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Propagation of Improvement Effects of Critical Inter-city Link --- The Japanese Decadal Change of the Available Travel Routes ---

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Abstract: Unlike the urban highway network, the inter-city network is composed of heterogeneous links of various speeds, costs and frequencies. Improvement of one airway link can possibly provide a new attractive travel route, such as an air connection route, as well as multi-modal route, including middle distance railway access. The improvement effect of a critical link may be propagated over the nation-wide network, unlimited to the direct neighbor connector of the improved link. How such propagation occurred in Japan between 1995 and 2005 is investigated. K-th shortest path search algorithm is applied to find the available set of routes. Remarkable changes in the Tohoku-Western Japan pairs are detected. This paper further analyzes the effects of the Shinkansen expansion to Hachinohe in 2002 on the service level of the available routes for those OD pairs, proving that there are strong multi-modal propagations on the air links at Sendai airport.

Key Words: *inter-city network, multi-modal routes, set of routes, Shinkansen*

1. INTRODUCTION

1.1 Background

Financing schemes for transportation development have been drastically diversified in recent decades. While European countries having long history of transportation operations that separate infrastructure provision from operations, developing countries try to take BOT, BOO and internalize the operation profit as to cover the initial building cost. When we design an appropriate financial scheme, we must analyze the flow of the investment effect, but such analysis for an inter-city transportation project is not so easy as that for an urban transportation project, where most users can be limited to the inhabitants of that city, especially along the line of the project. That condition is not the case in large scale inter-urban transportation projects, but transportation economists insist that the benefit of the improvement is generated in the transport service market at first, then, construction cost should be covered with the overcharge on the fare, and be gathered from the operators. Based on that belief, cost allocation scheme for new Shinkansen (rapid train system) Project is controversial, especially how they determine the cost sharing among the Japanese national government, local governments along the lines, and JR, as an operator. For example, JR West

is asked to cover a part of the construction cost of the Kyushu Shinkansen to be operated by JR Kyushu, while JR East is asked to cover a part of the cost of the Hokuriku Shinkansen expanded into the area of JR West.

Furthermore, such effect propagation would not be limited to one mode --- railways in the above examples. As we will show in this paper, a newly constructed Shinkansen line can be used as a middle-distance access to a local airport, and a route shift is occurring to support an air link departing at the local airport. Such wide, and multi-modal propagation is a unique phenomenon in an inter-city network already constructed to certain degree of density.

1.2 Related Studies

In the inter-city passenger transportation, competition between railway and air service have been frequently discussed and analyzed (Janic, 2003; Gonzalez-Savignat, 2004). Recently, however, complementally mixture of these two different modes gathers interests: one of the typical mixture use is railway access service for an airport (Lythgoe and Wardman, 2002), which take advantages of reliability of the railway service. Railway service has also another characteristics that it can collect demands distributed thinly along the line. It can be used as an effective demand collector for a hub airport, especially when it is difficult to expand the airport for several reasons (Givoni and Banister, 2006).

In reality, there are not a few Multi-modal routes are chosen by passengers (Horn, 2003; Tsukai and Okumura, 2003), but the connectivity between the different modes is far from the satisfactory (O'Sullivan and Patel, 2004; Tapiador *et al.,* 2009). From the passengers' viewpoint, not only physical and spatial, but also temporal connectivity are very crucial (Cascetta and Papola, 2003; Krygsman *et al.,* 2004; Malighettia *et al.,* 2008). Concerning the measurement index for connectivity, Daily Reachable Sphare and Maximum Stay Duration are proposed in the Japanese national infrastructure development planning process (Sato and Totani, 2005; Morichi *et al.,* 2005). Mathematical methodologies to find several routes on a dense network, and to efficiently calculate the indices have been studied (Kato et al., 1978; Miller-Hooks and Patterson, 2004). The present authors applied these methods to the Japanese inter-city public transportation network (Tsukai and Okumura, 2005; 2006), followed with the propose of a network design model (Okumura and Tsukai, 2007). However, the realistic service level evaluations have not yet executed, mainly because of data availability problem.

1.3 The Aim of This Paper

This paper aims to show how such propagation occurred in Japan between 1995 and 2005. The k-th shortest path search algorithm is applied to find the available set of inter-city trip routes. Remarkable changes in Tohoku-Western Japan pairs, due to the Tohoku Shinkansen expansion up to Hachinohe City in 2002, are detected. This paper analyzes the change of the service level of the available routes in those OD pairs, by comparing the air, multi-modal, and rail routes from the Hachinohe zone to the zones in the Western. It is proved that there are strong multi-modal propagations of the Shinkansen expansion on the air links at Sendai airport, owing to the improvement of frequency and maximum staying time at the destination.

2. CHANGE OF THE AVAILABLE SET OF TRAVEL ROUTES

2.1 Network Data

An inter-regional network database was prepared corresponding with the spatial unit of the Japanese Inter-city Net Passenger Traffic Survey using 207 zone divisions. We used 194 areas for the analysis excluding some isolated islands. The dataset consists of 246 nodes (194 zone centroids and 52 airport nodes) with 560 links (217 air, 291 trunk railway, and 52 airport access links). The prepared attributes of each link were physical distance, travel time, standard fare (for air and access links), name of express train, and the hourly frequencies of 18 hours from 6:00 to 24:00 for each direction. The source of the diagram information is referred to the timetables published in October 1995 and in October 2005.

Major changes of inter-city transportation services around this decade are summarized in table 1. Besides the two international airports of Kansai and Chubu, most of the airport improvements appeared in rural area - far from the metropolitan regions (events 3,4,9 in table 1). This is why the improvements of the frequency was not so large as that of the travel time, especially in the case of new airports in rural areas, where flight frequency to Haneda Airport (Tokyo) could not so increase as to have been expected, due to the capacity limit of Haneda. The Hachinohe expansion of the Tohoku Shinkansen in 2002 (event 8) cut 34 minutes of nominal travel time, and the previous transfer time at Morioka Station became unnecessary, while the increase of frequency was small. The Kyushu Shinkansen solely did not have any direct service to Tokyo in the Shinkansen projects, shown in table 1 (event 11), but it provided large amount of shortening of travel time, as well as the remarkable increase of frequency as much as 16.5 times in a day. While the opening of Chubu International Airport resulted in an increase in the frequency of air ways (event 12), Kansai International Airport has lost more than half of its air lines by 2005.

Table 1 Major events of Japanese inter-city transportation around 1995-2005

No.	year	date	event	travel time, frequency, no. of lines		
				1995.10	2005.10	unit
	1992	3.14	Nozomi (270km/h) on Tokaido Shinkansen (Tokyo-Osaka)	16	53.5	times
		7.18	Yamagata Mini-Shinkansen (Fukushima-Yamagata) opened	11.5	14	times
	1993	3.18	Nozomi on Tokaido-Sanyo Shinkansen (Tokyo-Fukuoka)	13.5	17	times
	1994	9.4	Kansai International Airport (Osaka) opened	68 / 25	45 / 12	times / lines
1	1997	3.22	Akita Mini-Shinkansen (Morioka-Akita) opened	104 / 13.5	84 / 14	minutes / times
2	1998	4.5	*Akashi Strait Bridge (Hyogo) opened with bus service*			
3		7.18	Odate-Noshiro (North Akita) Airport (Akita) opened		3 / 2	times / lines
4		7.28	Saga Airport (Saga) opened		5 / 2	times / lines
5		10.1	Nagano Shinkansen (Takasaki-Nagano) opened	91 / 18.5	51 / 18	minutes / times
6	1999	12.4	Yamagata Mini-Shinkansen (Yamagata-Shinjo) expanded	53 / 9	46 / 8.5	minutes / times
7	2000	3.23	New B Runway of Haneda Airport (Tokyo) replaced	250 / 36	373 / 40	times / lines
8	2002	12.1	Tohoku Shinkansen (Morioka-Hachinohe) expanded	71 / 14	37 / 16	minutes / times
9	2003	7.7	Noto Airport (Ishikawa) opened		2 / 1	times / lines
10		10.1	Shinagawa Station on Tokaido Shinkansen (Tokyo) opened	16	54	times
11	2004	3.13	Kyushu Shinkansen (Yatusushiro-Kagoshima) opened	122 / 12	39 / 28.5	minutes / times
12	2005	2.17	Chubu International Airport (Nagoya) added to old airport	61 / 25	106 / 29	times / lines

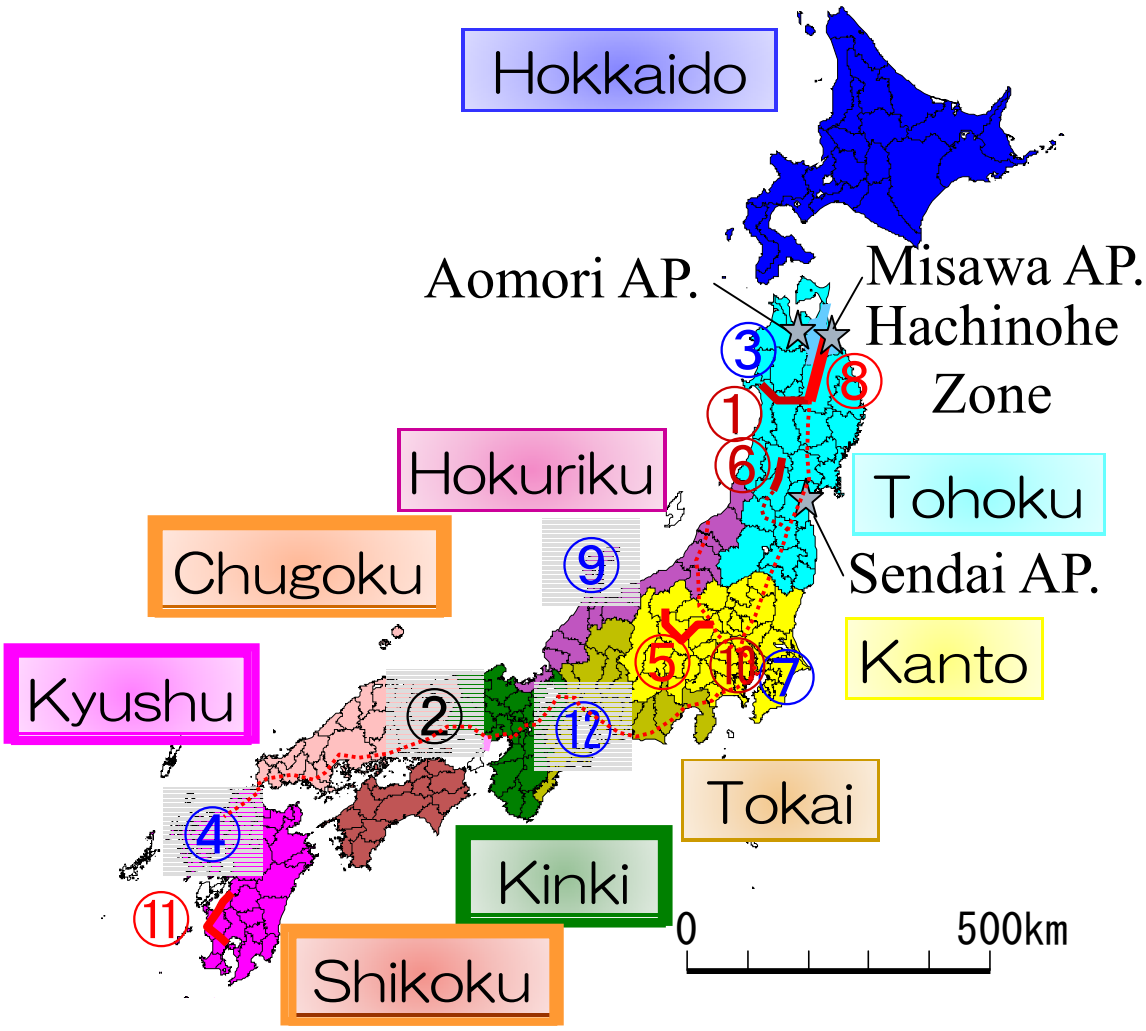

Figure 1 Location of the Major Projects and Division of Regions

2.2 Route Search Algorithm

The available travel route for each OD pair is defined as follows: At first, the shortest time paths in 1995 and 2005 are found by the Dijkstra algorithm, without considering transfer time or frequency. Secondly, k-th path search algorithm is used to search other routes up to 40. If travel time of that route exceeds 1.5 times of the shortest time in 1995, or if that route includes more than three air links, that route is deleted form the available set. Comparing to a sparse air network, the railway network is too dense to produce many similar routes. Therefore, several calculated routes including the common air links, are represented by the shortest time route of them. This procedure means that all routes including only railway links are represented by the shortest one.

The k-th path search algorithm, proposed by Kato, et. al (1978) consists of the 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 find the details about the procedure.

Table 2 Average number of available travel routes per one OD pair classeified by region

Region	Hokkaido	Tohoku	Kanto	Tokai	Hokuriku	Kinki	Chugoku	Shikoku	Kyushu
Hokkaido		11.1 11.9	13.9 15.6	16.1 17.5	10.1 9.8	14.8 14.8	11.1 12.5	7.7 8.1	8.8 9.7
Tohoku	0.8 +6.9%		9.4 8.9	8.7 9.5	13.1 12.3	9.7 10.4	14.1 16.0	15.2 14.5	12.0 14.6
Kanto	1.7 +11.2%	-0.5 −5.1%		6.0 7.4	5.9 5.8	9.7 8.8	11.8 11.7	11.2 9.8	13.9 15.3
Tokai	1.4 +8.2%	0.7 +6.9%	1.5 +20.5%		3.6 4.3	2.6 2.0	7.3 6.4	6.3 5.9	13.0 13.4
Hokuriku	-0.3 −2.5%	-0.8 −6.7%	-0.1 −1.2%	0.7 +1.3%		5.4 6.2	9.6 9.7	10.2 9.3	8.7 9.8
Kinki	0.1 +0.4%	0.7 +7.0%	-0.9 −8.4%	-0.5 −11.6%	0.9 +10.5%		6.5 5.0	5.9 4.9	13.0 11.3
Chugoku	1.4 +11.9%	1.9 +12.4%	0.0 −0.2%	-0.9 −12.2%	-0.1 −0.8%	-1.4 −24.1%		8.4 6.3	8.7 8.4
Shikoku	0.4 +4.6%	-0.6 −4.0%	-1.4 −12.3%	-0.4 −6.7%	-0.8 −8.6%	-0.9 −25.2%	-2.1 −25.7%		9.1 7.9
Kyushu	0.9 +9.5%	2.6 +19.8%	1.4 +9.6%	0.4 +2.7%	1.1 +11.0%	-1.8 −12.7%	-0.3 −7.4%	-1.2 −12.5%	

Note:

	No. of routes in 1995 No. of routes in 2005
Increase (2005-1995) Change Rate(%) (05-95)/95	

2.3 Number of Available Travel Routes

The result of the route search is summarized for the nine regions as table 2. The upper-right triangle shows the average number of available routes in 1995 and 2005 for one OD pair included in the region pair, while the bottom-left triangle shows the difference and ratio of them. At a glance, the numbers are larger in the remote regions, compared to the near regions. The reason of this result comes from the representation of the multi-modal routes including the common air links and representation of railway routes. The short distance OD pairs are usually connected with a railway route, and hardly have other routes up to 1.5 times of the shortest time, including air links. Besides that, there are fewer routes for the Shikoku Region than for other cases.

2.4 Change of the Available Routes

2.4.1 Effect of Airport Openings

As shown in table 1, newly opened airports excluding Chubu International, are located in rural areas and the new air service is limited to small destinations such as Haneda or Itami. Therefore, the opening of Odate-Noshiro Airport (Akita) (event 3) never contributed to increase the routes between Tohoku and Western Japan (Kinki, Chugoku and Kyushu). Similarly, the opening of Saga Airport (event 4) did not affect on the number of routes between Kyushu and the Eastern Japan (from Hokkaido to Hokuriku). While the increase of Eastern Japan lines from Chubu International (event 12) gave positive effects on the route availability between Tokai region to Eastern Japan, but not the case for Western regions. In

Table 3 Average number of available routes from Hachinohe zone

Average No. of Routes		Kinki	Chugoku	Shikoku	Kyushu
Hachinohe	1995	8.1	10.3	10.9	8.0
	2005	10.9	18.8	15.8	16.3
Increase (2005-1995)		2.8	8.6	4.9	8.4
Change Rate(%) (05-95)/95		34%	84%	44%	105%

Table 4 Service levels of air lines at Hachinohe zone

Airport	Year	Misawa	Aomori	Sendai
Access time (min)	1995	45	108	159
	2005	55	99	120
Frequency to Osaka (Itami)	1995	1	2	7
	2005	1	2	13
Frequency to Kansai	1995	0	1+4/7	2
	2005	0	1	0
Frequency to Fukuoka	1995	0	3/7	2
	2005	0	4/7	5
Frequency to other West Japan (Hiroshima,Okayama,Takamatsu)	1995	0	0	2 (3cities)
	2005	0	0	3 (3cities)
Number of daily users	1995	66529	96276	14620
	2005	53885	51445	18114
(increase)	05-95	-12644	-44831	3494

Note: 3/7 means 3 times per week

all, we can conclude that there are not strong positive effects of airport openings on the inter-city route availability.

2.4.2 Effect of Air link Service Change

Table 2 shows a remarkable increase of travel routes from the Hokkaido area. This result is because of the opening of eight air links inside the Hokkaido region, especially the air services from Hakodate Airport which yield new air connection routes from other regions.

In the Hokuriku region, the number of available routes to other regions has decreased, despite the opening of the Noto Airport (Ishikawa)(event 9). This is the result of the abandonment of the flight service between Toyama and Nagoya, which concurrently occurred in the same decade. The opening of the Akashi Strait Bridge connecting the Kinki region and the Shikoku Island in 1999 (event 2) encouraged new frequent express bus services which resulted in the abandonment of the competing air service between Itami (Osaka) – Tokushima, Itami – Takamatsu (Kagawa), Kansai – Takamatsu, Kansai – Kochi, and Nagoya – Takamatsu. The failure of commuter air service between Hiroshima and Matsuyama (Ehime) also affected negatively on the route availability between Shikoku and other Chugoku, Kinki, Kanto regions.

We should mention that the domestic hub role of Kansai International Airport was strongly decreased due to the wide abandonment of air service for Tohoku, Chugoku and Kyushu

airports, as well as Shikoku airports.

2.4.3 Effect of Openings of Shinkansen

Although the opening of the Shinkansen service may cause the abandonment of competing air services (such as Akita – Itami in 2003) in the middle run, we can detect a positive effect on the number of available routes by the calculation in this section, excluding the positive effect on alternate rail routes. Faster Shinkansen service accessing to alternative airports in different areas, which sometimes have more air lines than the local airport, increased the number of available travel routes.

We can show examples of this effect in all new Shinkansen lines. The most particular one is the Hachinohe zone connected by the Tohoku Shinkansen expansion (event 8). New multi-modal routes are added by using Sendai airport for 120 minutes of access time, rather than 159 minutes before. Table 3 shows the remarkable increase in the average number of the available routes for OD pairs from the Hachinohe zone to zones in the Western Japan regions. This increase of routes is a result of the Shinkansen access improvement to Sendai, Fukushika and Haneda airports, in addition to the traditionally used local airports such as Misawa, Aomori and Hanamaki, through the Shinkansen service. The difference in frequencies for those airports is shown in table 4. The number of routes using Sendai airport increased from 35 to 227, that using Fukushima airport from 0 to 65, and that using Haneda airport from 0 to 47. We will analyze the service level change more precisely in the next section.

In addition, the Nagono Shinkansen (event 5) provides new routes including Haneda Airport to Nagano and Ueda zones. The Kyushu Shinkansen (event 11) provides accessibility of Kumamoto and Fukuoka Airports to Kagoshima and Sendai zone, as well as accessibility of Kagoshima Airport to Kumamoto zone, mutually. Those multi-modal effects are reflected in table 2.

3. CHANGE OF THE SERVICE LEVELS OF TRAVEL ROUTES

3.1 Estimation of the Service Levels for each Available Route

In this section, the change of the service levels for the available routes from the Hachinohe zone to zones in Western Japan, are examined in more detail. To accomplish this objective, we first estimate several practical service levels under the user's point of view, based on the attributes data of each link in year of 1995 and 2005.

3.1.1 Estimation of Route Distance and Nominal Time

Route distance ($D^k{}_{od}$) and nominal travel time ($T^k{}_{od}$) are simply calculated as a sum of physical distance and travel time of the links included in the route.

3.1.2 Estimation of Monetary Cost

Monetary cost of route ($C^k{}_{od}$) is estimated by the summation of the cost of air and access ($CA^k{}_{od}$) and the cost of railway ($CR^k{}_{od}$). The former is given simply as the summation of link fare. On the other hand, the latter railway cost is estimated by the following manner, in order to consider the difference of express fare related to the travel speed, and non-linearity to the travel distance. Firstly, railway distance ($DR^k{}_{od}$) and railway nominal travel time ($TR^k{}_{od}$), then nominal railway speed is calculated.

$$vR^k{}_{od} = DR^k{}_{od} / TR^k{}_{od} \times 60 \tag{1}$$

Based on the nominal speed, we select one of the following formulas originally estimated by statistical analysis, in order to describe the express fare,

$$F1_{ex} = 3.46DR^k{}_{od} + 972.37, \quad (\delta 1 = 1 : vR^k{}_{od} \le 120), \tag{2}$$

$$F2_{ex} = 5.70DR^k{}_{od} + 1971.0, \quad (\delta 2 = 1 : 120 < vR^k{}_{od} \le 170), \tag{3}$$

$$F3_{ex} = 6.49DR^k{}_{od} + 2528.5, \quad (\delta 3 = 1 : 170 < vR^k{}_{od}). \tag{4}$$

On the other hand, normal nonlinear railway fare of JR can be well estimated by the following quadratic function.

$$F_n = 58.47 + 16.49DR^k{}_{od} - 0.0043(DR^k{}_{od})^2 \tag{5}$$

As a result, monetary cost of railway in a route is given as follows.

$$CR^k{}_{od} = F_n + \delta 1F1_{ex} + \delta 2F2_{ex} + \delta 3F3_{ex} \tag{6}$$

3.1.3 Estimation of Effective Frequency

In our earlier papers (Tsukai and Okumura, 2003; 2005), we gave the minimum value of daily link frequencies included in the route as the daily route frequency, but that method clearly overestimates the effective frequency, because it neglects the time passage. Tsukai and Okumura (2006) proposed a more precise procedure to follow the time passage based on the link frequencies per every three hours. The present study takes that procedure into account to utilize hourly link frequency data.

The procedure is based on the idea that a traveler's trip schedule must be selected from the available trains or flights. At first we assume in each link, trains (flights) are set with the same interval time in each hour. If the hourly frequency of an hour beginning h o'clock is f_h, the i-th train (flight) is assumed to depart at the node at $(2i-1)/2f^h \times 60$ minutes after h o'clock. Secondly, we begin the simulation of the time passage at the origin node, and select one starting train (flight) of the first link. We add the link nominal travel time and proceed to the following node, until we meet the different train (flight) name in the following link. If we meet a different name, waiting time before the transfer is considered. We select the earliest departure time of the next link no earlier than the arrival time of the node. When the simulation reaches the destination node, the arrival time of that starting time is determined. Thirdly, such a calculation is repeated for each of the all trains (flights) at the first link departing from the origin node. If the calculated time exceeds 24:00, that starting time is judged as unreachable. If the arrival becomes the same time with that of the later starting train (flight), such schedule is considered to be ineffective.

Table 5 Service level comparison over the representative routes

		1995				2005				Change (2005-1995)			
		Rail	Air	M.M.	M.M.-Air	Rail	Air	M.M.	M.M.-Air	Rail	Air	M.M.	M.M.-Air
Kinki	Distance (km)	1195	1098	1077	-21	1206	1115	1029	-85	12	17	-48	-64
	Nominal Travel Time (min.)	449	216	278	62	365	224	261	37	-85	9	-17	-25
	Monetary Cost (yen)	22519	36670	37115	445	23895	41670	40813	-856	1376	5000	3699	-1301
	Effective Frequency	7.55	1.09	1.95	0.87	9.23	1.18	7.93	6.75	1.68	0.09	5.98	5.89
22	No. of Reacheable zones	22	21	22	1	22	21	22	1	0	0	0	0
zones	EAT at destination (min)	15:27	17:05	15:44	-81	13:39	17:03	12:02	-301	-108	-1	-221	-220
	LDT at destination (min)	13:43	13:13	14:14	60	16:25	13:46	16:15	149	162	32	121	88
	EAT at Hachinohe (min)	15:29	15:23	15:00	-22	12:58	14:54	12:44	-131	-151	-29	-137	-108
	LDT at Hachinohe (min)	14:18	11:38	12:44	66	16:35	11:01	17:32	391	137	-37	288	325
	Zones of positive MSD	10	1.5	8	6.5	19.5	1.5	19.5	18.0	10	0	11.5	12
	Average of positive MSD (min)	38	135	82		231	165	330					
Chugoku	Distance (km)	1585	1317	1468	151	1586	1321	1302	-19	1	5	-165	-170
	Nominal Travel Time (min.)	566	243	281	38	473	252	304	52	-94	9	23	14
	Monetary Cost (yen)	27079	46970	50389	3419	28155	55467	51160	-4307	1076	8497	770	-7727
	Effective Frequency	3.99	1.33	1.97	0.64	6.37	1.41	5.47	4.06	2.37	0.08	3.50	3.42
19	No. of Reacheable zones	17.5	17.5	19	1.5	19	17	19	2	2	-0.5	0	0.5
zones	EAT at destination (min)	18:07	16:34	16:06	-28	16:08	15:53	12:56	-178	-118	-41	-190	-149
	LDT at destination (min)	11:44	13:20	13:09	-11	13:56	12:47	14:23	97	133	-33	74	107
	EAT at Hachinohe (min)	18:04	15:37	16:11	34	15:34	14:37	14:19	-18	-150	-60	-112	-52
	LDT at Hachinohe (min)	11:33	11:01	12:07	65	14:39	11:57	15:59	242	185	56	233	177
	Zones of positive MSD	0	1	1	0	6	0.5	12.5	12.0	6	0	12.0	12
	Average of positive MSD (min)		20	11		128	62	226					
Shikoku	Distance (km)	1537	1216	1326	110	1548	1241	1243	2	11	25	-83	-108
	Nominal Travel Time (min.)	595	242	305	63	510	256	311	55	-85	15	7	-8
	Monetary Cost (yen)	26075	42143	47516	5374	27566	50893	48864	-2029	1492	8750	1348	-7402
	Effective Frequency	3.96	1.00	1.79	0.79	6.04	1.36	5.89	4.54	2.07	0.36	4.11	3.75
14	No. of Reacheable zones	14	14	14	0	14	14	14	0	0	0	0	0
zones	EAT at destination (min)	18:31	19:52	17:51	-120	16:29	17:36	13:29	-248	-122	-135	-263	-127
	LDT at destination (min)	10:42	13:39	13:58	20	13:36	13:11	15:04	113	174	-27	65	93
	EAT at Hachinohe (min)	18:09	14:54	15:32	38	15:40	14:22	13:47	-35	-149	-32	-105	-73
	LDT at Hachinohe (min)	11:11	8:32	10:39	127	13:54	10:25	16:10	346	163	113	332	219
	Zones of positive MSD	0	0	2	0	3.5	0.5	11	10.5	4	1	9.0	11
	Average of positive MSD (min)			78		47	48	169					
Kyushu	Distance (km)	1953	1513	1633	120	1963	1551	1539	-12	11	38	-94	-132
	Nominal Travel Time (min.)	706	277	334	57	597	285	339	54	-109	8	5	-3
	Monetary Cost (yen)	29994	48245	52490	4246	30888	56266	55138	-1128	894	8022	2648	-5374
	Effective Frequency	3.14	0.78	1.36	0.58	4.61	0.75	4.75	4.00	1.47	-0.03	3.39	3.43
26	No. of Reacheable zones	22.5	23	23.5	0.5	25.5	22.5	26	3.5	3	-0.5	2.5	3
zones	EAT at destination (min)	18:58	19:52	17:32	-140	17:41	19:43	14:13	-330	-77	-9	-199	-190
	LDT at destination (min)	10:18	13:38	11:57	-101	12:01	13:21	14:24	63	103	-17	147	164
	EAT at Hachinohe (min)	19:33	14:52	15:55	63	17:25	14:21	14:33	12	-128	-31	-82	-51
	LDT at Hachinohe (min)	10:20	8:55	10:12	77	12:19	7:42	15:15	453	119	-73	303	376
	Zones of positive MSD	0	0	1	1.0	2	0	16.5	16.5	2	0	15.5	16
	Average of positive MSD (min)			64		30		153					

In this way, we can count the number of reachable and effective starting time at the origin node for the given travel route. If the result numbers for each direction are different, we define the average of those two values as the effective frequency of that travel route.

3.1.4 Earliest Arrival Time, Latest Departure Time to Return, and Maximum Stay Duration

Through the above procedure of effective frequency calculation, we can get the earliest arrival time at the destination under the condition that we can start at the origin no earlier than 6:00. Similarly, we can determine the latest time of departure of return trip at the destination node, in order to arrive back at the origin node no later than 24:00. Those two values are used for the earliest arrival time (EAT) and the latest departure time to return (LDT), and the interval between them gives the maximum stay duration at the destination (MSD). Those three indices are direction dependent. Then we use the directional average of those values for evaluation.

3.2 Service Level Comparison over the Representative Route of the Different Mode

3.2.1 Definition of the Representative Route of the Different Mode

In order to assess the role of railways and air for the route service level, we compare the three different type of mode, with each other; air, rail and multi-modal. Comparison will be done over the representative route from each category. The railway route is uniquely calculated in this research as mentioned in section 2.2.

At first, we determine the nearest airport from the origin node and that from the destination node. Air routes are defined as the available routes that use one or more air links connecting between the nearest airports. Furthermore, those air routes are represented by the route having the shortest nominal travel time. Multi-modal routes are defined as the available routes that use air link, but either of the nearest airports is not used. In other words, this type includes middle distance railway access, as well as an air link. Furthermore, we select a representative one in this category based on the effective frequency.

3.2.2 Service Level Comparison

Comparison of service level indices over the representative routes is summarized in table 5. Both in 1995 and 2005, the difference of travel distance and nominal travel time is similar for air routes and multi-modal routes, while they are much shorter than those for the railway route. On the other hand, the monetary cost shows the opposite order: the railway route is much cheaper than the other two including the more expensive air service. In 1995, the cost of an air route is slightly cheaper than that of a multi-modal, but that is not the case in 2005. Rail routes have superiority of effective frequency over multi-modal routes in both years, with the exception of Kyushu in 2005, while air routes are always lag behind, in terms of effective frequency.

In table 5, EAT and LDT indices are shown for each direction for the travel from Hachinohe to Western Japan, or in the opposite direction. Although the nominal travel time of air routes are short, EAT at the Kinki, Shikoku and Kyushu destinations of air route are not earlier than that of the rail route, as well as the multi-modal route. On the other hand, EAT at Hachinohe of an air route is comparable to that of a multi-modal route, and much earlier than that of a rail route. This difference comes from the flight schedule on the Misawa airport without night stays, where the first flight departure is late in the morning. The very low frequency of Misawa airport also makes that the LDT of an air route at Hachinohe as early as 8:00 in the morning. As a result, the air route cannot take its fast speed advantage and fails to provide a positive MSD for most of the zones in Western Japan.

On the contrary, the multi-modal routes take much advantage of high frequencies and provide much earlier EAT and later LDT than air routes in many cases, especially in 2005. As a result, the multi-modal routes successfully provide positive MSD in many destinations, while both air and rail almost fails for the zones in Chugoku, Shikoku and Kyushu regions.

3.3 Decadal Difference of the Service Levels

3.3.1 Change of Railway Route Service

Introduction of rapid and frequent service of the Shinkansen has given the multiple positive effects on the service levels of the railway routes. The 37 minutes reduction of link travel time between Hachinohe and Morioka (see table 1) is reinforced with other railway speed up projects to provide 85 through 109 minutes reduction of the nominal travel time to Western Japan. The effective frequencies were improved around 1.5 in Kyushu, and 2.4 in Chugoku. These combinational changes yielded the EAT more than two hours earlier than before, and the LDT two or three hours later. Such remarkable improvement in terms of the time dimension resulted in the increase of the zones that have positive MSD in 2005. Because we indirectly estimate the railway cost based on a regression formula, the speed improvement is concurrent with the cost increase. But the change of the cost does not seem serious: it is as small as 6 percent change.

3.3.2 Change of Air Route Service

The service level of air routes did not improve very much, although the airfare was raised from 5,000 to 9,000 yen in the decade. There were not large effects from either improvement of Western lines from Chubu or decline of lines from Kansai, because both in 1995 and 2005, no air service was provided either from Misawa or Aomori airport. As a result, the number of zones reachable in a day and that of positive MSD was not augmented.

3.3.3 Change of Multi-modal Route Service

Multi-modal routes improved considerably, owing to the usability of several airports of more frequent service. Because the length of the air way in route distance is not so long, and limited on the trunk lines where air carrier was reluctant to raise the airfare considering the fierce competition to Shinkansen service, the increase of the monetary cost was suppressed as small as 3,700 yen at most. Large positive impacts are certified in all destination regions: effective frequency increased between 3.4 to 6.0 per day, EAT became earlier for 82 to 260 minutes, LDT got later for one to three hours, and the remarkable increase of the zones of positive MSD.

It is very important that those service improvements in multi-modal routes are usually larger than that in railway routes. We can say that the impact of the Shinkansen expansion was propagated with multi-modality. The far right column of table 5 shows that the superiority of multi-modal routes to the air routes were remarkably expanded in the decades. It implies that we must pay much attention to multi-modal connectivity in the nation-wide inter-city transportation planning.

3.4. Evidence in the Passenger Behavior

Improvement of multi-modal routes including air link from Sendai airport is widely accepted by the users, and resulted in the increase of such routes in 2005. Evidence of this is the increase of Sendai airport users in the travelers between Hachinohe and zones in Western Japan region, already shown in table 4, with a remarkable contract to the decrease of users of Misawa and Aomori airports. Figure 2 also shows another evidence: the weekday users of Sendai airport remarkably increased in the zones including the expanded Shinkansen, such as the Hachinohe zone, between 2000 and 2005.

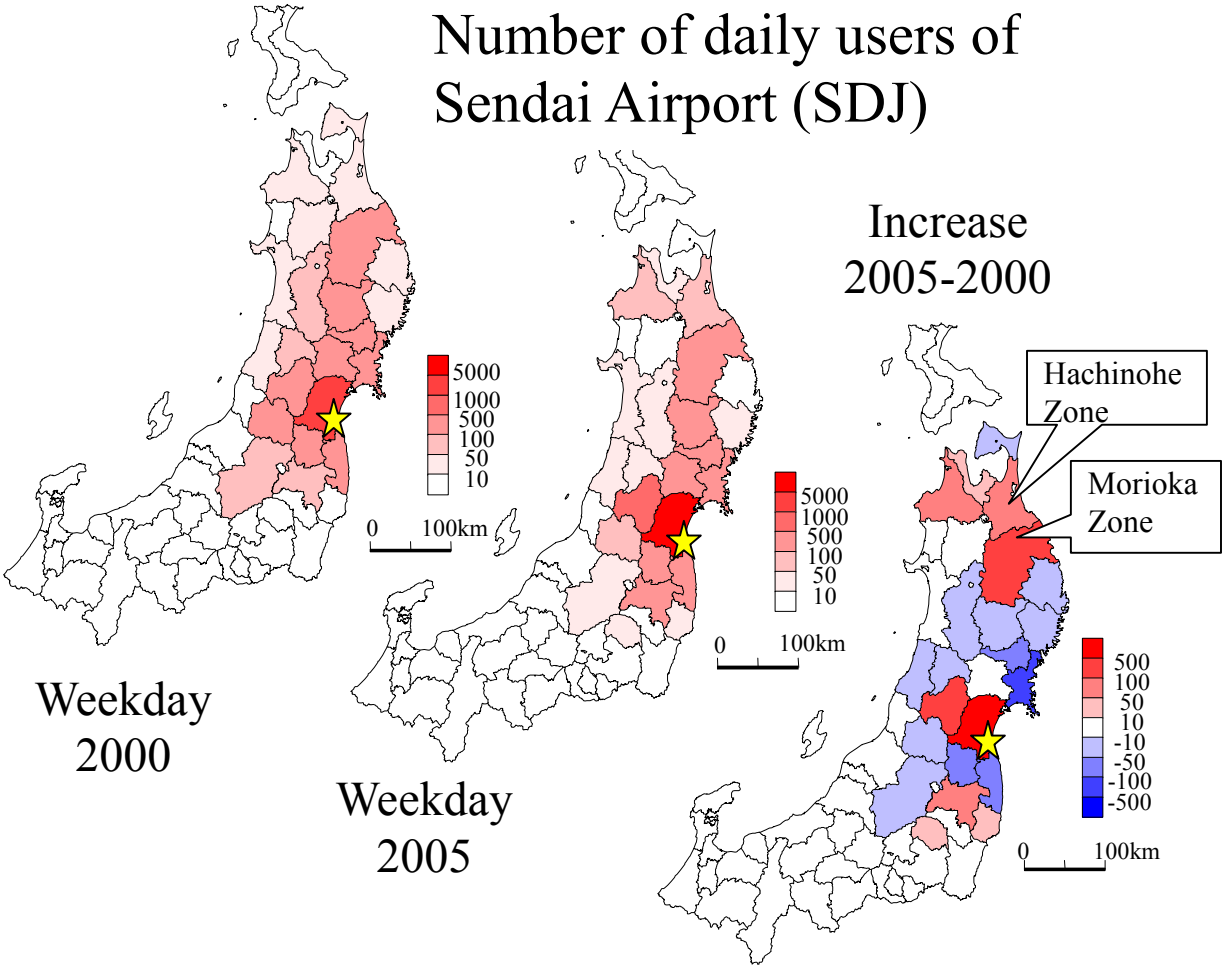

Figure 2 Trip-end Distribution of the Flights at Sendai Airport (2000 and 2005)

4. CONCLUSION

In an inter-city network already constructed to certain degree of density, as in Japan, an improved link can be used connectively with other links, sometimes to a different transportation mode. For example, a newly constructed Shinkansen line can be used as middle-distance access to a local airport, and the route shift that occurs supports the air link departing at the local airport. As a result, the improvement effects are propagated in a wide, and multi-modal, way. This paper has shown quantitatively how such propagation actually occurred in Japan between 1995 and 2005. The k-th shortest path search algorithm was applied to find the set of inter-city trip routes. Remarkable changes due to the Tohoku Shinkansen expansion up to Hachinohe City in 2002 were found. This paper also analyzed the change of the service level of the air, multi-modal, and rail routes from the Hachinohe zone to other zones in Western Japan, and indicated the strong multi-modal propagations of this Shinkansen expansion on the air links at Sendai airport, proved by the increase of Sendai Airport users from the neighbor of the expanded Shinkansen line.

The most important implication of this study on transportation infrastructure planning is the need of comprehensive multi-modal planning. Historically, airway have been frequently

considered as a competitive mode for railway and the substitution effects between those two modes had been gathered attentions in the planning of each mode. This study, however, shows the possibility of complementally mixture of these two different modes. Railway service can collect demands distributed thinly along the line, then can be used as a demand collector to air service from a regional airport. On the other hand, a regional airport located at the far end of a Shinkansen railway line can be used as a demand collector for the Shinkansen line to support enough frequency in the far end part of the railway network. Railway demand usually goes down along the distance from the National Capital (Tokyo in Japan), but train capacity cannot easily be decreased accordingly. Cut of train frequency cut in that portion would be harmful for the service level and result in the lost of users. Then the attractive power of regional airport at far end become helpful for affordable service. This study teaches the importance of such complementally use of the modes in transportation planning.

The methodology explained in this paper has important applications in national transportation policy formulation. In Japan, air carriers are thinking about the most appropriate service-shrinking strategy for rural airports, whilst, at the same time, they are seeking more competitive power on the trunk lines connecting the densely populated metropolitan areas. As a result, the transportation service levels for the passengers from the rural areas are not secure in the future. They will have to rely more on multi-modal routes than they do today. Thus, improvement to rail-air connectivity in rural areas may become more and more critical, and the methodology applied in this paper will be of considerable practical importance.

The future research issues to address include: the behavioral analysis on the route choice set of inter-city travelers; and the building of model describing the attributes of routes included in the choice set. Realistic policy evaluation of the proposed government projects and operational projects, such as timetable coordination and physical transfer shortening, will also be undertaken.

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