

AIR-RAIL INTER-MODAL NETWORK DESIGN UNDER HUB CAPACITY CONSTRAINT

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Abstract: Recently, while building or expanding of a large hub airport becomes controversial in economic, social and environmental facets, the idea of inter-modal substitution of short-haul air spokes by high-speed trains (HST) becomes a realistic option. This paper aims to analyze what shape of inter-modal network is efficient, and how beneficial it would be on passengers. Genetic Algorithm is applied to find the best mixture of Haneda Airport's operation capacity allocation to domestic destinations and the spatial configuration of HST network, maximizing the consumer surplus of Japanese domestic inter-city passengers. The result of our analysis shows that HST service of 2400 km as provided in 2000 is essential for keep mobility, and that operation capacity shortage problem at Haneda is solved by additional HST service. The shape of optimal HST network becomes different according to the change of the operation capacity of Haneda.

Key Words: *Network Design, Inter-modality, Genetic Algorithm*

1. INTRODUCTION

This paper focuses on domestic passenger air transportation in Japan. As shown by Feldhoff (2002) Japanese airport development projects had been concentrated on local airports and resulted in eight-fold magnification of domestic air passengers in 30 years after 1970. Reflecting the long insular geography and economic activity concentration, more than half of the domestic passengers concentrate to Tokyo Metropolis. Therefore, the shortage in operation capacity of Haneda Airport (HND) became serious problem even international flights are allocated to Narita Airport. Due to the completion of the new parallel runway in 1997, daily operation capacity (6:00 to 23:00, excluding inconvenient direction of early morning and late night) was increased from 450 to 620, followed by the continual improvements up to 812 by 2004, when 702 of them were already used. In 2000, the Ministry of Land, Infrastructure and Transport (MLIT) decided to build a new runway with reclamation, and that construction work began in 2006. After the completion of it in 2009, increased capacity (40% more than the present) will be reallocated.

This reallocation of the operation capacity gathers attentions of people in peripheral areas where the preferred number of flights to HND could not be realized due to the capacity shortage in HND. But people in Tokyo area foster a different dream for the new coming capacity. Comparing with other capital cities of East Asian countries where new international hub airport has been just opened, the people in Tokyo feel inferiority in the race of international hub airport building, because of the distant location of Narita International

Airport (NRT) from downtown Tokyo. Therefore, they insist that the HND's new operation capacity should be used for international flights, rather for domestic flight routes from peripheral areas to Tokyo.

Now in Japan, frequent HST service is provided between Tokyo and other metropolises. For example, more than 80 fast trains run daily to Osaka for 150 minutes. Parallel to them, 55 flights (28 to Itami (ITM), 15 to Kansai (KIX) and 12 to Kobe (UKB)) are operated and consuming one fifth of the operation capacity in HND. Considering the environmental issue, HST substitution of relatively short distant flights seems valuable to be analyzed. In year 2000, we have 1313 km of full speed HST lines (average speed is over 160 km/h) including Tokaido Shinkansen between Tokyo and Osaka, and 1090 km of middle speed HST lines (average speed is 100 – 150 km/h). Moreover, several new HST lines are under construction or planned. Thus, there are several possibilities of air to rail substitution in Japan. As Hazemoto *et al.* (2003) shows, not a few passengers travel on inter-modal routes including the inter-city access by HST and the trunk airline flight, where direct flight service is not satisfactory. Then we should pay attention to such inter-modal (connective) use of air and middle-haul HST.

This paper aims to analyze what shape of inter-modal network is efficient, and how beneficial it would be on passengers under the several level of Haneda's operation capacity allocated to domestic flights. If HST service network is carefully laid out, inter-modal substitution and inter-modal complementary can strengthen the mobility for domestic passengers under even the small capacity. Even though our analysis is limited for Japanese domestic setting, air-rail inter-modality may gather interests in several East Asian countries, especially in China, Malaysia and Thailand, where domestic intercity trips are considered to exceed over the domestic air capacity, soon.

In the next chapter 2, related research papers are reviewed. In chapter 3, details of the network design model are shown. In chapter 4, calculated results are discussed, followed by the conclusion in chapter 5.

2. RELATED RESEARCH

2.1 Capacity Problem in Hub and Spoke Network in General

Hub and spoke network have been prevailed as an effective airline network structure, when airline wants to provide service for travelers of various OD pairs (Pels, *et al.*, 2000; Burghouwt and Hakfoort, 2001). The intensified international economic competition stimulated the notion of "global city" in many countries especially in Asia, and the international hub airport development near to their capital city became an important issue of national development (Feldhoff, 2002; Martin and Roman, 2003). The hub construction fever may, however, result in over allocation of development funds on the capital area and further expansion of regional disparity between capital metropolis and peripheral local cities. Recently, when enough larger demand for direct flights are exposed, low-cost carriers begin to serve direct flights, usually using a secondary less-congested airport, while full service carriers already having invested much to the primal hub airport. Therefore, the hub and spoke network structure can not be easily changed (Fujii, *et al.*, 1992; Raynolds-Feighan, 2001).

In order to minimize the required transfer time, arrival and departure time at a hub airport are

concentrated, so then many 'banks' are seen on flight timetable there. As a result, airport facilities, such as runway, taxiway, spots and landside facilities face strong temporal oscillation of occupancy, therefore capacity limit of the hub has been frequently criticized as a serious problem (Button, 2002). Discussion of congestion pricing in landing fee at congested airport is a historical issue and several papers have been published (e.g. Levine, 1969; Morrison, *et al.*, 1989; Daniel, 1995; Pels and Verhoef, 2004). Morrison (1983) and Brueckner (2002) analyzed the possibility of investment funding from the congestion fee. Reynolds-Feighan and Button (1999) discussed the congestion levels at European airports and even in major hubs, the temporal congestion can be leveled by economic measure; congestion pricing, then capacity expansion is not necessary. Through the several assessments of realized congestion pricing however (Barrett, *et al.*, 1994; Schank, 2005), it is not promising for flight schedule leveling, because of inelastic air-travel demand and hard institutive barriers.

Another possibility for effective use of the airport capacity is an optimized allocation of operation capacity (Starkie, 1998; Abeyrantne, 2000; Madas and Zografos, 2006). However, the existing studies are focused much on inter-firm competition issue (Balbot, 2004) but the passenger utility issue is not focused importantly.

2.2 Air-Rail Inter-modal Network Design

Recently, while building or expanding of a large hub airport becomes controversial in economic, social and environmental facets (e.g. Janic, 2003; May and Hill, 2006), the idea of inter-modal substitution of short-haul air spokes by HST becomes a realistic option. With reference of air-rail integration at Frankfurt, CDG in Paris and Schiphol in Amsterdam, Givoni and Banister (2006) suggested that HST can be used as short-haul feeder service at London Heathrow Airport. They assessed benefit and cost of new HST station and line, instead of No.6 Terminal Construction Project.

Similarly with Givoni and Banister (2006), this paper discusses air-rail inter-modal network formation from the viewpoint of passengers, but rather focuses on domestic transportation network in Japan. Besides the air-rail connection at the domestic hub, HND, we also consider the connection at local airports in order to provide mobility to the area where direct flight is not served. An optimal inter-modal network design problem is formulated as follows; under the given number of air departures at HND, and given length of nation-wide HST service lines, we find the allocation of flights to each destination and the spatial configuration of HST lines to maximize passenger's mobility which is calculated as total consumer surplus of intercity passengers over 300 km. Because this problem is nonlinear combinatorial problem, we take Genetic Algorithm (GA), most popular heuristic method (Tamura, *et al.*, 1993; Magnanti and Wong, 1994; Palmer and Kershenbaum, 1995).

Optimized network design will be calculated by the model for several combinations of the different level of HND operation capacity and total HST service line length. Firstly, through comparison of consumer surplus of each case, we assess the performance of the inter-modal policy; to what extent, HST service can substitute the air hub capacity, and how operation capacity can be released for international usage. Second, we see the spatial configurations of HST lines for different level of operation capacity in Haneda, and discuss the stability of HST network formation.

3. NETWORK DESIGN MODEL

3.1 Problem Setting

The target network in this study is limited in domestic Japan. The nodes on the network are set for all the airports and important railway stations on Japan Railway network, and the links are set for all the domestic flights with over once-a-day frequency, access paths between railway station and airport, and railway links with different speed standards. The network design model here tries to find simultaneously the optimal combination of two elements, flight frequencies to other destination airports from HND, and railway track standards deciding the train operation speed.

We consider re-allocation of operation capacity of HND over the destination airports, where regular flights are actually operated in year 2000. Under our zone system of prefectures, we cannot analyze the effects of eight local airports in Hokkaido Prefecture, except Chitose (CTS), then the frequency of the 8 lines from HND are fixed and excluded from our design variables. HND-Okinawa(OKA) line is also fixed because of no possibility of railway substitution, then 28 airports are considered as possible destinations from HND. Furthermore, we exclude local flights between local airports besides HND (143 routes) from our design variable; they are also kept with the same frequency as year 2000, which are possibly used as feeder service. All the fare and travel time on each of 180 air link including local airport to HND line are kept constant.

In order to concentrate our discussion on HST configuration, we only control the speed level of the 275 JR railway links actually operated in year 2000. Both train frequency and length of each link j are kept constant. As to keep the design variable space small, we describe the speed of railway link by the four discrete categories, S_j , related to the rail track standards; rank 1 is full standard gage Shinkansen; rank 2 is “Mini-Shinkansen” of standard gage but steeper curvature and inclines; rank 3 is electrified conventional narrow gage line; and rank 4 means un-electrified conventional narrow gage line. Among these categories, the first and second ranks are referred as HST. According to the actual operation speed of railway links, operation speed for each of the four categories are set as follows; rank 1: 178 km/h; rank 2: 118 km/h; rank 3: 74 km/h and rank 4: 48 km/h, respectively. Design variables are therefore, the number of daily one-way flights F_i operated between HND and local airport i , and the operation speed rank S_j on each railway link j . The designed network is evaluated from the passenger's viewpoint; consumer surplus for the nation-wide inter-city passengers.

3.2 Consumer Surplus Measurement

For the evaluation of alternative network design, we employ the total consumer surplus of the nation-wide inter-city passengers over 300 km. 46 Prefectures besides Okinawa are used as analytical zones, then 841 pairs over 300 km out of 1035 are considered. For each alternative network, through the demand estimation of OD pairs, total consumer surplus is calculated by the following equation (Hazemoto *et al.* 2003),

$$H = \sum_{OD} \frac{1}{\phi \beta_{GC}} (T_{OD}^{NW1} - T_{OD}^{NW0}), \quad (1)$$

where, T_{OD}^{NW1} : the estimated number of travels for the alternative network, T_{OD}^{NW0} : the actual number of travels surveyed in 2000, ϕ, β_{GC} : parameters (to be appeared afterwards).

The population of the cities and the service level influences trips among the cities for the OD. The following gravity type model describes such causation. The parameters of the model were statistically estimated using the number of railroad passengers, extracted from the Net Passenger Travel Survey in 2000.

$$T_{OD}^{NW} = \Lambda(N_1)^\alpha (N_2)^\beta (LOS_{OD})^\gamma, \quad (2)$$

where, N_1, N_2 : population of the two cities ($N_1 > N_2$) (10000 inhabitants), LOS_{OD} : service level between the two cities, $\Lambda, \alpha, \beta, \gamma$: parameters to be estimated using the survey data. Based on the previous study, value of the parameters are estimated as follows; $\Lambda=1.127$, $\alpha=1.29$, $\beta=1.14$, $\gamma=1.52$ (Hazemoto *et al.* 2003).

The service level between the two cities is synthetically described by the following “log-sum” utility of the three available routes for the OD pair.

$$LOS_{OD} = \sum_m \exp(V_{OD}^m), \quad (3)$$

where, V_{OD}^m is systematic utility level of the alternate route m for the OD. Here, we build a route choice model of the inter-city passengers. For every OD, we consider the tri-nominal choice among a shortest time rail route and two inter-modal routes by a logit model. The systematic utility of each route is calculated by the following function of the generalized travel cost and the dummy variables for inter-modal routes.

$$V_m = \beta_{GC} GC_m + \beta_{m1} c_{m1} + \beta_{m2} c_{m2}, \quad (4)$$

where, GC_m : generalized travel cost of route m (10000 yen), c_{m1}, c_{m2} : dummy constant for the first and second shortest inter-modal route, $\beta_{GC}, \beta_{m1}, \beta_{m2}$: parameters to be estimated. These parameters were also statistically estimated using the 8622 samples of the survey data, as follows; $\beta_{GC}=-0.16$, $\beta_{m1}=-0.12$, $\beta_{m2}=-1.62$.

In order to get the generalized travel cost GC_m from the fare C_m and travel time T_m , the time value is considered to be 3000 yen/hour. Further, the rail-fare is considered to reflect the difference of the provided train speed.

$$GC_m = C_m + 0.3T_m, \quad (5)$$

where, C_m : fare of route m (10000 yen), T_m : travel time of route m (hour). Travel time is given as the summation of link travel time, average waiting time and additional transfer time.

$$T_m = \sum_{i \in m} t_i + \sum_{j \in m} \frac{d_j}{S_j} + \sum_{k \in m} ta_k + w_m + s_m, \quad (6)$$

where, t_i : exogenously given flight time of airline link i (hour), but 40 minutes is added for boarding and embarking time, d_j : length of rail link j (km), S_j : operation speed of railway link j , ta_k : exogenously given travel time of airport access link k from the nearest railway node (hour), w_m : average waiting time (hour) along route m , explained afterwards, and s_m : additional transfer time for standard gage train and narrow gage, 10 minutes is added if only

one of conjunctive links is HST (rank 1 or 2) and the other is conventional speed (rank 3 or 4).

The waiting time actually depends on the number of flights or trains that go through the route from origin to the destination city. Passengers can also use two or more trains if their timetable is well coordinated for changing. However, the calculation of the exact waiting time for all OD based on a complete timetable in domestic flights and trains requires huge amount of data. We do not use complete timetable to obtain waiting time considering data availability. Instead, the number of trains or flights operated on each link is used to calculate approximated waiting time since waiting time depends on the frequency of each link along the route. Therefore, in our analysis, we firstly find the least frequent link within 18 hours from 6 to 24 o'clock along the route in consideration, and set it as a representative frequency on that route in order to consider the largest transfer inconvenience. It may be small if the route includes less frequent air service, and partly describes the gap of time schedule between air and rail system. The approximated waiting time w_m is calculated as expected waiting time for the representative frequency of route m .

$$w_m = \frac{1}{2} \frac{18}{F_m}, \quad (7)$$

where, F_m : number of the trains or flights per day on the least frequent link along the route m . Once, control variables F_i and S_j are given, w_m and F_m are re-calculated through eq.(7). Combined with other exogenous variables such as flight time, fares, frequency of railway links, time and fare for airport access links, we can calculate the OD demand and consumer surplus inversely through eq.(1)-(6). Furthermore, number of air route passengers can be calculated as follows;

$$X_m^{OD} = T_{OD}^{NW} \frac{\exp(V_m)}{\sum_{m' \in OD} \exp(V_{m'})}, \quad (8)$$

$$XX_i = \sum_{OD} \delta_{im} X_m^{OD}, \quad (9)$$

where, X_m^{OD} : passenger flow of given OD through route m , δ_{im} : dummy variable indicating whether route m include link i or not, XX_i : expected number of passengers at link i .

Different from the flexible capacity of trains, sheets availability of aircraft is strictly determined. On the other hand, through the demand forecasting process showed here may possibly give the number larger than the provided seats. In order to avoid this inconsistency, required flight frequency FF_i is calculated as follows, and replace it to the firstly set frequency, F_i .

$$FF_i = \sum_{i'} F_{i'} \frac{\max(F_i, (XX_i / xx))}{\sum_{i'} \max(F_{i'}, (XX_{i'} / xx))}, \quad (10)$$

where, xx : average number of seats in a aircraft, here, we set $xx = 300$, reflecting that middle or large size aircrafts are used for HND line to secure maximum number of seats under the limited operation capacity. Ideally, adjustment by eq.(10) should be repeated until the difference between FF_i and F_i become negligible, but such iterations are very harmful to GA calculation time. Here, we repeat this adjustment five times.

Table 1 Case setting of HST line length constraints

cases	0.6(1442km)	0.8(1992km)	1.0(2403km)	1.2(2884km)	1.4(3364km)
Rank 1(km)	788	1050	1313	1576	1838
Rank 2(km)	654	872	1090	1308	1526
Rank 3(km)	8320	8058	7795	7532	7270
Rank 4(km)	7424	7206	6988	6770	6552

3.3 Definition of the gene and constraints

In our GA procedure, we use the chromosome composed of two parts. The former half of it contains the arrangement of gene specifying the HND capacity distribution over destinations, while the latter half contains gene for speed rank of each railway link. We use 5-bit code gene (meaning a value between 1 through 32) in order to indicate relative allocation of HND operation capacity for each of 28 destinations. As the gene showing speed level of railway service, we use 2-bit code specifying the four ranks, “178, 118, 74, 48 (km/h)” which are each average speed of “Shinkansen, mini Shinkansen, electrified conventional lines, un-electrified conventional lines.”

Alternative network design must satisfy two constraints; total domestic operation capacity of HND (number of one way flights except 8 Hokkaido local airports and Okinawa) and total length for each speed rank railway. As the benchmark case, we set those values based on the actual network in year 2000; $\sum F_i = 250$, and total distance of railway links of each speed rank are given as 1313, 1090, 7745 and 6988 (km), respectively. With proportion to the gene for HND capacity allocation, total flights are assigned for each destination. In order to determine the railway speed rank, firstly all links are sorted by the gene value from higher to lower and then operation speed for each link is determined following by the sorted order; when the total distance limit is consumed up, then slower rank will be successively assigned.

Outside the GA calculation process explained in 3.4, we set several different levels of those constraints. Total operation capacity in HND is also set as 200, 350, 450 and 550, besides the 250 as benchmark. HST line length is also shifted by multiplying 0.6, 0.8, 1.2 and 1.4 to the standard length of rank 1 and rank 2 lines; 1313 and 1090 km, respectively. In each case, increase (decrease) of rank 1 line is balanced by decrease (increase) of rank 3 line, and change of rank 2 is balanced by rank 4, as shown in **Table 1**.

3.4 Genetic Algorithm

Standard GA operations of selection, crossover and mutant processes are applied for the set of 50 individuals, which include 49 random chromosomes and one individual indicating the real HST network in year 2000 at initial situation. Despite the dual structure of the chromosomes, we apply a single point crossover operator and top five elite individuals are left without crossover operation in the successive cycle. By checking the improvement trajectory of the objective value of the best individuals along the operations, 10000 iterations seemed enough to get saturated value. Then we employ 20000 iterations in the optimization.

4. PERFORMANCE OF THE DESIGNED INTER-MODAL NETWORK

4.1 Possibility of inter-modal substitution

First, let us check the calculated consumer-surplus under different level of constraints, and

Table 2 Consumer surplus maximized in different constraints

HST length Capacity	0.6 0.6(1442km)	0.8 0.8(1922km)	1 1.0(2403km)	1.2 1.2(2884km)	1.4 1.4(3364km)
200	-51.5	0.0	26.2	35.8	49.5
250	-45.0	6.2	33.5	45.4	56.4
350	-17.8	26.7	40.3	53.3	66.0
450	8.7	39.1	50.8	59.3	73.9
550	17.7	45.1	50.8	61.0	76.5

(billion yen / year)

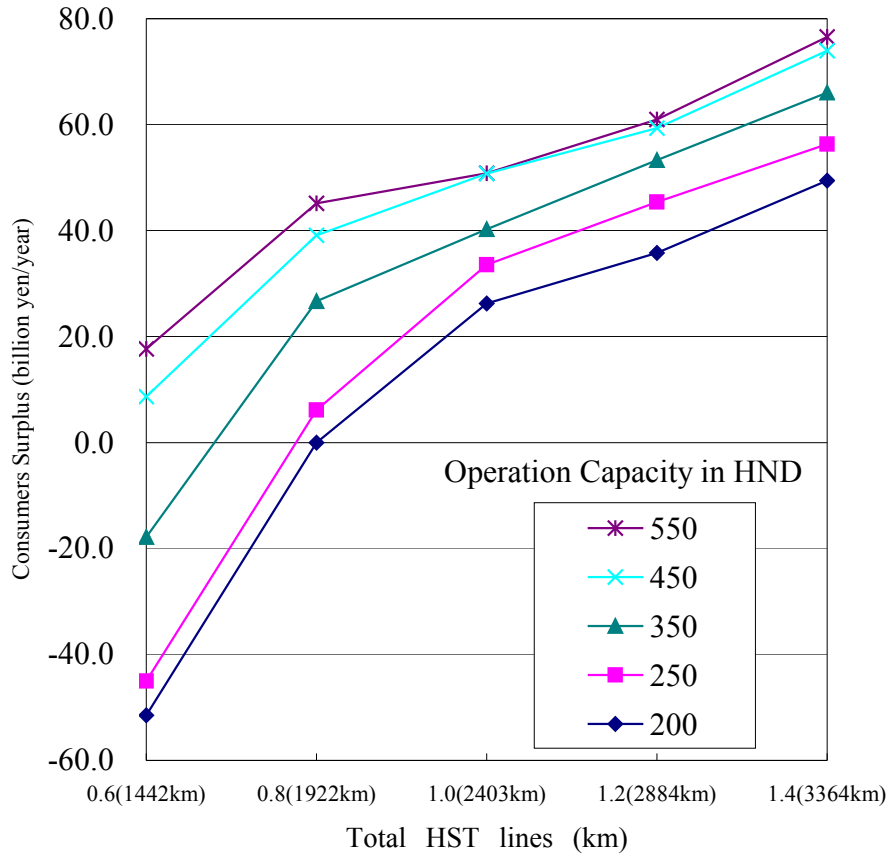


Figure 1 Consumer surplus maximized in different length of HST lines

discuss the possibility of HST substitution for HND operation capacity allocated for domestic flights. **Table 2** and **Figure 1** show the maximized value of the consumer surplus, which is measured relative to the actual service level in year 2000. First of all, we can say that the actual network configuration does not perfectly utilize resources, 33.5 billion yen/year inferior to the optimized network of the same resource level (the benchmark case indicated as 1.0(2403km)-250). If rearrangement of network were possible, the network with 80% length of HST and with 80% operation capacity in HND would be enough to achieve the same surplus (see case 0.8(1922km)-200). **Figure 2** compares the actual network configuration in year 2000 and the solution of the benchmark case. As the purple lines show, HST is consecutively laid from Tohoku to Kyushu Region via Sendai, Tokyo, Nagoya, Osaka and Hiroshima Metropolises by the optimization, just identical with the actual service. The optimization gives priority to several local fragmented links which can be used as short spoke to local airports, such as Chitose (CTS), Toyama (TOY), Izumo (IMO) and Kumamoto (KMJ), as shown by blue lines, instead of HST lines recently opened in Tohoku and Kanto

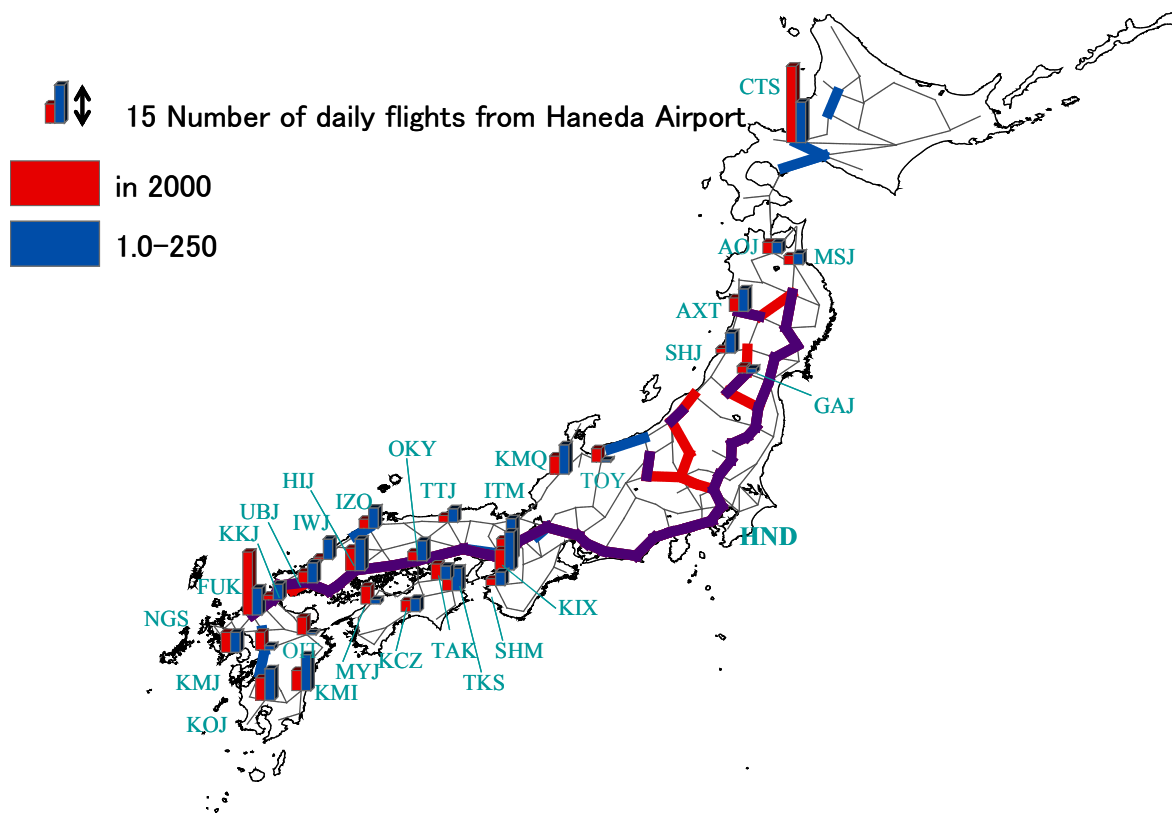


Figure 2 Comparison of actual and optimized network

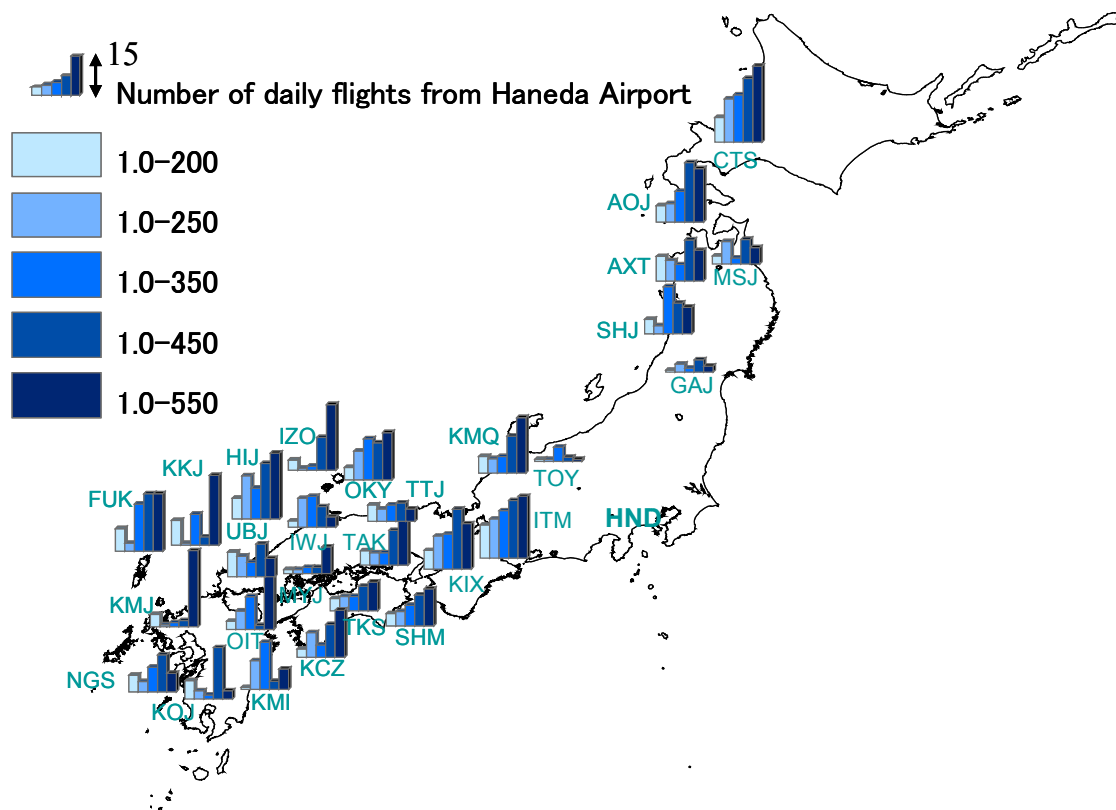


Figure 3 Daily HND flights to 28 destinations, under different capacity constraints in HND

Region. In the optimized solution of the benchmark case, flight capacity is reallocated from CTS and Fukuoka (FUK) to other local airports. According to the steep incline in left part of the graphs in **Figure 1**, HST length must be longer than 0.8 level (1922km), in order to keep the basic mobility. If domestic operation capacity is limited as many as 250, the present length of HST (2403km) must be provided. Secondly, the additional effect of HND operation capacity seem to be constant until it will exceed 450, because lower four graphs locates with similar intervals, but not the top graph.

Now we check the possibility of inter-modal substitution. Due to the on-going construction of the Runway D, capacity of HND is estimated to be 1.4 times larger. This means that, in year 2009 we can expect the situation as Case 1.0(2403km)-350, benefit of 6.8 (= 40.3 – 33.5) billion yen seems to be generated by the capacity-expanding project. That level of consumer surplus could be realized by adding new HST lines instead of the HND Project; about 300km of HST expansion would give the same level of surplus without any capacity increase.

If HST would become 1.2 times longer than that in year 2000, about 230 domestic operation capacity were sufficient to keep the mobility level, and the released operation capacity of 120 could be utilized for international use. Resulting from **Table 2** and **Figure 1**, we can say that HST substitution has a possibility to solve the hub capacity shortage problem.

4.2 Network Configuration Change Due to Various HND Capacity Constraints

Figure 3 shows the change of daily HND flights to 28 destinations, when operation capacity are expanded (Cases: 1.0(2403km)-200 to 1.0(2403km)-550). Naturally, many airports proportionally gain additional flights with the operation capacity increase, but the increase is not seen for some local airports. In Chugoku and Kyushu Region in Western Japan, while relatively large airports such as Okayama (OKY), Hiroshima (HIJ), IZO, FUK and KMJ gain additional flights, smaller airports such as Tottori (TTJ), Iwami (IWJ), Yamaguchi-Ube (UBJ), Nagasaki (NGS) and Miyazaki (KMI) loose flights. Flights at TOY also disappear while neighboring Komatsu (KMQ) gets additional flights. This phenomenon would be the result of increasing return to scale nature of the air travel demand. Once the frequency at larger airport increases, it results in shorter average waiting time, higher utility and larger demand, which enables further round of frequency increase. On the other hand, smaller airports loose their share, especially in Kyushu Region, where many airports are competing with short distance in between, increase of flights at one airport coincides with decrease of flights at neighbor airports. Such patterns can be found between NGS-KMJ, KMJ-Kagoshima (KOJ), KOJ-KMI and Kitakyushu (KKJ)-UBJ. Comparing to Kyushu Region, flights to Shikoku Island change smoothly and independently, because railway service between the major cities are not high enough to produce inter-airport substitutions through railway access.

Figure 4 shows the HST (speed rank of 1 or 2) network configurations for the cases of the same length of HST but various capacity constraints of HND (Cases: 1.0(2403km)-200 to 1.0(2403km)-550). We can find that the HST axis from Tohoku to Kyushu via Tokyo, Nagoya, Osaka and Hiroshima Metropolises seems quite stable and important. This result is partly due to the given high train frequencies along this axis, but it strongly reflects the continuous distribution of local cities along the axis, where large middle-haul travel demand can be expected for HST service.

Some HST service disappears after the increase of HND operation capacity; additional flight allocations to Akita (AXT) and Yamagata (GAJ) in Tohoku Region directly decrease the HST

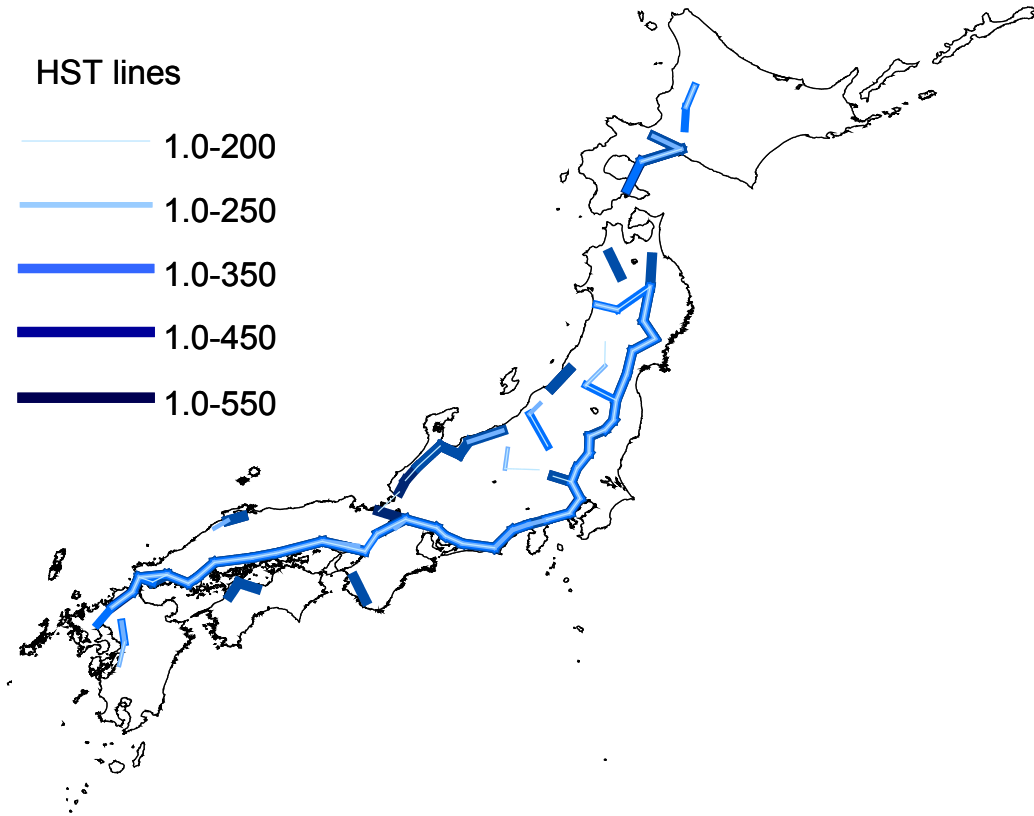


Figure 4 HST lines configurations, under different capacity constraints in HND

demand between these cities and Tokyo. In Hokkaido and Kyushu Region, similar but inter-modal substitution occurs; while flights to CTS are limited, travelers from Sapporo city in Hokkaido try to bypass other local airports in Hokkaido, where number of flights are set constant in the analysis, then feeder HST service e.g. Sapporo-Asahigawa (AKJ) becomes favorable. But CTS provide many flights enough, such feeder service loses necessity. Similarly, HST feeder service to FUK becomes favorable only while KMJ can not get sufficient number of direct flights to HND. Contrary, several local lines begin to have a role of feeder to local airports after the increase of direct flights; we can see those examples around CTS, Shonai (SHJ), KMJ, IZO and Matsuyama (MYJ).

4.3 Network Configuration Change Due to Various HST Line Constraints

Next, we assess the effect of change in HST line length constraint on network configuration. **Figure 5** shows the spatial layout of HST (speed rank 1 or 2) for the Cases 0.6(1442km)-250 through 1.4(3364km)-250. This figure shows that HST lines laid out even under the strict constraints keep their necessity after the increase of total HST length, with few exceptions. This is due to the increment nature of railway service with contrast to the competitive selection in airport usage. In railway network, each link can be used for many OD pairs, and one improvement of a link stimulates possibility of successive usage and further investment of the links connected with the first one. The exceptional links that disappear under longer HST constraints are seen Sapporo-Asahikawa, Toyama-Kanazawa, Izumo-Matsue and Fukuoka-Kumamoto, and many of them can be explained by the decline of feeder function to the neighbor local airport due to the increase of flights at the nearest airport.

Role of each airport is affected by the expansion of HST service. **Figure 6** shows the number

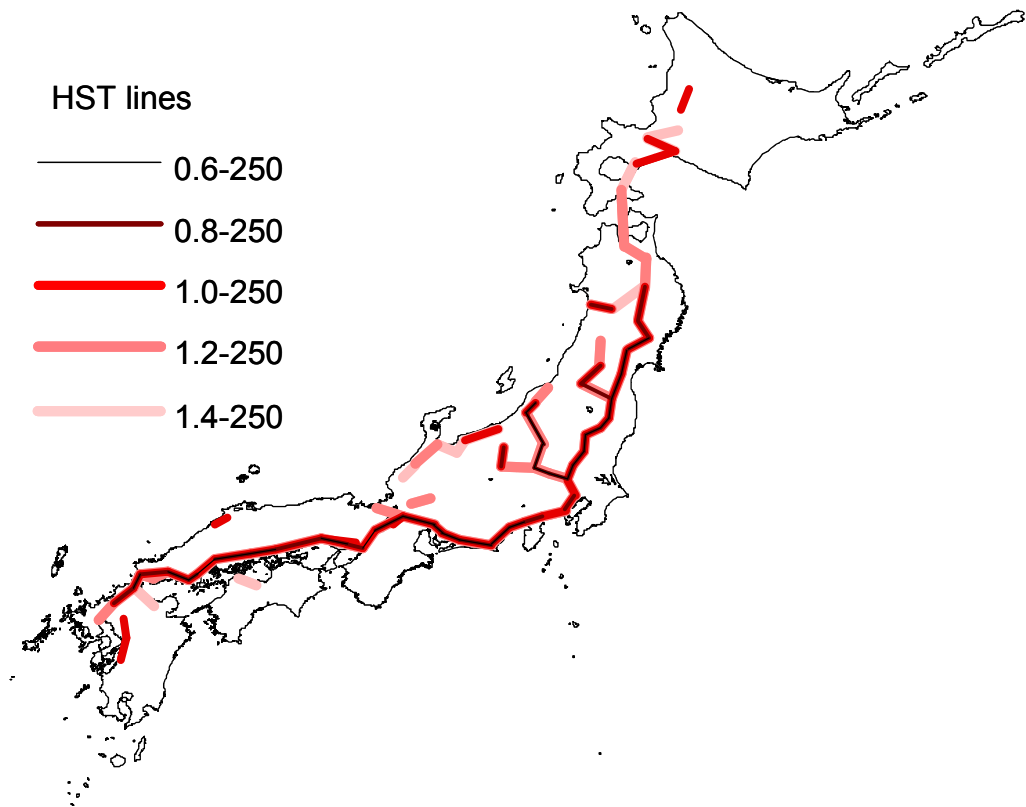


Figure 5 HST lines configurations, under different HST length constraints

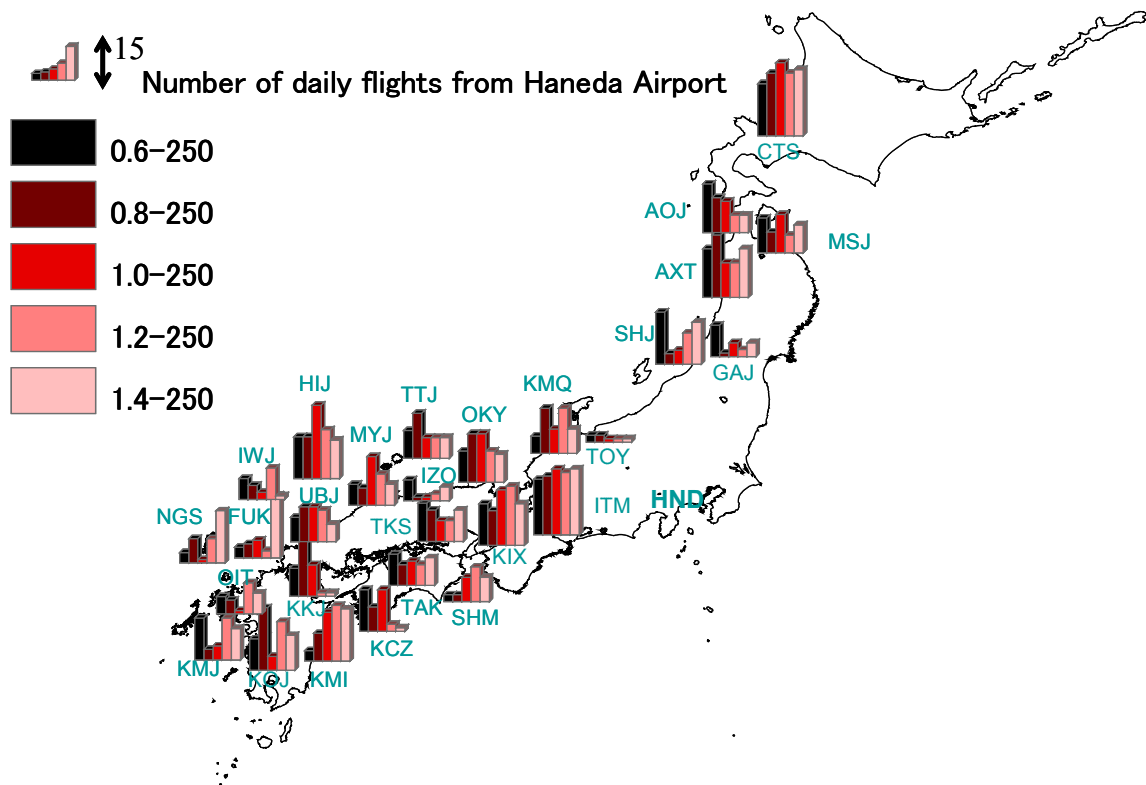


Figure 6 Daily HND flights to 28 destinations, under different HST length constraints

of flights between Haneda and local airports, under different length of HST (Cases 0.6(1442km)-250 through 1.4(3364km)-250). The flight pattern under the most strictly constrained HST service (Case 0.6(1442km)-250) is different from the other four cases with longer HST. In that situation, flights are independently allocated to large cities without HST service based on point-to-point demand. Once availability of HST expands, however, HST service begins to be used as feeder spoke, then flights begin to concentrate regional hubs with local HST connection, such as AXT, KMQ, KIX, OKY, HIJ, and KKJ. But further HST service yields different flight allocation to the remote airports, where HST service has not connected, such as SHJ, Takamatsu (TKS), NGS, KMJ, KOJ and KMI.

4.4 Inter-modal substitution and complementary

The above calculation results imply that air service network and railway network affect each other, once we take inter-modal connective use of both services in one trip. While airline frequency has all or nothing nature due to increasing return economy, railway frequency grows incrementally. Inter-modal network may have very complex performance, because it intermingles those two different natures. HST sometimes behaves as short-haul ground spoke or feeder links to local airport and shows complementary relationship to air network, but it becomes a competing alternative to flight service due to the consecutive formation of HST links comparable to airline routes, and substitution occurs.

We cannot easily tell whether the relationship of the two modes is complementary or substitution, but simulations by the presented GA model are helpful to find a better mix of the two modes from the viewpoint of inter-modal travelers.

5. CONCLUDING REMARKS

The Hub-and-Spoke Network has been prevailed as an effective air service network structure, but the capacity shortage of hub airport is often claimed. In Japan, the most important domestic hub, HND has been suffering the capacity shortage problem, and capacity expanding projects are now undergoing, aiming to provide some room for unrealized flights from/to local domestic airports, as well as international flights, possibly middle distant lines to East Asian countries.

Recently, while building or expanding of a large hub airport becomes controversial in economic, social and environmental facets, the idea of inter-modal substitution of short-haul air spokes by HST becomes a realistic option. This paper applied the HST as alternative to local flights, as well as middle-haul feeder service to local airports to collect the passengers around.

In order to analyze what shape of inter-modal network is efficient, and how beneficial it would be for travelers, we build a Genetic algorithm based network design model, paying attention to inter-modal (connective) use of air and HST. The model was applied to find the best mixture of HND operation capacity allocation to other destinations and the spatial configuration of HST network, which maximizes the total consumer surplus of Japanese inter-city domestic passengers, under given combinations of total operation capacity in HND and total HST lines.

The results show that the actually provided network in year 2000 was not the optimal one, and additional surplus can be obtained by reallocation of operation capacity of HND. Furthermore,

our analysis shows that HST service of 2400 km presented in 2000 is essential for keep mobility, but the shortage in HND operation capacity may also be solved if we provide additional HST service. The shape of optimal HST network changes with relation to the operation capacity of HND; besides direct connection routes between large metropolises, short-haul feeders to local airports appear in middle number of operation capacity. On the other hand, role of local airports is also affected by the total HST length; it changes from a local service provider into inter-modal local hubs and defenders for the overlooked demands at last.

The relationship of the two modes is very complex and we cannot distinguish it as either complementary or substitution. But anyhow, the presented GA model will give helpful information concerning a better mix of the two modes from the viewpoint of inter-modal travelers. We hope that methodology will be applied to discussion of inter-modal network planning in other countries such as China.

The remaining issues are as follows. The different objective functions other than consumer surplus, such as revenue of transportation service provider, would give a different network configuration. The comparative analysis between the networks under the different objective function is worth considering for making better policy mix strategy on intercity transportation. Further, the analysis for international flights by taking them into the proposed model would also give some useful information about the gateway design on a national airport system.

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