Empirical analysis between round trip area (RTA) and passenger demand in Japan

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Abstract:
Round trip area in a day (RTA) is an important performance index of the inter-regional public transportation. Since faster transportation can considerably decrease travel time, proximity to airline network is important to enlarge RTA. In Japan, many local airports were opened up to ‘90s. However, it is not enough to be clarified the difference in passenger demand whether an area belongs to RTA of the other areas, or not. This study aims to clarify the relationship between RTA and passenger demand characteristics, based on traffic data of passenger’s address and travel destination. On network, each destination node covered by RTA from the origin node has maximum stay-time constraint (MST) in a day, which mostly depends on flight time table especially to distant destination. Based on MST, RTA can be approximately calculated as follows; searching available path on the inter-regional arced transportation network for both direction considering link frequencies, then finding the areas with positive MST as RTA from the origin node by using both of travel time with departure and arrival time constraint with in a day with link frequency data per unit hour. The calculated RTA-dummy and MST are used as additional explanatory variable for a statistical model of inter-city passenger trips to clarify their statistical significance.

1. Introduction

The globalization of economic activities significantly stimulates airline market. There are several factors to make airline transportation market grow rapidly, such as opening of local airports, geographical characteristics and deregulation for airline market in terms of entry or exit. Increase of local airport provides a new market, but its demand is generally not so large at the first stage of entry. In order to hedge the business risk under those thin-markets, airline companies try to cut operating cost, for examples, by providing less comfort services with fewer attendants. This type of business model is known as Low-cost-career (LCC). A huge amount of research has been discussed on LCC, hub-and-spoke network structure, airline alliances, or the competitiveness of LCC compared against major careers (Noran *et al.* 2001; Burghouwt, *et al.* 2003). Fan (2006) reported difference in operating strategy between LCC and major careers based on longitudinal comparison over airline frequencies and number of provided seats between Ireland or Britain islands, and continental airports in EU area. The detailed analysis clarified that LCCs have generally explored new market even though it seems niche, and the major gateways do not lose their conventional flights by increase of direct flight between local airport and the other areas, which started by LCCs. Since LCC provides new alternate airline service, business travelers who conventionally use expensive service are also attracted into low cost service (Dresner, 2006). Hence, the entrance of LCCs makes worse of airline operator's profit in price competition (Mason, 2005). From local government standpoint, sustainability of the local airport in the own region is important. Dennis (2005) studied on hub-ness of airports by considering frequencies of linkadges and the type of alliances. This study reported that some limited hubs are attracting more frequencies scarified with losing frequencies of middle or small hubs, and some of alliance also seems become a winner in the market. Concerning to the thin-local market, Pagliari (2005) reported the importance of LCC in Scotland airport that LCC at local airport provides short-haul connection to large hub-airport, while a major career withdraws their services from a conventional principle airport. As the empirical study based on passenger traffic data, Matsumoto (2004) used ICAO's dataset in passenger and cargo to analyze the longitudinal change in hub function of world airports. All these conventional studies implies that transportation policy makers should understand the global airline network characteristic affected by LCC's behavior.

Parallel to the European drastic change, restructuring of airline network has also progressed in Japan. Increased number of local airports in Japan arranged on long and narrow series of Japanese islands, stimulates airport market with decreased operating risk by exit option. Even the rapid railway (Shinkansen) network is already shaped in Japan, airline is competitive over railway in the OD pair where modal advantage in velocity is dominant (Tsukai and Okumura, 2005). In Japan, the latest national planning concept named as "two layered broader regions", has been introduced (Morichi, *et al.*, 2005). The new concept is prepared to correspond to some critical changes around the national planning; e.g., from increase to decrease in domestic population, from developing to matured economies under globalization, and from young to aged societies. As the policy name indicates, "a regional block" and "a daily interaction area" are referred to be fundamental unit of infrastructure planning in this policy. The regional block is composed of about 30 daily interaction areas. Population of the daily interaction areas is about 200,000 to 300,000, therefore the regional block has around six or ten millions of population. In terms of transportation planning, a novel point of this policy is that the importance of airline network is clearly stated as that each regional block should have international airport as a gateway to Asian countries and the airport should appropriately be linked by domestic transportation network. On the other hand, each local government should be responsible for policy making in public transportation network with both the level of intra- and inter-regions. Such decentralized policy scheme enables local governments to take flexible and strategic approach, but it also requires local government to be sophisticated in transportation planning.

In the “two layered broader regions”, round trip area in a day (RTA) is referred as an important performance index of the inter-regional public transportation. Since faster transportation can considerably decrease travel time, proximity to airline network is important to enlarge RTA. RTA is similar index to hinter area of an airport, but it is different in whether destination of trip is considered. Each destination node covered by RTA from the origin node has maximum stay-time constraint (MST) in a day. In other words, RTA of an origin node is obtained as a set of positive MST for all the destinations. In national transportation planning history in Japan, line-haul time including expected transferring time has often been discussed as the goal of policies, but the difference with RTA to line-haul travel time is, again, that RTA considers difference of service levels by directions. Therefore, RTA can be considered as an outcome index to appropriately indicate actual transportation service (A workshop for evaluating Japanese transportation, 2003). RTA largely depends on time table of inter-regional public transportation. Airline time table significantly affects MST and RTA in middle to long distant OD pairs because an airline route often appears as the fastest in those OD pairs. Matsuda and Toshibe (2005) compared international airline network of Western Europe to of Eastern Asia, and then pointed out that improvement of Eastern Asia airline network is necessarily. Fujimura *et al.* (2005) focused on Kyusyu area which locates the western end of the four main islands in Japan. This study clarified the geographical potentials of Kyusyu area to realize regional block concept. However, as Sato and Totani (2005) pointed out the serious distortion of present transportation service in Japan; higher in regions along the Pacific side but lower in regions along the Japan Sea side. They also discussed the importance of improving transportation level in daily interaction areas in each regional block. These conventional studies suggest that empirical analysis on the relationship between actual passenger demand and RTA between daily interaction area in Japan would contribute to regional and national transportation planning.

This study purposes to clarify the relationship between RTA and airline passenger demand characteristics, based on traffic data of passengers. In order to conveniently calculate MST and RTA, we develop a calculation procedure based on k-th path search algorithm, which outputs approximated RTA. As a dataset for domestic inter-regional passengers, net passenger traffic survey recording true origin and destination of the whole trip-chain made by passengers is available for 1990, 1995 and 2000 (That survey has been also done in 2005, but its result has not yet published). In this study, we use an airline OD matrix of passengers whose representative mode on the trip-chain is airline, where we consider the recorded passenger’s home address as origin, and the recorded trip destination as destination in the OD matrix. Then combining both of information, we estimate a regression model to clarify the statistical significance of RTA on airline passenger demand. The calculated RTA-dummy and MST are used as additional explanatory variable for a statistical model of inter-city passenger trips.

2. Procedure for analysis

2.1 Calculation procedure of Round Trip Area and Maximum Stay-time

An RTA based on a set of MST is obtained by the repeatedly applying a route search among the target origin. However, the exact calculation of RTA requires huge amount of diagram information on public transportation such as departure / intermediate / destination nodes with each time for all scheduled flight, train, and access modes. Such database is already included in some commercial base software, but it is prohibited to extract the database by copyright, so the only available source for our study is paper-based time tables. Another difficulty to calculate exact RTA is relatively large calculation load on middle to large size network. In this study, we devise a feasible procedure to calculate approximated MST and RTA, based on simplified database of inter-regional public transportation. The proposed procedure uses an

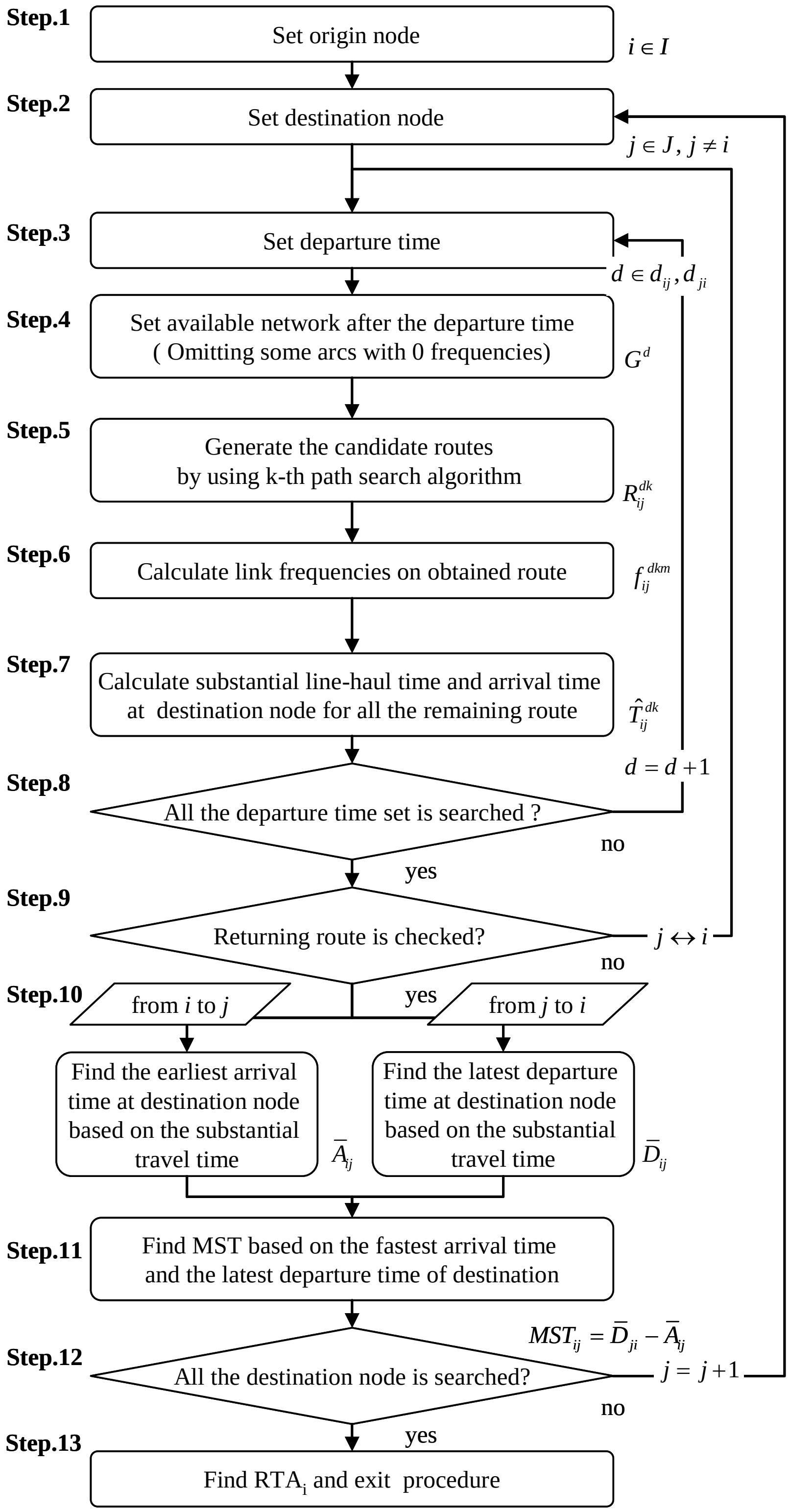

Figure 1 MST (RTA) calculation procedure

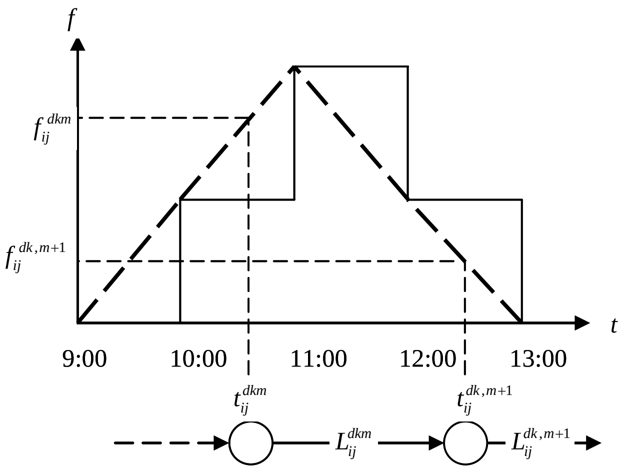

Figure 2 calculation image of link frequency based on the link entrance time

arced network having information for travel time and service frequency per unit hours, then finds the shortest route by a route search algorithm on the arced network.

The outline of the calculation procedure is summarized in **Figure 1**.In this procedure, k-th path search algorithm is effectively used to decrease calculation load. K-th path search algorithm, proposed by Kato, *et. al* (1978) consists of Dijkstra algorithm, second path search routine (FSP) including Dijkstra, and k-th path search algorithm (KSP) including FSP and Dijkstra. This algorithm can generate the shortest path with a sequential order from the shortest to k-th shortest path between an arbitral pair of origin and destination nodes. See Tsukai and Okumura (2005) to know the details about the procedure. Since the original k-th shortest path search algorithm is for non-arced network, we improved the original algorithm to be applicable for arced network as shown in **step. 1** to **step.5.** In **step.4**, inaccessible links with no frequencies after departure time d are omitted, then the accessible graph G^d is obtained. However, since our algorithm do not use the full information including timing of each flight or trains, transferring and waiting time for the next mode can not be directly calculated in the path searching. In **step.6**, the least frequency on each generated route without considering waiting time is calculated. Because the frequency information is available for some time band, frequency of a link on the specific route is calculated by using linear interpolating function connecting the frequencies of the neighbor hours ranges. **Figure 2** shows an image of the frequency calculation for each link. Link frequency f_{ij}^{dkm}; i.e. k th shortest path between OD pair ij at departure time d, m th link counting from the origin node i is defined as the frequency at the arrival time to enster the link t_{ij}^{dkm}.

A substantial travel time $\hat{T}_{ij}^{d}$, and the earliest arrival or the latest departure time are defined as eq.(1) to eq. (3), respectively (**step.7 to step. 10**)

$$\hat{T}_{ij}^{d} = \min_k \left(\frac{1}{2} \cdot \frac{D}{\min_m f_{ij}^{dkm}} + T_{ij}^{dk} \right) \tag{1}$$

$$\overline{A}_{ij} = \min_d \left(T^d + \hat{T}_{ij}^{d} \right) \tag{2}$$

$$\bar{D}_{ji} = T^d \mid \max_d \left(T^d + \hat{T}^d_{ji} \right) < 24:00 \tag{3}$$

where, D is a time band defined for frequency data counting, and T^{dk}_{ij} is a sum of link travel time along the route (without including waiting time).

In this study, we assume that an expected waiting time at the link with least frequency is an index of route waiting time. Eq.(3) means round trip constraint that the arrival time on the retuning trip should not exceed 24 hours.In this procedure, the departure time at origin node is set from 6:00 to 12:00 for every hour; i.e. $d_{ij} = 6:00, 7:00, \ldots, 12:00$ (7 points), while the departure time at destination node is set as $d_{ji} = 14:00, 15:00, \ldots, 21:00$ (8 points). The MST for each OD pair and RTA for each origin node are calculated in eq.(4), and eq.(5), respectively (**step.11 to step. 13**)

$$MST_{ij} = \bar{D}_{ji} - \bar{A}_{ij} \tag{4}$$

$$RTA_i = \left\{ j \mid MST_{ij} > 0 \right\} \tag{5}$$

Note that a set of frequencies in unit time band at a specific link would be generally different with its direction, especially in low frequent airline links. Therefore, the above procedure can calculate $MST_{ij} \neq MST_{ji}$ corresponding to service direction while the above procedure does not use full diagram information. The accuracy of MST_{ij} mainly depends on the size of D, but the more accurate calculation requires the more calculation load and the detailed database.

2.2 Influence of RTA on inter-regional trip

In order to clarify the influence of RTA or MST onto inter regional airline passenger traffic, we estimate a gravity model including RTA and MST as additional explanatory variables. The inference of the estimated parameter will show the statistical significance of RTA.

Note that the available passenger traffic data is not obtained by census. Therefore, 0 observation would not directly imply that the passenger flow at the OD is exactly 0, rather it means that the passenger traffic is below the level of lower limit of sampling. This is the typical problem known as sample selection. Considering the purpose of our analysis, 0 count data should not be naively omitted from the model estimation, because such observation would be brought by being destination are out of RTA of origin area. In order to avoid parameter distortion, we use Tobit model for the gravity model estimation. Tobit model can correspond to sample selection problem, such that structural equation is also valid for 0 count data but only the observation of dependent variable (i.e. traffic) is missing. See details in the discussion about a truncated dependent variables by Maddala (2001).

Taking the logarithm of all the variables, a gravity model with Tobit formulation is shown in eq.(6) and eq.(7).

$$Y_{ij} = \sum_k \beta^k \log X^k_{ij} + \gamma \log MST_{ij} + \rho \delta_{ij} + \varepsilon_{ij} \tag{6}$$

$$\begin{cases} Y_{ij} = \log T_{ij} & if \quad \log T_{ij} > 0 \\ Y_{ij} \text{ is missing} & if \quad \log T_{ij} \leq 0 \end{cases} \tag{7}$$

where δ_{ij} is dummy variable to indicate if the destination j is out of RTA_i, $\delta_{ij}=1$, otherwise $\delta_{ij}=0$, $\log X_{ij}^{k}$ is population of both regions, and β^{k},γ,ρ are parameters to be estimated. Note that Eq.(7) means that 0 count traffic is dealt as a latent observation that would possibly take the value below the lower limit. Therefore, eq.(6) is appropriate to clarify the influence of RTA on inter-regional traffic.

3. Result of analysis

3.1 Data set

Passenger traffic data set used in this study is in 1990 and 2000. The passenger traffic is aggregated in 207 areas that are designed at the first survey. Note that this survey do not record trips made inside each of the three metropolitan areas defined around Tokyo, Nagoya and Osaka cities. However, these missing observations are irrelevant to airline passengers, then no distortions are expected for our analysis. We used 194 areas for the analysis except some of remotely isolated islands. The trip data can be aggregated into several OD matrix with respect to several attributes. Among the available data, airline passenger traffic data aggregated between their home address to the trip destination is used for our analysis.

Inter-regional network database is prepared as to make a correspondence with the spatial unit of passenger traffic data. The dataset consists of 240 nodes with 501 links. Attributes of each link are travel time and frequency, and modal information (railway, airline, and access link). The frequency data is recorded with setting D as 3 hours. In this study, round trip area is defined to be returnable area within a day, and the first departure is 6:00. Therefore, there are 6 time band for each direction, so then a frequency dataset for a link is 12 attributes. The source of diagram information is published time table in November in 1990 and in 2000.

3.2 Calculated RTA / MST, with growth of airline passenger demand

Among the picked 194 areas, 9 representative areas to be a core area of each regional block are selected as origin area. These areas are as Sapporo, Sendai, Tokyo, Toyama, Nagoya, Osaka, Hiroshima, Kochi and Fukuoka. Among these representative areas, Sapporo, Tokyo, Osaka and Fukuoka's MST in 1990 and 2000 are displayed on left two maps (a,b) in **Figures 3-6**. The third map (c) shows change of MST between 1990 and 2000, and the right-end map (d) displays the changing ratio of passenger traffic between 1990 and 2000. In the last comparison map (d), gray-colored areas show zero observations for both cross sections.

In **figure 3**, Sapporo's MST is considerably extended for many destinations, except around Nigata city along the north side of the Honsyu island. In 2000, the areas with over 4 hours of MST are successively appeared from Tokyo to Osaka, along the Tokaido-Shinkansen line. Outstanding growth of airline passenger is seen in middle to western Japan. **Figure 4** shows Tokyo's MST. Many areas are painted with thick color in both cross sections, while growth of MST from 1990 to 2000 is not large. From **figure 4(d)** it is found that area with no airline passenger from Tokyo widely spreads around eastern half of the Honsyu island where are served by Shinkansen railways. Next to outskirts of those no airline passenger area, moderate

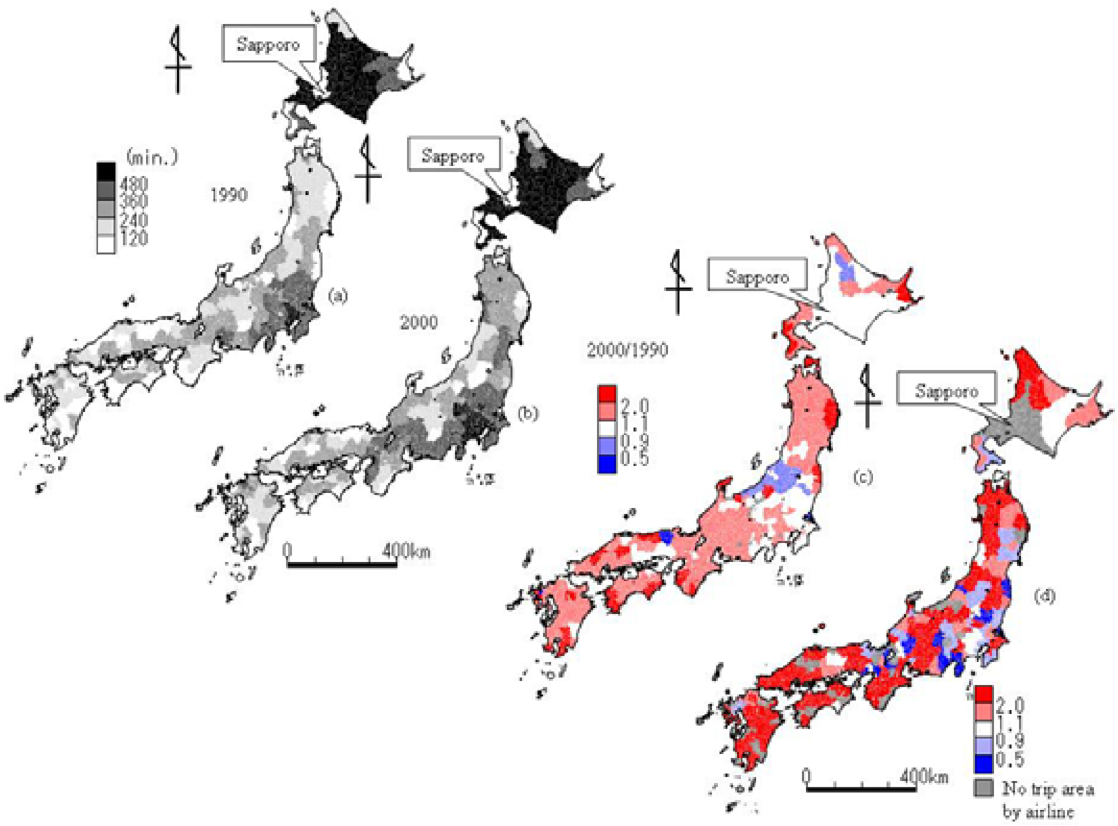

Figure 3 RTA of Sapporo in 1990, 2000, with temporal change of passenger demand

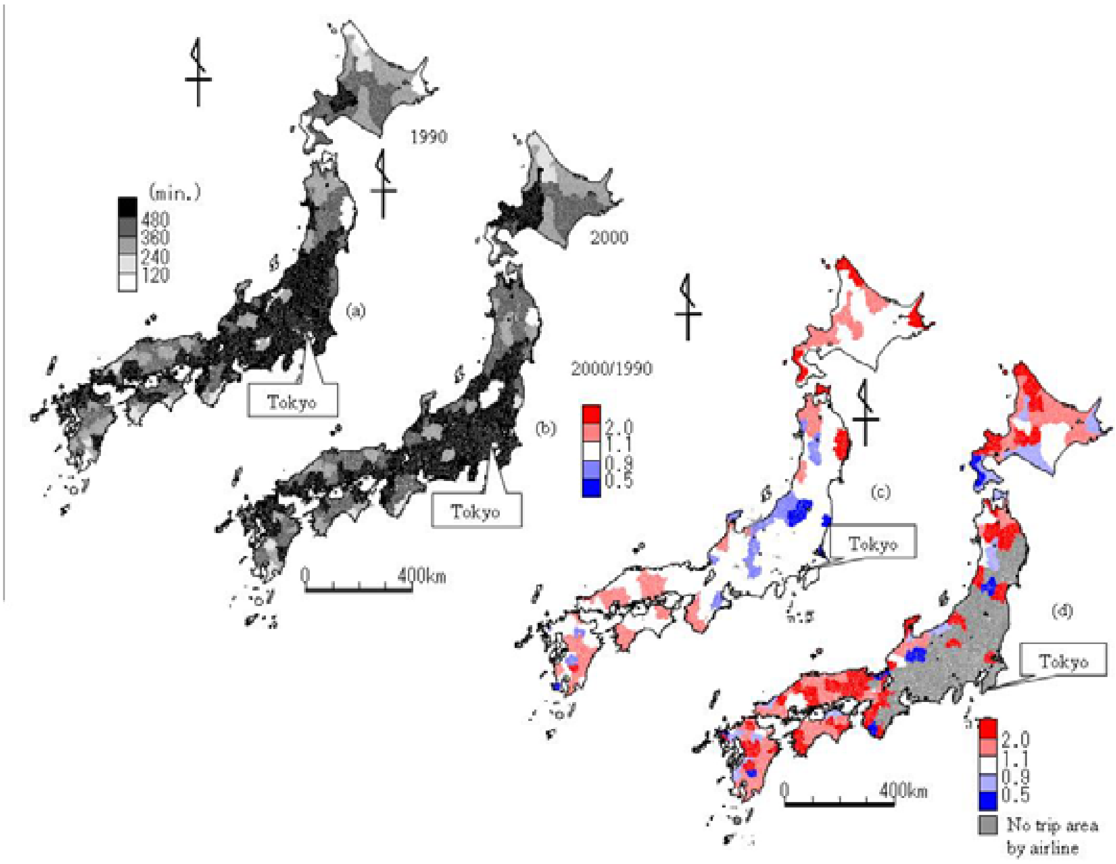

Figure 4 RTA of Tokyo in 1990, 2000, with temporal change of passenger demand

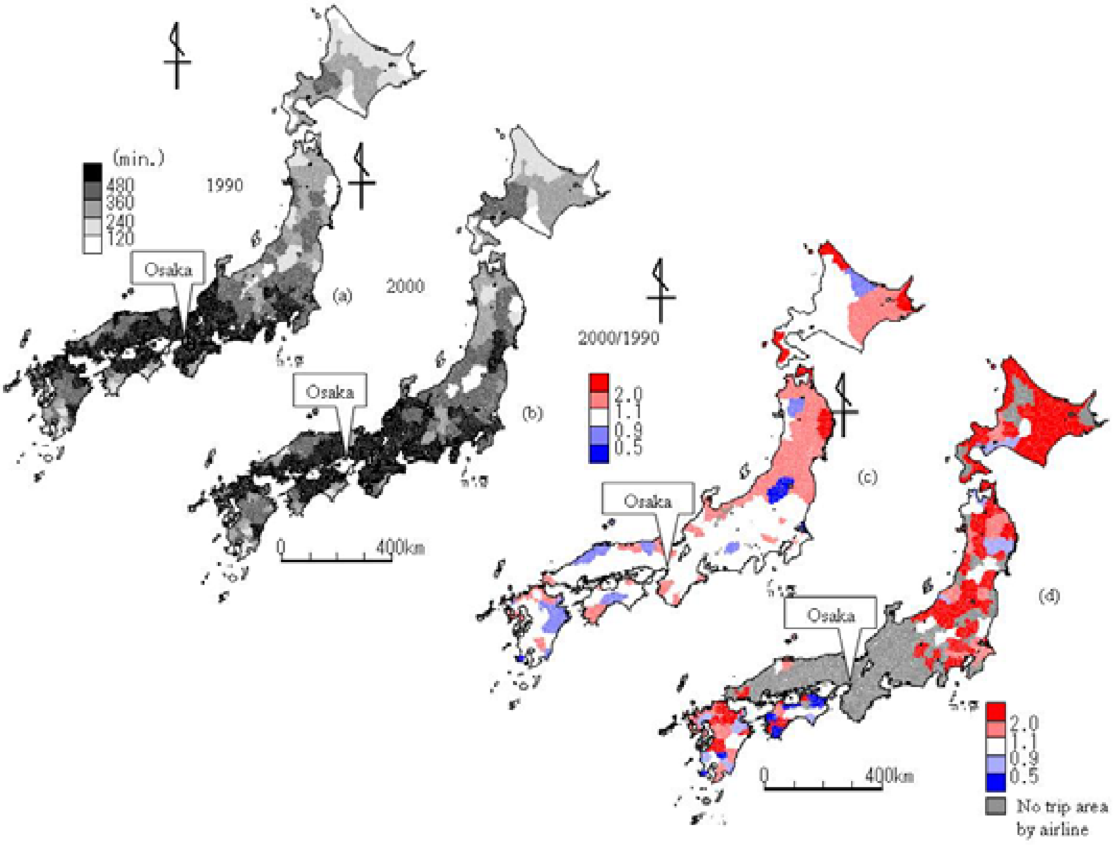

Figure 5 RTA of Osaka in 1990, 2000, with temporal change of passenger demand

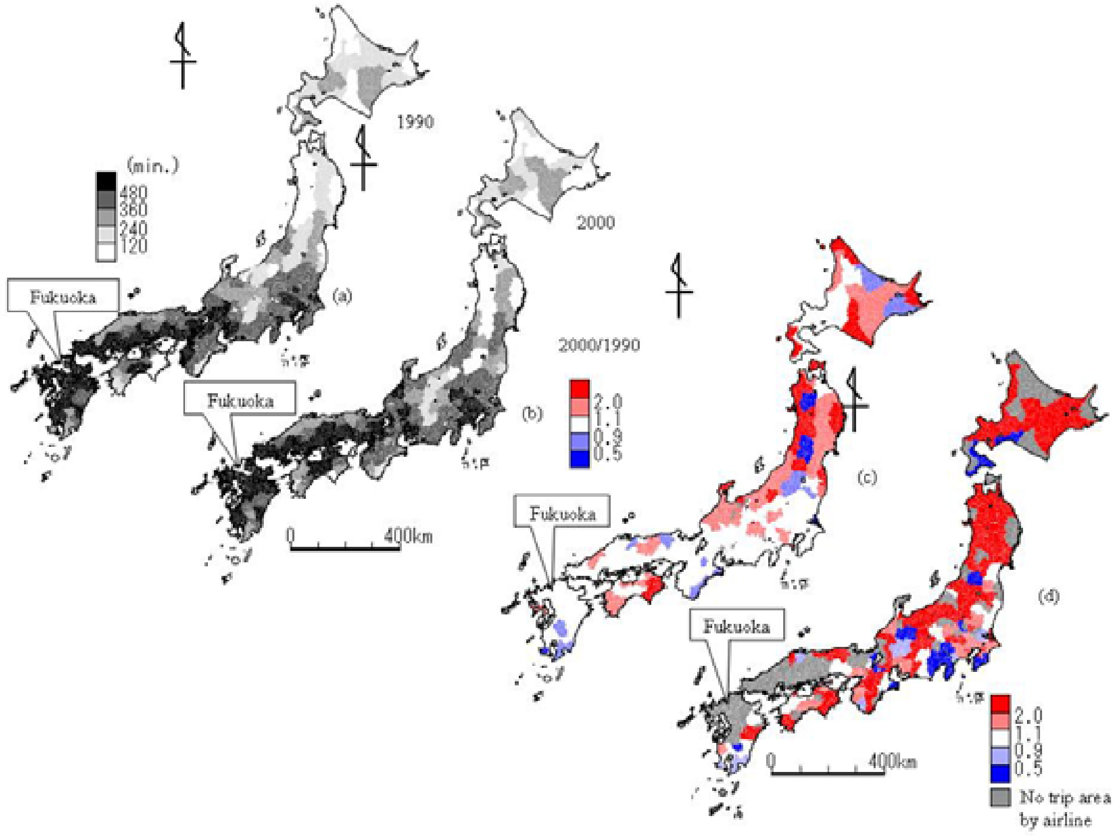

Figure 6 RTA of Fukuoka in 1990, 2000 with temporal change of passenger demand

Table 1 Result of parameter estimation

	1990		2000	
variable	parameter	t-value	parameter	t-value
Population at origin	0.567	(14.70)	0.499	(15.03)
Population at destination	1.129	(16.33)	1.181	(19.36)
MST at destination	1.512	(10.69)	0.595	(4.76)
Non-RTA area dummy	-7.698	-(9.42)	-2.395	-(3.21)
Constant	-22.557	-(20.41)	-21.896	-(22.26)
variance	1.734	(28.30)	1.620	(32.48)
Fraction of positive observation	40.2%		53.1%	
Adjustesd R-squared	0.685		0.699	
No. of observations	1174		1153	

growth of airline passenger is occurred. Intensive growth of airline passenger are scattered around Hokkaido, and around western Japan. Osaka's MST shown in **figure 5(a,b)** includes many thick color areas, describes high accessibility to other areas, similar with Tokyo. The growth of MST is mostly appearing from the western and eastern edges of Hokkaido island. **Figure 6(a,b)** show Fukuoka's MST. Along Sanyo-Shinkansen line as east as Osaka, long MST areas successively appear. Other than these Shinkansen connected areas, long MST areas are seen around Tokyo, Sendai and Sapporo area where are served by frequent airline service. Growth of MST and growth of airline passenger in northern and eastern Japan shows good correspondence in distribution.

3.3 Statistical analysis about the influence of RTA/MST on airline passenger traffic

Prior to model estimation, consider the modal choice of passenger traveling to closer area. A route including airline link is usually de-tour, takes more time than railway route, then he or she would use railway rather than airline route. On the contrary, passenger traveling to distant area tends to prefer airline to railway. However in such distant area travels, if the destination is not included in the RTA, travelers become very few and perhaps no passenger is recorded in sampled survey. This situation may also occur when the area is included in RTA but its MST is very short. Note that in both of the short-distance case and the short MST in long-distance case, observed airline passenger would be close to 0. In other words, the implication of 0 observations is very different from these two cases. In order to clarify RTA influence on airline passenger demand through the appropriately estimated parameter in eq.(6), samples observed in the areas where railway access has an advantage over airline should not be used for model estimation. For this purpose, representative mode of route to determine MST is used for sample selection standard; i.e. samples with railway served area are omitted.

As mentioned before, 9 areas are set to be origin node, and the number of destination nodes is 193 (except own area) for each origin, so that MST is calculated for 1737 destinations in total. Through the sample selection, number of samples is 1174, and 1153, for year of 1990 and 2000, respectively. The slight decrease of samples occurred by railway (Shinkansen) service improvements. Fraction of positive observations in logarithm (more than two in OD table) is 40.2% in 1990, and 53.1 % in 2000. This increase implies that number of area to generate airline passenger is increased in the airline served area. **Table 1** shows the result of the parameter estimation. Adjusted-R squared index is relatively high, showing that model reproduction meets satisfactory level. Looking at t-values of the estimated parameters except constant and variance, strength of determinant factor is commonly ordered as follows; 1) population at destination, 2) population at origin, 3) MST at destination and 4) non-RTA area dummy (at destination). Note that the parameter for MST is positive significant and the parameter for non-RTA area is negative significant in both crosssections. Both signs of parameters are appropriate. These results give statistical evidences that RTA and MST significantly influence on airline passenger demand.

4. Concluding remarks

This study analyzed for the relationship between RTA and airline passenger demand, based on passenger traffic data. In order to conveniently calculate MST and RTA, we develop a calculation procedure based on k-th path search algorithm, which outputs an approximated RTA. Using the proposed calculation procedure, MST and RTA are calculated for some representative origin areas. Some of the results are graphically shown in figures. As the airline passenger traffic data, the OD matrix of airline passenger that record origin node as passenger's home address, and destination node as the trip destination is used for the analysis. In order to clarify the statistical significance of RTA and of MST on airline passenger traffic, the calculated non-RTA-dummy and MST are used as additional explanatory variable for a gravity model of inter-city passenger trips. The gravity model used in this study was Tobit formulation because appropriate treatment of zero count observation is necessary to estimate all the parameters without distortion. The estimated parameters of the non-RTA-dummy and MST satisfied appropriate sign conditions, and they were significant. Therefore, we could clarify that RTA and MST significantly influence on airline passenger demand.

The remaining issues in this study are follows. The estimated RTA can be more closely analyzed, for example, aggregation for target airport, or shadow value of specific airport would be calculated. It is done by the comparison of RTA between the hypothetical RTA under the target airport is omitted, and usual RTA. This analysis would clarify the importance of an airport on the network. About the gravity model analysis, significance of RTA should be checked under more samples. By considering the modal choice into the gravity model, reproduction ability of the model would be improved, and then structural parameters would be more appropriately estimated.

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