ANALYISIS OF INTER-CITY PASSENGER'S ROUTE CHOICE BEHAVIOR ON NON-SHORTEST-TIME ROUTES

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Abstract: In Japan, inter-city public transport services are mainly provided by railways and airlines. Since the opening of Tokaido-Shinkansen connecting Tokyo and Osaka in 1967, rapid railways and domestic airlines have been significantly improved. On a highly improved public transport network enabling seamless transfer and transit, many alternative routes having enough short line-whole travel time become available. Inter-city passengers now can choose the most desirable route among alternatives on such network, considering to their purpose, budgets and time constraints. This study purposes to clarify the inter-city passenger's non-shortest-time routes use based on the net passenger inter-city trip survey in 1995. Through aggregation analysis in actually used routes, the characteristics of alternative non-shortest time routes are clarified. Then we estimated the route choice model of inter-regional passengers, and clarified the effect of LOS on different route alternatives. Results indicate that the multimodal route with long access should be counted on network planning.

Key Words: Inter-city passenger travel, Route choice behavior, Non-shortest-route use, Multimodal route

1. INTRODUCTION

In Japan, inter-city public transport services are mainly provided by railways and airlines. The opening of Tokaido-Shinkansen between Tokyo and Osaka in 1967 was the start of intensive investment for inter-city rapid railway networks. After the deregulation of Japan's domestic airlines in 1986, many airline companies were newly founded and competed much to attract passengers. Because economic and leisure activities were spatially expanded in '90s, increased inter-city passenger demands stimulated further improvements of inter-city public transport network; e.g., new link construction, rapid vehicle introduction, direct flights between local cities, and improvement of access between local airport and hinter primal cities.

On the improved public transport networks, many alternative routes having enough short line-whole travel time are available. Each inter-city passenger can choose the most desirable route among other possible alternatives on the network, considering purpose, budget, and individual time constraints. Therefore, the routes actually used on the improved public transport network do not always concentrate on the shortest-time route; rather they diverge over several non-shortest-time routes.

This study purposes to clarify the inter-city passenger's non-shortest-time routes use through the route choice modeling, We analyzed inter-city passenger's route recorded in the net passenger traffic survey in 1995. That database includes the information about passenger's transit or transfer nodes, additionally to OD nodes, purpose of the travel, and characteristics of passenger, In order to get the line-whole travel time information lacked in this survey, we prepare level-of-service data for each inter-city railway and airline link, and the line-whole travel time on the network is efficiently imposed by using K^{th}-shortest-path searching algorithm. Characteristics of actually used routes are analyzed in terms of fare, number of required transfers, and multimodal routes included in the route. Based on the processed route information, we estimate inter-city passenger's route choice model.

2. ROUTE CHOICE BEHAVIORS IN INTER-CITY TRIP

Comparing to vast number of studies on intra-city passenger's route choice, few studies on inter-city passenger's route choice are reported. Such the imbalanced interest among researchers is due to immediate needs to alleviate heavy congestion problem of intra-city traffic from '60s. An additional reason is that a sparse inter-city public transport network in early days, which provides not so many routes in most city pairs, could not provide alternative routes having enough short time against the shortest-time route. Therefore, the aggregated passenger's travel demand concentrates on the shortest-time route.

However, inter-city public transport network has been intensified through the continuous investment to the main corridors linking with major cities, together with the improvement in access links to major railway stations and airports. Since various routes having enough short line-whole travel time become provided adding to the shortest-time route, inter-city passengers can take both the shortest-time and alternative routes with enough short travel time. The alternative routes can be classified into different types, corresponding to the characteristics of network structure, as follows.

In the OD pairs almost directly connected by both railway and airline, passengers would choose both of the routes. Such passenger's choice behavior is considered as a simple modal choice as conventional studies (see **Fig. 1**). Terabe, et. al. analyzed the demand in the specific OD with a middle distance, in terms of modal choice between rail and air (Terabe, et. al., 1999). A questionnaire survey was conducted for the passengers in order to estimate a modal choice logit model. The estimated parameters showed that access and egress travel time also influence on the modal choice as well as line-whole travel time. This result indicates that passengers do not choose a mode, but a route based on the level-of-service of the routes.

In other OD pairs where the line-whole travel time of the routes including airline link is definitely shorter than any other routes without airline link, the used routes would always include airline link. For example, passengers may face the following alternatives; i.e. a direct flight with low frequency departing from close, but smaller local airport, or trunk flight with high frequency departing form far but larger airport (see **Fig. 2**). In this case, passenger's route choice is not modal choice but similar to airport choice. Because of long distance, a number of route alternatives are substantially increased. When inter-city rail (or bus) is used as access, the route boarding at the far airport would be competitive in line-whole travel time against the route via closer airport. Such route would often appear for the passengers from/to local cities. To sum up, the access time to the major airport is also important in terms of providing multiple routes to the passengers.

An importance of access time is pointed out in existing studies, but all of those studies concentrate on modal choice, and heterogeneity of passengers, e.g.; difference or variation in

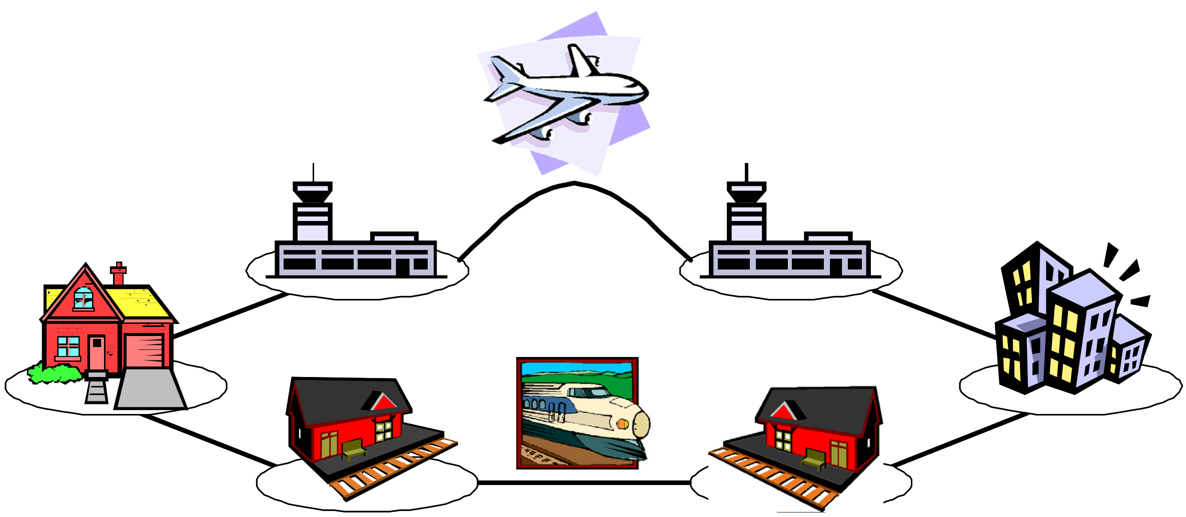

Figure 1. Inter-city route; middle distance, competitive case

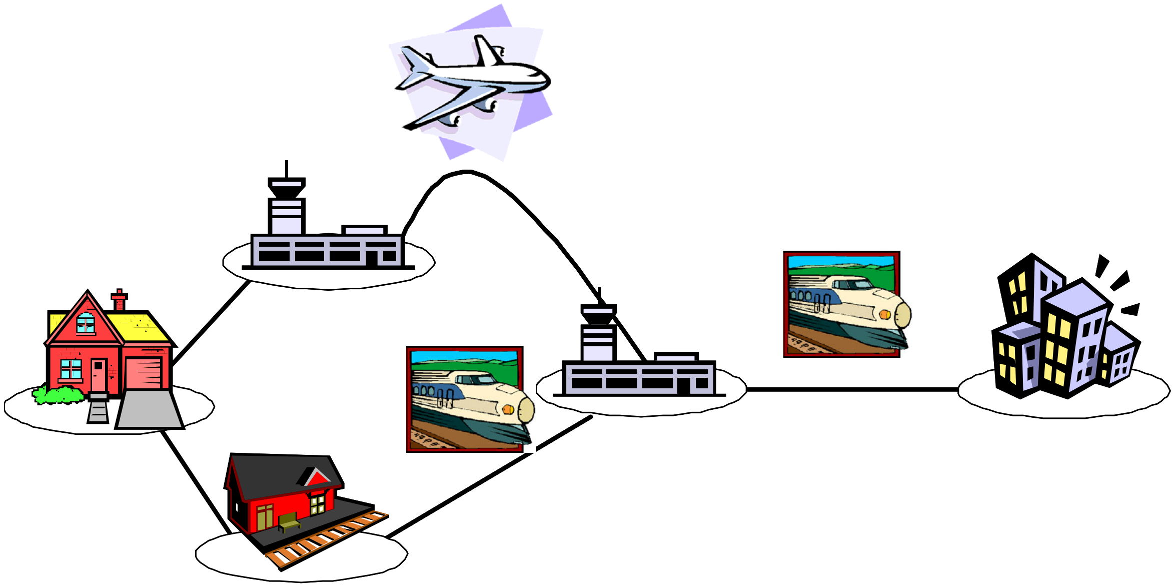

Figure 2. Inter-city route; long distance, multimodal case

value of time are often focused. Yai and Iwakura modeled inter-city passenger's modal choice by mutinominal-logit model, and discussed the difference in value of time based on time and cost parameters set derived for each region (Yai and Iwakura, 1993). Muto et. al., or Baht also adopted the same approach for inter-city passenger trip by using mixed-logit model, and by using random coefficient model, respectively (Muto, and Uchida, 2001; Baht, 1998). These studies do not explicitly consider the multiple routes. All the passengers do not choose a representative (shortest-time) route, so that LOS of the route they face is actually different. Such the variation can be considered as one of reasons for difference in value of time.

Aoyama, et, al., and Hatoko intended to improve an accuracy in a line-whole travel time between ODs, proposed an average line-whole time of the specific route, using the actual time table on each mode transfer and waiting time, and named it "expected line-whole travel time" (Aoyama, et al, 2000; Hatoko and Ikeda, 2002). Such an elaborate line-whole travel time would be useful to grasp the difference in substantial public transportation service among cities, but still this approach has difficulties in handling of huge database, ignore the possibility of non-shortest route use. Inoue, et. al. applied four-step model generally used in intra-city for inter-city passenger travel (Inoue, et. al., 2000). This study adopts logit-model for modal choice, gravity-type model for trip distribution, and linear regression model for trip generation. Gravity-type model is also adopted by Bell (Bell, 1997). Both of these studies analyze the distribution of net passenger trip, but also lack the sub-procedure to assign estimated demand to each route.

As discussed in above, "routes" are implicitly considered in each mode, which one representative mode corresponds to one route. A neglect of alternative route use results in a biased estimation to aggregated inter-city passenger demand on the specific link. The bias would appear in both direction for an over-, or an under-estimation of passengers on a link, depending on the network structure. Note that passengers actually choose a desirable route considering its LOS, conventional approaches are inappropriate to describe passenger's choice behavior. **Fig.2** shows that passengers from surrounding local area of major city would face composite route alternatives including both inter-city railway and airline. In order to efficiently use the existing public transport network, convenience for such passengers should be carefully considered (Morichi, Asakura, et. al., 1999). Such strategic planning policy often called "multimodal network planning" which aims seamless transfer and transit between different modes, requires empirical analysis on inter-city route choice behavior focusing on transfer and transit behavior.

3. DATA PROCESSING FOR PASSENGER'S ROUTE INFORMATION

The inter-city net passenger trip survey has been conducted three times, up to 2000. This survey is mainly processed from three different statistics, such as air passenger traffic, railway trunk line passenger trips, and car passenger traffics. Further, three additional surveys for bus, ferry and passenger ships, and night owl train are done in order to complement inter-city demand of these modes (Moroboshi, et. al., 1993). The survey was conducted in a week day of autumn. The OD table is estimated by integrating 6 kinds of data (three kinds of the statistics and three kinds of the additional surveys) with statistically adequate expansion parameters. Among three times of surveys, '95s disaggregated original data is available (details on the web-site*). The data includes about 350,000 records (90,000 records are railway trips, and about 260,000 records are airline included trips). In this study, we used those disaggregated data.

*: http://www.mlit.go.jp/seisakutokatsu/soukou/ppg/ppg2/ppg2data.html

The net passenger trip survey records the route information with following format; departure node, boarding on / off nodes (for each mode, if used), transit nodes, transfer nodes, and arrival node. This format includes only the nodes that some events as boarding, boarding off, changing trains or flights, or changing modes are occurred. But the other intermediate modes passenger passes by are not recorded. Further, a line-whole fare and line-whole travel time are not surveyed, either. Hence, a passenger's route and its time and cost need to be estimated.

In order to interpolate nodes between the nodes recorded in the survey, and to calculate line-whole time and fare based on the estimated route, we prepared public transportation network data covering Japanese four main islands (Hokkaido, Honsyu, Shikoku, Kyusyu) in 1995. Nodes are placed for one by one "Seikatsu-ken"unit, and links connecting the nodes reflect actual inter-city network. The network consists of 193 railway station nodes, 41 airport nodes, and 501 links. **Fig.3** shows the network and "Seikatsu-ken" zones with population (Airline links are not displayed on **Fig.3**, for simplicity).

We consider that the most possible route between the recorded nodes is the shortest-time route. For example, two transferred nodes are observed with origin / destination nodes in a record and three routes in between them, Dijkstra algorithm to search the shortest route can be repeatedly applied for the missing routes, and then a complete route for the record is made by gathering the three interpolated routes. A simple Dijkstra based interpolation can generate the route information, but not efficient.

Instead of such simple Dijkstra based interpolation, K^{th}-shortest-path algorithm which calculate the routes from the shortest to K^{th} for an OD pair, can be used to efficiently identify the passenger's route. A route-interpolating-procedure consists of four sub-procedures for each OD pair.

1. Calculate the possible routes by using K^{th}-shortest-path algorithm, and repeatedly generate K^{th}-shortest-path, until $k=20$. A possible route starts from the shortest travel time route $k=1$.
2. Comparing recorded nodes with nodes on a possible route.
3. If all the nodes of the record are included in the compared (possible) route with the same order, the route corresponding to that record is identified. Nodes information of the route wth line-whole travel time and cost are stored.
4. If compared (possible) route does not match the recorded route, $K+1^{th}$ route is set as possible route, and go back to 2.

After the interpolation, "line-whole-time" is calculated by summing up each link of travel-time on a route. If a transfer form railway to airline, or from airline to airline is included on the route, 20 minutes is added for each time. Minimal frequency defined by the lowest frequency on the route, is considered as an index of the route availability, since the link with minimal frequency strongly constrains a trip schedule.

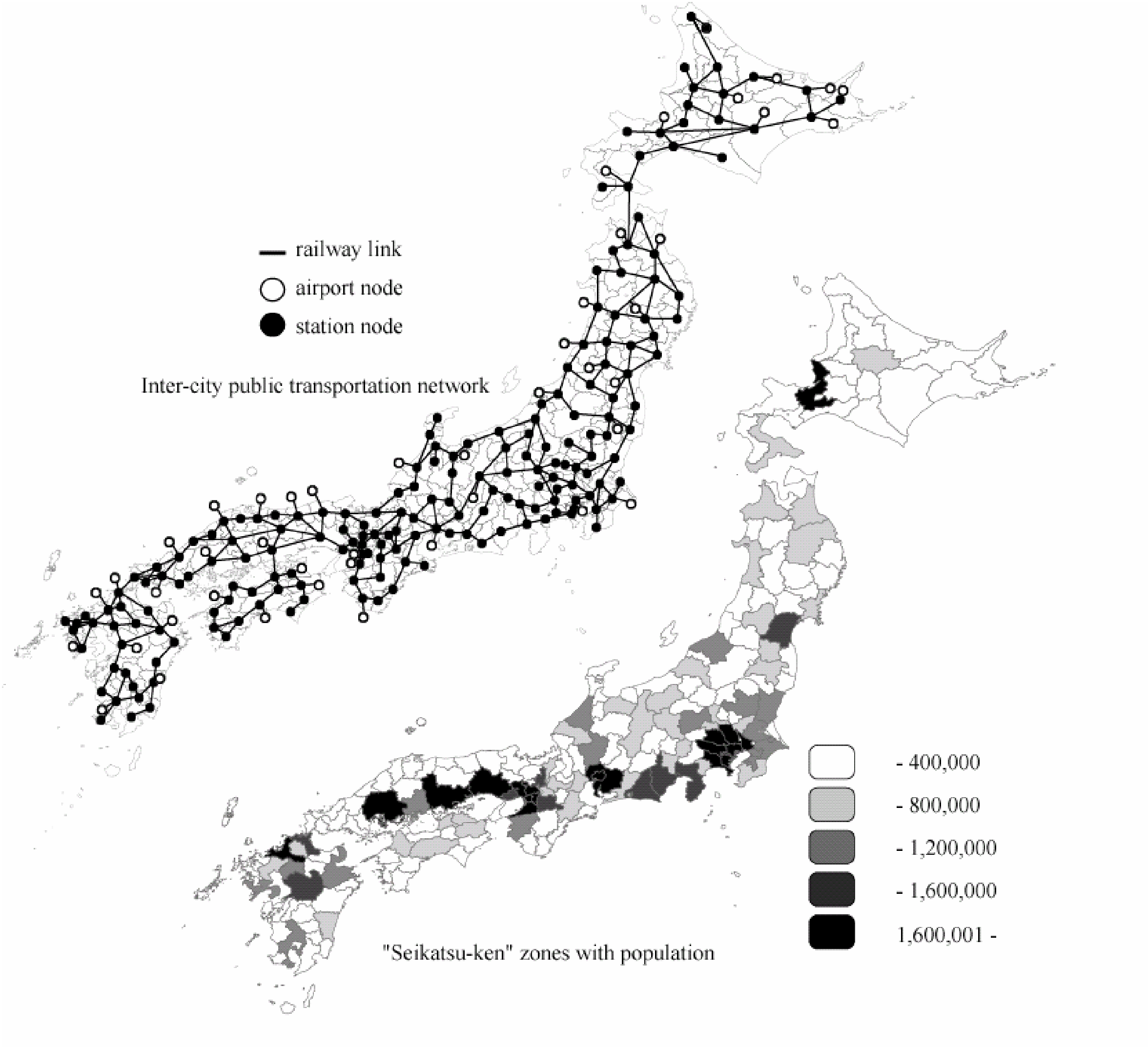

Figure 3. Inter-city route; long distance, multimodal case

4. CHARACTERISTICS OF INTER-CITY PASSENGER'S ROUTE CHOICE

Airline service is very different from train service in terms of speed and frequency. Hereafter, we divide inter-city routes into two categories (1) including flights, and (2) railway routes using only railway. **Fig. 4** shows trip purposes on the trips using only railway classified by trip distance ranges. Business, sight-seeing and private are sharing from 65% to 73%, from 9% to 13%, from 10% to 15%, respectively. Up to 1,200 km range, business share increases, but it decreases over 1,200 km range. Contrary, sight-seeing shares decreases up to 1,200 km range, but increases in over 1,200 km range. Private and other purpose shares increase with the distance. **Fig. 5** shows trip purpose shares on airline included routes by trip distance ranges. Business, sight seeing and private shares are sharing from 52% to 71%, from 18% to 37%, from 6% to 9%, respectively. Up to 1,000 km ranges, business ratio increases, but decreases over 1,000 km range. Sightseeing share increases with the distance, and private and other purpose shares decrease with the distance, contrarily. Comparing **Fig. 4** with and **Fig. 5**, private trip shows larger share in railway route, and sightseeing trip shows larger share in airline included route for all trip distance range. **Fig. 6** shows the share of access plus egress time to the main mode time in line-whole time (called as access time share) aggregated by trip distance ranges (Main mode time in a route is defined by the priority of modes such as flight, railway, and the others). Railway access time sometimes becomes longer than flight time. Access time share is larger in shorter distance range, but the share of a trip over 1,500 km still marks 32%. Therefore, access link improvement would certainly lessen the line-whole trip time. This effect cannot be ignored.

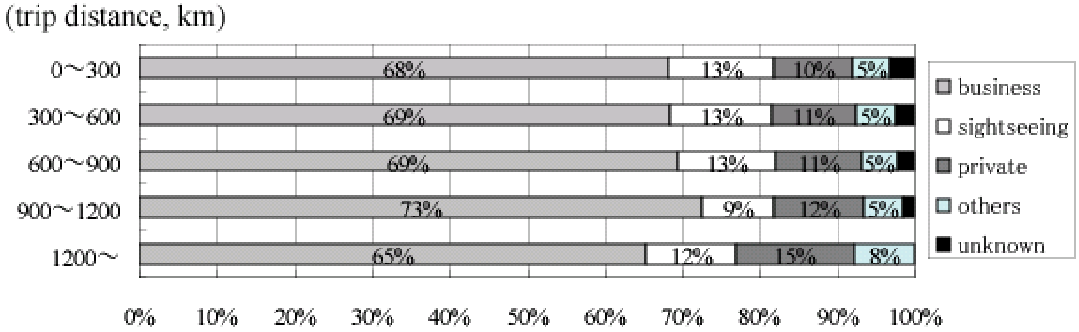

Figure 4. Share of trip purposes on railway route, by trip distance ranges

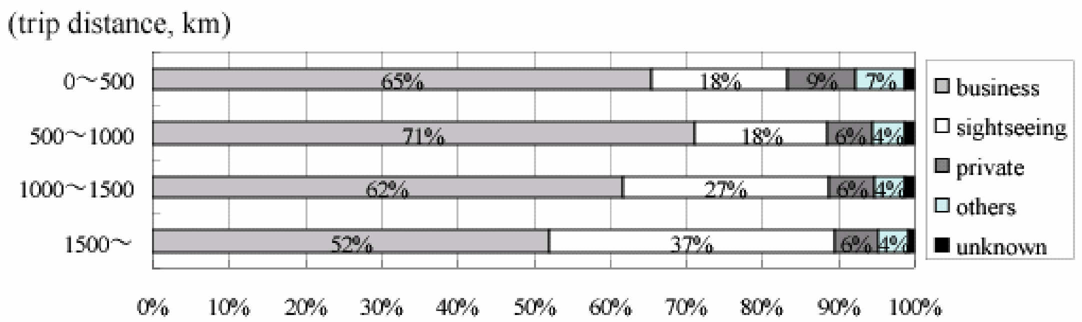

Figure 5. Share of trip purposes on airline included route, by trip distance ranges

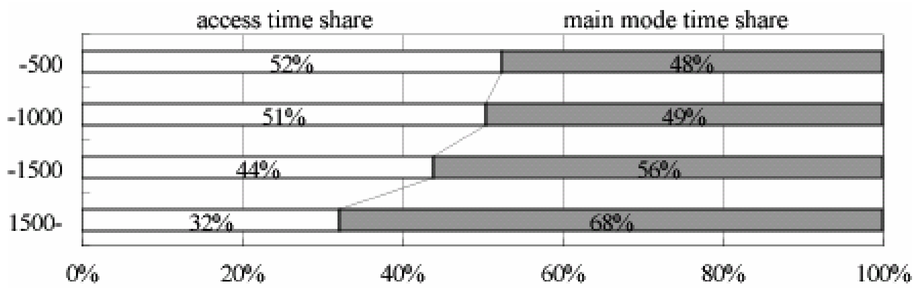

Figure 6. Access time share in line-whole trip time, by trip distance ranges

Table. 1 and **Table. 2** shows the number of OD pairs where multiple route are used, for railway routes, and airline including route, respectively (definition of regions are shown in **Fig. 7**). Multiple railway routes use in **Table. 1** mainly appear from/ to Kanto area, including Japan's capital of Tokyo, which would reflect rapid railway ("Shinkansen") network structure expanding from Kanto (Tokyo) area to Tohoku, Tokai, Kinki, Cyugoku, and Kyusyu (to Fukuoka) region. Contrary, multiple airline included routes often appear between Hokkaido (northern edge region) to others, and Kyusyu (western edge region) to others. **Fig. 8** shows the passenger's routes using specific airline link. The routes including Chitose (Hokkaido) to Haneda (Kanto) airline link is shown in the upper map, the routes including Haneda to Fukuoka (Kyusyu) airline link is shown in the lower map. In the upper map, Chitose widely gathers passengers from Hokkaido area including via both railway and local airline links.

Table 1. Number of OD pairs of multiple route, only railway

	Hokkaido	Tohoku	Kanto	Hokuriku	Tokai	Kinki	Cyugoku	Shikoku	Kyusyu
Hokkaido	1	3	2	1	0	0	0	0	0
Tohoku	-	27	79	5	5	7	1	0	0
Kanto	-	-	15	73	49	122	27	10	8
Hokuriku	-	-	-	5	18	32	6	0	1
Tokai	-	-	-	-	8	35	8	4	4
Kinki	-	-	-	-	-	4	43	14	26
Cyugoku	-	-	-	-	-	-	9	5	7
Shikoku	-	-	-	-	-	-	-	4	2
Kyusyu	-	-	-	-	-	-	-	-	34
									704OD

Table 2. Number of OD pairs of multiple routes, airline link included

	Hokkaido	Tohoku	Kanto	Hokuriku	Tokai	Kinki	Cyugoku	Shikoku	Kyusyu
Hokkaido	1	9	34	5	15	10	1	13	15
Tohoku	-	0	10	4	13	4	3	7	6
Kanto	-	-	0	10	0	3	19	11	43
Hokuriku	-	-	-	0	0	2	2	2	16
Tokai	-	-	-	-	0	0	0	1	21
Kinki	-	-	-	-	-	0	0	0	3
Cyugoku	-	-	-	-	-	-	0	0	1
Shikoku	-	-	-	-	-	-	-	0	7
Kyusyu	-	-	-	-	-	-	-	-	4
									295OD

Figure 7. Definition of regions

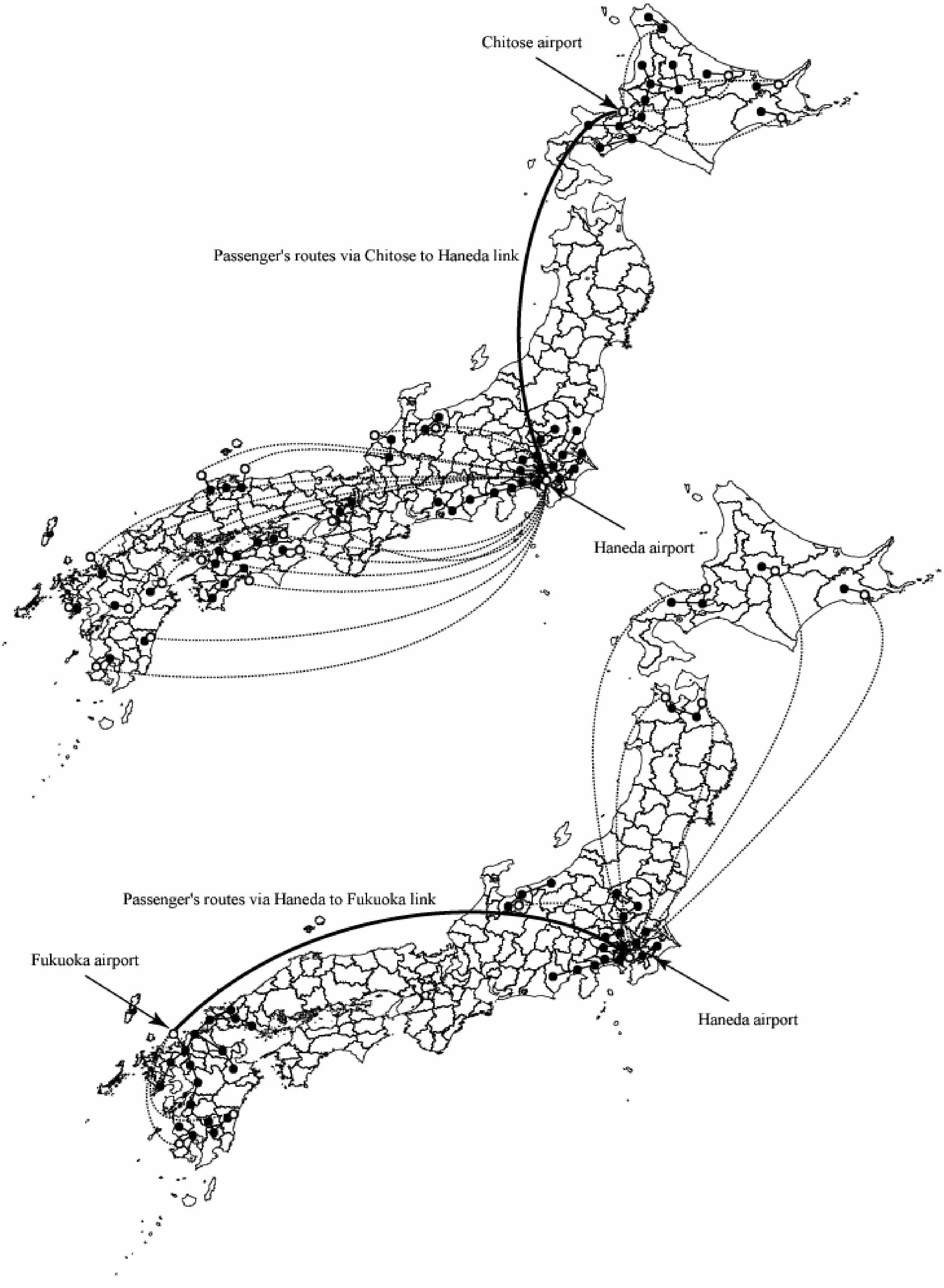

Figure 8. Airline including routes via Chitose to Haneda, and via Haneda to Fukuoka

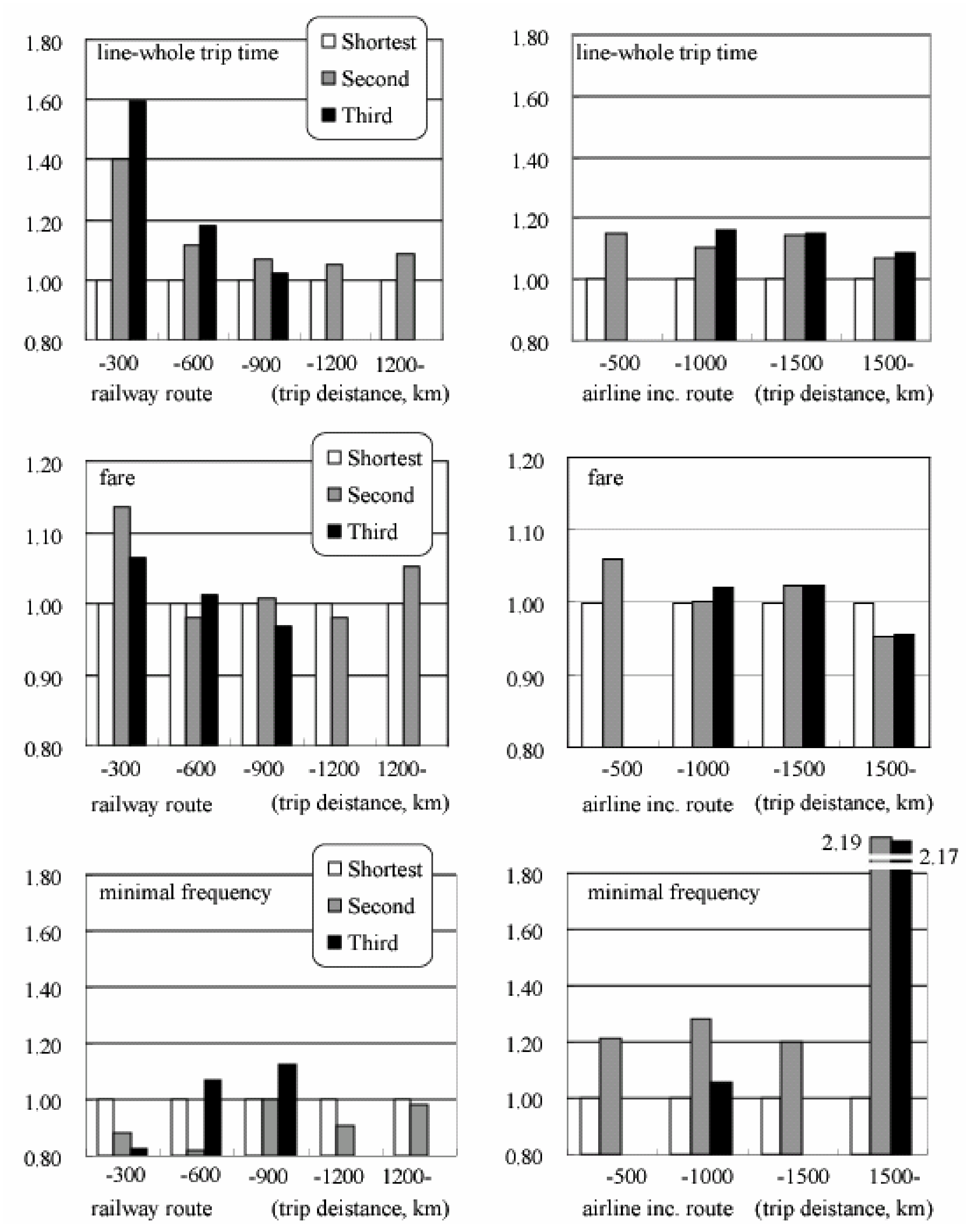

Figure 9. Difference in line-whole trip time, fare , and minimal frequency

Short access passengers to Haneda from Kanto and Tokai area uses railway, but long access from western area to Haneda is realized by additional flight and short railway. In the lower map showing Haneda to Fukuoka users routes, Fukuoka gathers passengers from Kyusyu and western Cyugoku area, similar to the Hokkaido case, stated above. However, only a few passengers access to Haneda from Tohoku area different from the upper case. A reason of this difference is considered that Haneda airport is more accessible from the western side but not so well accessible from the eastern side. Note that routes shown in **Fig. 8** are constrained to use a specific link. For example, a Chitose to Fukuoka airline link is omitted in these two maps, but of course such direct connecting link is included in multiple route alternatives for Hokkaido-Kyusyu OD pairs. Those who live in distant areas from Chitose or Fukuoka airport might use railway as an access link to the airport, therefore seamless multimodal route would be needed for passengers from Hokkaido and Kyusyu area.

Fig. 9 shows the comparison of line-whole trip time, fare, and minimal frequency, for the shortest, second shortest, and third shortest routes. **Fig. 9** is classified into 6 groups by main modes, each LOS are standardized by the shortest route value in order to level the average among different distance ranges, hence all the LOS of shortest routes equal to 1 in definition. Considering the difference between the shortest to the third route, there is large difference in line-whole trip time in short range on railway route, but the difference becomes smaller (ratios are close to 1) in longer ranges. On airline including routes, difference of line-whole trip time in short range is not so large, but the difference does not become small in longer ranges. Concerning to the fare, the second shortest route for short distance railway use seems relatively expensive, but contrarily, second route in 300 to 600 km, third route in 600 to 900 km, and second route in 900 to 1,200 km have relative fare below 1, so that fares of these routes are lower than the corresponding shortest route. On airline including route, fare differences are commonly not so large. Fare of second and third route is lower in over 1,500 km range than the corresponding shortest route. Minimal frequency means the lowest link frequency on the route. On railway route, third route in 300 to 600 km range, second and third route in 600 to 900 km range give value over 1, so that minimal frequency of these route is better than the corresponding shortest route. On airline including route, minimal frequency is higher in second or third route except in 1,000 to 1,500 km range, and particularly higher in over 1,500 km range.

5. INTER-CITY PASSENGER'S ROUTE CHOICE MODEL

In order to clarify the effect of LOS on different route alternatives, we estimated inter-city passenger's route choice models by using disaggregated logit model. Before the model estimation, OD pairs are classified into the following three groups based on the type of alternatives; (1) two railway routes, (2) two airline including routes, and (3) one airline including route and two railway routes. According to trip purpose, models are separately estimated. Results are shown from **Table. 3** to **Table. 5.**

Table. 3 shows the estimated result of the model for choice between two railway routes. Average OD distance of the 60 OD pairs is 518 km. Parameters of time, fare, and minimal frequency has the expected sign with significant in both model. According to *t*-value, most important LOS factor for business passenger is line-whole trip time, frequency is second, and fare is not so important. However, sight-seeing & private passengers consider fare the most important, then secondly line-whole trip time, and lastly frequency. Value of time calculated from time and fare parameters are 3,448 *yen/hour* (29.5 $/hour) for business trip, and 2,983 *yen/hour* (25.5 $/hour) for sightseeing & private trip. **Table. 4** shows the estimated model for the choice between two airline including routes. Average OD distance of the 34 OD pairs is 938 km. In this model, access + egress time parameter is added. Parameters (except constant) in business purpose model are significant. The order of importance of LOS is access + egress time, line-whole trip time, frequency, and lastly fare. In sightseeing & private purpose model, fare is most important, and secondly access + egress time, but line-whole trip time and frequency parameters are not significant. Value of time for business and sightseeing & private trip are 11,040 *yen/hour* (94.4 $/hour), and 4,640 *yen/hour* (39.7$/hour), respectively, which are higher than those of the corresponding railway route model. **Table. 5** shows the estimated model for case (3), triple choice among 2 railways and one airline including routes. Average OD distance of 23 OD pairs is 716 km. In this model, number of transit parameter is added. Parameters of time, fare, frequency, and transit number are significant for business passenger. In this model, the order of importance of LOS is line-whole trip time, frequency, fare, and lastly number of transits. In sightseeing & private purpose model, line-whole time is most important, and secondly fare, but other parameters are not significant. Value of time of business and sightseeing & private trip are calculated as 5,849 *yen/hour* (50.0 $/hour), and 4,347 *yen/hour* (37.2$/hour), respectively. The following examples present some of the most typical cases of referencing at the end of the paper; please follow them as strictly as possible.

Table 3. Number of OD pairs of multiple routes, airline link included

variables	trip purpose	Business estimates		t-value	Sightseeing & private estimates		t-value
line-whole trip time	(min)	-0.031	**	-(3.08)	-0.027	*	-(2.55)
fare	(*10^3yen)	-5.228	*	-(2.41)	-5.450	**	-(2.90)
frequency	(per day)	0.116	**	(2.97)	0.090	*	(2.12)
age$		0.440	*	(2.24)	-0.046		-(0.23)
constant$		3.734	**	(3.15)	-2.193		-(1.82)
log-likelihood		-510.4			-206.8		
ρ^2		0.215			0.263		
no. of records	(60ODpairs)	938			441		

$: for the shortest route, * : significant in 1%, ** : siginificant in 5%

Table 4. Number of OD pairs of multiple routes, airline link included

variables	trip purpose	Business estimates		t-value	Sightseeing & private estimates		t-value
line-whole trip time	(min)	-0.037	**	-(6.20)	-0.019		-(1.68)
fare	(*10^3yen)	-1.995	**	-(2.64)	-2.472	**	-(4.80)
frequency	(per day)	0.036	**	(3.94)	0.009		(0.80)
egress time	(min)	-0.048	**	-(6.50)	-0.048	**	-(4.56)
age$		0.010	**	(2.11)	-0.006		-(0.81)
constant$		0.366		(0.93)	0.588		(1.82)
log-likelihood		-744.9			-249.3		
ρ^2		0.318			0.421		
no. of records	(34ODpairs)	1576			621		

$: for the shortest route, * : significant in 1%, ** : siginificant in 5%

Table 5. Number of OD pairs of multiple routes, airline link included

variables	trip purpose	Business estimates		t-value	Sightseeing & private estimates		t-value
line-whole trip time	(min)	-0.010	**	-(13.10)	-0.018	**	-(10.28)
fare	(*10^3yen)	-1.036	**	-(5.25)	-2.472	**	-(6.26)
frequency	(per day)	0.071	**	(7.28)	0.019		(1.54)
no.of transit$		-0.224	*	-(2.25)	0.212		(1.63)
age#		0.026	**	(2.59)	0.007		(0.87)
constant$		0.196		(1.66)	0.396		(1.77)
constant#		-2.167	**	-(3.95)	0.900		(1.13)
log-likelihood		-703.2			-277.8		
ρ^2		0.215			0.267		
no. of records		815			345		

$: for the shortest railway route, # : for the shoetest airline inc. route
* : significant in 1%, ** : siginificant in 5%

6. DISCUSSION AND CONCLUSIONS

In this study, we studied on multiple route use of inter-city passengers that have been often ignored in conventional approach. In order to analyze the characteristics of the alternative non-shortest-time route, we interpolated incomplete routes of surveyed inter-city passenger's route, by using the K^{th}--shortest-path algorithm. Then we analyzed the effect of LOS on different route alternatives through the disaggregated logit model. Aggregation analysis for alternative routes showed that access (+egress) share in line-whole trip time is considerably high; therefore improvement of accessibility between major stations and airports would certainly lessen the line-whole trip time. Comparing of LOS on multiple routes, some of non-shortest-time route such as the third-railway routes in 600 to 900 km range, or the second- and third-airline including routes in over 1,500 km range have advantages in fare and minimal frequency, than the shortest-time routes. Disaggregated route choice model shows that passengers on business consider line-whole time and frequency important, but passengers on sightseeing & private purpose consider line-whole time and fare important. Besides the additional improvement for decrease in line-whole trip time should be done, the convenience to transfer to other mode also enlarges the passenger's demand for inter-city transportation service.

Multimodal routes including both railway and airline links are proved to be frequently used. On the multimodal routes, many passengers use not short access link of railway to the trunk link. But such the access links have not been yet considered in conventional network planning. Therefore, when the access link improvement is planned, not only short access service from the neighboring city, but also long access service by train from the larger hinterland should be considered in.

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