
44 taken into account in the developed model system by segmenting the travelers by age subgroup.
45   Second, the expected changes in land-use patterns are incorporated into the models. As shown in
46 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 α_G^{pag} and α_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

1   destination zone. The rail-station access/egress mode choice is formulated as a MNL while the rail
2   route choice is formulated as Multinomial Probit (MNP) model with structured covariance (6). It is
3   important to note that the rail route consists of an access link connecting the origin zone to a rail station,
4   rail line-haul links connecting the boarding rail station with the alighting rail station, waiting and
5   transfer links at stations, and an egress link connecting the alighting rail station to the destination zone.
6   The rail route flows are computed as

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

8   where $XU_{ij,r}^{ap}$ represents the daily trips of a rail route r from zone i to j with purpose p for

9   age subgroup a, and $pu_{ij,r}^{ap}$ is the probability of choosing route r, which is formulated as

10
$$pu_{ij,r}^{ap} = \int_{\varepsilon_r=-\infty}^{+\infty}\int_{\varepsilon_1=-\infty}^{\varepsilon_r+v_{ij,r}^{ap}-v_{ij,1}^{ap}} \cdots \int_{\varepsilon_r=-\infty}^{+\infty}\cdots\int_{\varepsilon_R=-\infty}^{\varepsilon_r+v_{ij,r}^{ap}-v_{ij,R}^{ap}} \phi\left(\varepsilon_1^{ap},\cdots\varepsilon_r^{ap},\cdots,\varepsilon_R^{ap}\right)d\varepsilon \tag{8}$$

11   where ε_r^{ap} is the error component of utility function of rail route r with purpose p for age

12   subgroup a, $v_{ij,r}^{ap}$ is the systematic utility of route r, and $\phi(\cdot)$ is a multivariate normal density

13   function defined as

14
$$\phi(\mathbf{\varepsilon}) = (2\pi)^{-\frac{j}{2}}|\Sigma|^{-\frac{1}{2}}\exp\left[-\frac{1}{2}\mathbf{\varepsilon}\Sigma^{-1}\mathbf{\varepsilon}^T\right] \tag{9}$$

15   and

16
$$\Sigma = \sigma^2\begin{pmatrix} L_{11} & L_{12} & \cdots & L_{1R} \\ L_{12} & L_{22} & & \vdots \\ \vdots & & \ddots & \\ L_{1R} & \cdots & & L_{RR} \end{pmatrix} + \sigma_0^2 I \tag{10}$$

17   where $\mathbf{\varepsilon} = \left(\varepsilon_1,\cdots\varepsilon_r,\cdots\varepsilon_R\right)$, $L_{rr'}$ is the overlapped length between routes r and r', I is the

18   identity matrix, and σ^2 and σ_0^2 are the variance parameters. The MNP model with structured

19   covariance can incorporate correlations of overlapped routes through its error structure. The systematic

20   utility $v_{ij,r}^{ap}$ is specified as a linear function of the explanatory variables such as the logsum variable

21   computed from the rail-station access/egress submodel.

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

24
$$qu_{am}^{ap} = \frac{\exp\left(VU_{am}^{ap}\right)}{\sum_{am'}\exp\left(VU_{am'}^{ap}\right)} \tag{11}$$

25   where VU_{am}^{ap} is the systematic utility of travel mode am for trip with purpose p and for age

26   subgroup a. The choice set of this submodel includes walk, bicycle, bus, and car. The logsum variable
27   for the rail route choice submodel is then derived as

1
$$\Lambda U_r = \ln \sum_{am} \exp\left(VU_{r,am}^{ap}\right) \quad (12).$$

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

4
$$xu_l = \sum_a \sum_p \sum_{ij} \sum_r \delta_{ij,r,l} \cdot XU_{ij,r}^{ap} \quad (13)$$

5 where xu_l is the passenger flows of rail link l estimated from the URD model and $\delta_{ij,r,l}$ is the

6 dummy variable if the rail link l belongs to rail route r from zone i to j.

7
8
9 **AIRPORT RAIL ACCESS DEMAND (ARAD) MODEL**
10
11 **Market Segmentation**
12 The ARAD model system predicts the rail passenger demand to/from the Haneda and Narita airports
13 in TMA. The airport demand consists of domestic and international air passengers. The domestic air
14 passengers are categorized into eight subgroups by their trip purpose, residential area, and
15 access/egress. The trip purposes are business or nonbusiness; the residential areas are TMA or other
16 areas; and access/egress is the access to or the egress from an airport. The international air passengers
17 are also categorized into six subgroups by their trip purpose, residential area, and access/egress.
18 International air passengers residing in Japan are categorized into four subgroups: access to the airport
19 for business, access to the airport for nonbusiness, egress from the airport for business, and egress from
20 the airport for nonbusiness. International air passengers residing outside of Japan are categorized into
21 two subgroups: access to and egress from the airport. A shortage of traveler data resulted in a lack of
22 segmentation with respect to trip purpose for non-Japanese residents.
23
24 **ARAD-Trip Distribution Submodel**
25 This submodel assumes the present pattern of O-D matrix of airport access/egress trips would be
26 maintained in the future for both national and international air passengers. The air passenger demands
27 of the two airports in 2030 are provided from other demand forecasting results by the Ministry of Land,
28 Infrastructure, Transport and Tourism (MLIT) (7). The forecasts include domestic and international
29 air travel demand across regions in Japan and between Japan and other countries, which have been
30 estimated using an inter-regional travel demand analysis system.
31
32 **ARAD-Mode choice Submodel**
33 This submodel predicts the trip demand of each transport mode. Traveling from the two airports to
34 other destination zones or origin zones to the two airports under the given O-D matrixes are estimated
35 from the trip distribution submodel. The choice set includes bus, rail, and car. The trips are predicted
36 using the MNL model as

37
$$XA_{ij,m}^{dphg} = \frac{TA_{ij}^{dphg} \cdot \exp\left(VA_{ij,m}^{dphg}\right)}{\exp\left(VA_{ij,bus}^{dphg}\right) + \exp\left(VA_{ij,rail}^{dphg}\right) + \exp\left(VA_{ij,car}^{dphg}\right)} \quad (14)$$

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

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

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

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

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.

1   The same demand models are shared for all HSR lines while the demand is predicted for each
2 subgroup by their trip purpose (business, leisure, and private). Therefore, the model assumes that trip
3 patterns are not affected by access/egress, residential locations, or nationalities. This is due to the poor
4 data availability necessary for detailed analysis.
5

6 **HSR-RAD-Trip Distribution Submodel**
7 This submodel predicts the daily trips to/from HSR stations as well as from/to each zone using MNL-
8 based destination choice models. The passenger demands of the HSR stations including new maglev
9 stations in 2030 are provided from another travel demand forecast conducted by MLIT, in which the
10 inter-regional travel demand in Japan is estimated with a large-scale demand analysis system.
11   The HSR-RAD-trip distribution submodel is formulated as

12
$$TH_{Sj}^{p} = \frac{\exp\left(VH_{Sj}^{p}\right)}{\sum_{j'} \exp\left(VH_{Sj'}^{p}\right)} \cdot GH_{S}^{p} \quad \text{or} \quad TH_{iS}^{p} = \frac{\exp\left(VH_{iS}^{p}\right)}{\sum_{i'} \exp\left(VH_{i'S}^{p}\right)} \cdot GH_{S}^{p} \tag{17}$$

13 where TH_{Sj}^{p} represents the trips from HSR station S to zone j with purpose p; TH_{iS}^{p}

14 represents the trips from zone i to HSR station S with purpose p; VH_{Sj}^{p} and VH_{iS}^{p} are the

15 systematic utilities; and GH_{S}^{p} is the generated/attracted trips to/from HSR station S with purpose

16 p. The individual-specific choice sets are constructed according to the HSR lines they would use.

17

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

23
$$XH_{ij,m}^{p} = \frac{TH_{ij}^{p} \cdot \exp\left(VH_{ij,m}^{p}\right)}{\exp\left(VH_{ij,bus}^{p}\right) + \exp\left(VH_{ij,rail}^{p}\right) + \exp\left(VH_{ij,car}^{p}\right) + \exp\left(VH_{ij,taxi}^{p}\right)} \tag{18}$$

24 where $XH_{ij,m}^{p}$ is the trips by mode $m \left(= bus, rail, car, taxi\right)$ from zone i to j (either i or j is

25 a HSR station) with purpose p; TH_{ij}^{p} represents the trips from zone i to j; and $VH_{ij,m}^{p}$ is the

26 systematic utility.
27

28 **HSR-RAD-Rail Route Choice Submodel**
29 For the rail-route choice submodel, MNL model is employed as

30
$$XH_{ij,r}^{p} = \frac{\exp\left(VH_{ij,r}^{p}\right)}{\sum_{r'} \exp\left(VH_{ij,r'}^{p}\right)} \cdot XH_{ij,rail}^{p} \tag{19}$$

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.

1   **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.

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

1 **Model Estimation**
2 *URD Model.* The estimation results with nonlinear least squares method of the trip distribution models
3 in the URD-Trip Distribution Submodel are summarized in TABLE 2. The distance-based modal
4 shares of walk/bicycle in the URD-Mode Choice Submodel are estimated by assuming that the travel
5 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
6 MNL-based model in the URD-Mode choice Submodel is estimated with disaggregate data from the
7 2008 PT Survey. These results are summarized in TABLE 3. Model fitness and statistical significance
8 of all variables are considered high.
9   TABLE 3 also summarizes the estimation results of the URD-Rail Route Choice Submodel. The
10 MNL-based rail-station access/egress mode choice models are estimated with disaggregated data and
11 shows that McFadden's Rho-squared values are all sufficiently high and all explanatory variables are
12 statistically significant. The disaggregate MNP-based rail route choice models are estimated in which
13 the in-vehicle congestion index (*2, 5, 6*) is defined as

14
$$Cong_{ij,r} = \sum_{l} \delta_{ij,r,l} \cdot t_l \cdot \left(\frac{x_l}{Cap_l} \right)^2 \tag{22}$$

15 where $Cong_{ij,r}$ is the in-vehicle congestion index for rail route r from zone i to zone j; t_l is

16 the travel time of rail link l; x_l is the passenger flows of rail link l; Cap_l is the capacity of

17 passenger flows of rail link l; and $\delta_{ij,r,l}$ is the dummy variable for rail link l that belongs to rail

18 route r from zone i to zone j. The route choice set is formulated following a method proposed

19 by Kato et al. (*8*). The level-of-service of each route (e.g. representative rail route travel time) is
20 computed following the observed data in the model estimation process while it is computed following
21 a concept of "hyperpath" (*9, 10*) in the model verification and future forecast processes. Note that the
22 concept of hyperpath is newly introduced into the proposed model system. The disaggregate data used
23 for estimating the route choice model is resampled from the original entire dataset, reflecting the
24 population distribution relative to trip distance. For each sample trip, four or less alternative routes are
25 prepared. The estimation results show that model fitness is good and all explanatory variables are
26 statistically significant.

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

Type	G/A	Age	Constant Coeff.	t-stat.	Gener. Trips Coeff.	t-stat.	Attract. Trips Coeff.	t-stat.	General. cost Coeff.	t-stat.	0/1 (<10 km) Coeff.	t-stat.	0/1 (10-20 km) Coeff.	t-stat.	0/1 (20-30 km) Coeff.	t-stat.	0/1 (30-40 km) Coeff.	t-stat.	0/1 (40-50 km) Coeff.	t-stat.	0/1 (50<km) Coeff.	t-stat.	0/1 (CBD) Coeff.	t-stat.	R-sq.	# obs.
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

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

3   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.

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

5

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									

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.

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.

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.

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

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

19
$$SD_{ij,r} = \underset{(32.6)}{28.805\,Cl_{ij,r}} + \underset{(45.5)}{0.092\,D_{ij,r,\exp}} + \underset{(9.7)}{0.130\,D_{ij,r,multi-lane}} + \underset{(15.3)}{0.145\,D_{ij,r,two-lane}} - \underset{(-31.8)}{34.416} \quad (23)$$

20
$$N = 1{,}559 \quad R^2 = 0.73$$

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

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

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

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

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

Variables	Business (Japanese Passengers)								Nonbusiness (Japanese Passengers)								Foreigners	
	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	-13.2							-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	

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

1   Japanese business passengers accessing airports while it is fairly significant for non-business Japanese
2   passengers accessing airports. For international passenger accessing an airport, the opposite held true.
3   Finally, the MNL-based rail route choice model is estimated for international air passengers in
4   the ARAD-Rail Route Choice Submodel. Level-of-service data is also computed using the hyperpath
5   algorithm (9) at the L-zone level. The model fitness is high while all variables are statistically
6   significant.
7

8   *HSR-RAD Model.* TABLE 5 summarizes the estimation results of the HSR-RAD Model. First, the
9   MNL-based model is estimated in the HSR-RAD Trip Distribution Submodel. The explanatory
10 variables are generalized travel cost to access/egress from/to HSR stations; daily passengers of HSR
11 stations; HSR travel time from HSR station to destination or from origin to HSR station; and HSR
12 travel cost from HSR station to destination or from origin to HSR station. The final destinations/origins
13 of inter-city trips by HSR are assumed to be Nagoya for Tokaido Shinkansen passengers; Sendai for
14 Tohoku Shinkansen passengers; and Takasaki for Jyoetsu Shinkansen passengers. The results indicate
15 the model fitness is sufficiently high.
16   The MNL-based model is estimated in the HSR-RAD-Mode Choice Submodel. McFadden's
17 Rho-squared value is high and all variables are statistically significant. Finally, the MNL-based model
18 is estimated in the HSR-RAD-Rail Route Choice Submodel. The model fitness is satisfactory and all
19 variables are statistically significant.
20
21   **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

22
23

1 **VALIDATION OF MODEL SYSTEM**

2

3 FIGURE 1 shows daily passengers observed from 2014 versus those estimated with the developed
4 model system which used the observed socio-demographic and level of service in 2014 in terms of
5 rail link flows and in station-use passengers as inputs. The R values are 0.995 and 0.983 for the rail
6 link flows and for station-use passengers, while the RMS errors are 33.7 and 33.2 thousand passengers
7 per day for rail link flows and for station-use passengers. Hence, forecasting with the estimated model
8 allow for reproduction of the observed rail-related passenger flows without large biases or dispersions.
9 FIGURE 2 illustrates the model reproducibility in the rail link flows in which the rates of the
10 estimated rail link flows with respect to the observed flows in all links are categorized into eight colors
11 from 0-0.5 to over 2.0. The link flows in suburban areas tend to be overestimated whereas those in
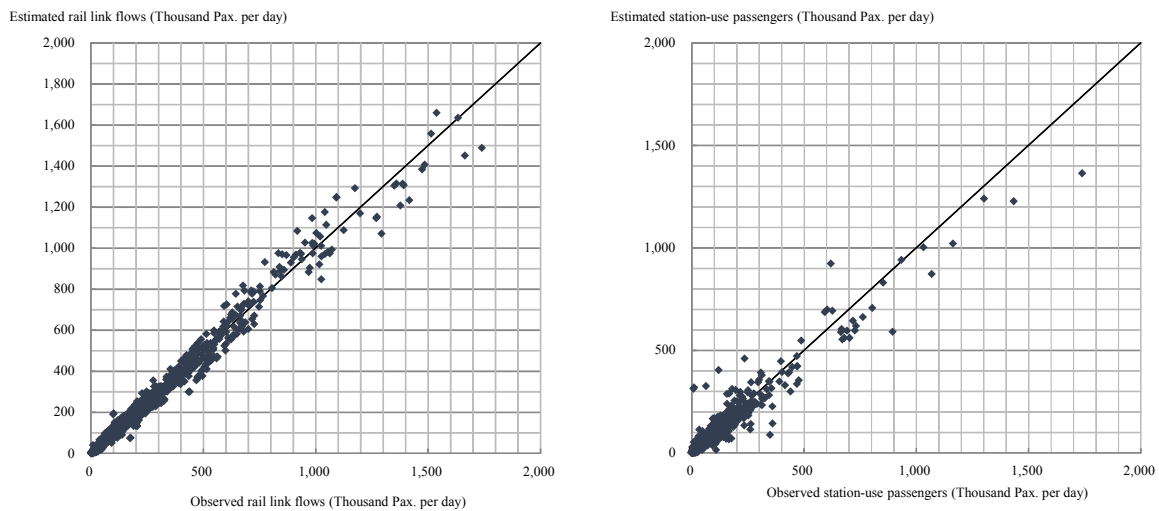
FIGURE 1   Correlation between Observed and Estimated Passengers
(Left: Rail Link Flows; Right: Station-use Passengers)
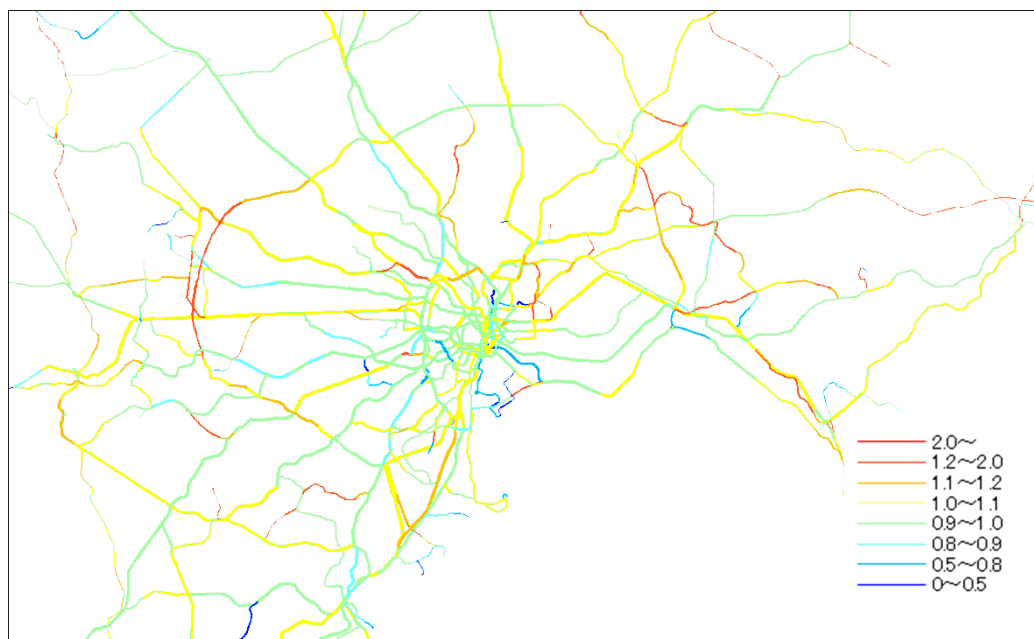
FIGURE 2   Comparison of Estimated and Observed Rail Link Flows in the Urban Rail Network
(>1.0: Overestimation; <1.0: Underestimation)

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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