DOMESTIC AVIATION NETWORK ANALYSIS AND AVIATION POLICY SCENARIO

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Abstract

This paper proposes a model to analyze the impact on the domestic air passenger's flow when a new airport is constructed. The domestic air passenger's flow can be regarded as the resultant equilibrium of the airlines and the passenger in the transportation market. The model formulates the equilibrium based on so called as Stackelberg Problem. The model is applied to the domestic air market in Japan, and forecast the impact on the air passengers' flow by the construction of the New Chubu International Airport under planning, and discusses the optimal service routes and service frequency by airlines, and the change of passengers' flow.

INTRODUCTION

Recent tendency of globalization and /or internationalization stimulates the air-demand more and more. In Japan, the 66.9 million passengers used the domestic flights in 1995. About 56.4 million passengers, 81 % of domestic air passengers, used either of Tokyo International Airport (henceforth called as TKY) or Osaka International Airport (henceforth called as OSA) or both. Only 19 % of domestic air passengers used other local airports. The flight number of both airports has reached almost the limit of their capacity, and also that of Kansai International Airport (henceforth called as KIX) opened in 1994, is estimated to be saturated in the near future. Thus, New Chubu International Airport is being planned. Under these situations, it is needed to develop a suitable and simple tool to analyze the impact on the air passengers' flow by the construction of the new airport. There has been many researches in the field of demand forecast under a given aviation network. Researches by Morichi et al (1993), and Furuichi et al (1993) are the examples of introducing the logit type models. However, these do not consider the both strategic behavior of airlines. Todoroki et al (1992), Kita et al (1995) and Takase et al (1995) developed models to consider the behavior of airlines and passengers. These are quite interesting in the sense that they include the objective functions of both of airlines and passengers. However, they lack the approach to an "equilibria" between airlines and passengers. Ohashi et al (1996) formulated the equilibrium between airlines and passengers as the "general equilibrium" considering the aviation fee and flight frequency. Their model is very precise from the theoretical viewpoint. However, when that model is applied to the real aviation network, it may be difficult to take the equilibrium solution because it requires the quite huge size of computation. Taking these into account, the present paper aims to develop an simpler analytical model to obtain the equilibrium flow in the air transportation network.
In the real air transportation market, (1) the flow of passengers and / or goods is the resultant equilibrium in the market through strategic behaviors of transportation agencies (henceforth called as carrier) and passengers or shippers (henceforth called as user) under the governmental policies which include airport construction and its management, (2) the carrier has the perfect information about the users' behavior, but users have the limited information provided by the carrier, (3) the relationship between the carriers and users is not interactive. This situation of air transportation market constituted of the government, the carrier and the user can be regarded as the game so called as Stackelberg Problem. Under these understandings, Kuroda and Takebayashi (1996, 1997) developed a model to obtain the Stackelberg equilibria among carriers (airlines and railways) and passengers under given inter-regional O.D. distribution of demand. The present paper analyzes the impact of the construction of New Chubu International Airport on the air passengers' flow based on their model.

MODEL FORMULATION

As discussed previously, the equilibrium of the behavior of the carriers and the users can be regarded as the Stackelberg equilibria in the transportation market. The Stackelberg problem is characterized as follows;

1) There are two types of players in the game; the leader and the follower.
2) The leader has the perfect information about the follower's behavior, while the follower must behave under the constraints of the strategy provided by the leader.

The carriers, in this paper, are regarded as the leader, and the users as the follower. It is notified that in the Japanese domestic transportation market, the airlines and the railway company take the role of the carrier, because the long distance bullet train is a competitive mode to the air transportation. The structure of the problem is shown in Figure 1.

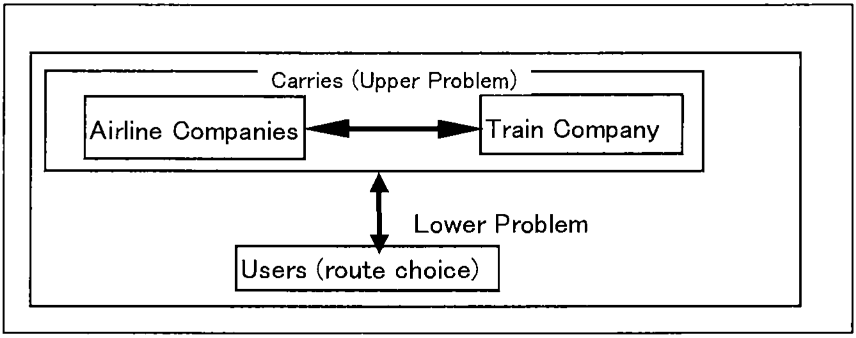

Figure 1 - The Structure of the Problem

In the real world, Nash-type equilibrium between the airline company and the railway company must be explicitly discussed. However, since the present paper focuses on the influence of the strategy of the airline company on the domestic air transportation market, the railway company is treated as the player who does not change his present service level even if it plays a role as an alternative transportation mode.

Premises and Assumptions

In modeling of the airlines' and the passengers' behavior, followings are assumed and premised;

1) Airport locations and their capacities are a priori given as the policy scenario by the government.
2) The capacity of train is assumed to be large enough to carry all the passengers between any origin and destination.
3) Railway stations are assumed to locate at the centroid of each zone.
4) The access and the egress to the bullet train station in the zone are limited by the ordinary train, while those to the airport are available by either of the ordinary train or the limousine bus.
5) The O.D. distribution of passengers is a priori given. This means that the present paper does not treat the long-term equilibrium of the system, but the short-term flow equilibrium.
6) Passengers can choose whichever the railway or the airway.
7) Competition among air carriers is not explicitly treated, but implicitly considered by introducing a load factor.
8) The airlines can decide their airway service route, the craft capacity, the fair, and the scheduled frequency under the constraints of the airport's capacity.
9) The purpose of the airlines is assumed to maximize their net revenue, while the passengers behave to minimize the total travel time, total travel cost, or the total generalized cost.
10) At the hub airport, the connecting time necessary for transit passengers is assumed constant. This means the flight schedule is planned to satisfy this constraint.
11) The airfare per person for each airline service route is assumed constant. This means there is a regulation on airfare by the government in Japan.

Airline's Behavior

The airlines can decide their strategy to maximize their net revenue under the perfect information about the passengers' behavior, but their scheduled flight frequency is constrained by the airport capacity. Their revenue comes from the fare of total passengers of their flights, and they expend the running costs such as depreciation of crafts, fuel, crew expenditure, and so forth, and the airport costs such as landing charge, rental fee of terminal facilities. Thus, referring to Figure 2, the objective function of the airline and the constraints are given by

$$\max B(y_m^l) = \sum_i \sum_j \sum_{l \in La} \left(\sum_k AP^l \cdot \delta_k^l \cdot x_{ijk} \right) - \sum_{l \in La} \sum_m y_m^l \cdot RC_m^l - \sum_{l \in La} \sum_{h \in Ha} \sum_m \delta_h^l \cdot APC_m^h \cdot y_m^l \tag{1}$$

s.t.

$$\sum_{l \in La} \sum_m \delta_h^l \cdot y_m^l \le CAP^h \qquad (for \quad \forall h \in Ha) \tag{2}$$

$$y_m^l = y_m^{\hat{l}} \qquad (for \quad \forall l, \hat{l} \in La, \quad \forall m) \tag{3}$$

$$y_m^l \ge 0 \tag{4}$$

and

passenger's behavior

(5)

where

L: a set of links
La : set of airway links ($La \in L$).
k : a route consisted of a series of links.
l : a link as an element of a route with its direction.
$\hat{l}$: same link as l with opposite direction of l.
i,j: origin and destination zones.
x_{ijk}: travelers volume per day from the zone i to the zone j using the route k.
AP^l: airfare per person for the link l.
Ka : set of routes including airway links.
RC_m^l : one flight operational cost of a craft of size m for the link l.
APC_m^h : one flight airport charge of a craft of size m at the terminal h.
CAP^h: capacity of terminal h, expressed by maximum flight number.
H: a set of terminals.
Ha: a set of airports ($Ha \in H$).
δ_k^l : Kronecker's delta defined as

$$\delta_k^l : \begin{cases} 1 : \text{the link } l \text{ is included in the route } k \in Ka \\ 0 : \text{others} \end{cases}$$

δ_l^A : Kronecker's delta defined as

$$\delta_l^A : \begin{cases} 1 : \text{the link } l \text{ is an airway} \\ 0 : \text{others} \end{cases}$$

y_m^l : daily service frequency of crafts at the link l.

δ_h^l : Kronecker's delta defined as

$$\delta_h^l : \begin{cases} 1 : \text{terminal } h \text{ is included in the link } l \\ 0 : \text{others} \end{cases}$$

The constraint eqn.(2) means that the total flight number at the airport h does not exceed the capacity of the airport h. The constraint eqn.(3) means that the flight frequency of the link l is the same number as that of $\hat{l}$. The constraint eqn.(4) means the non-negative number of each flight frequency.

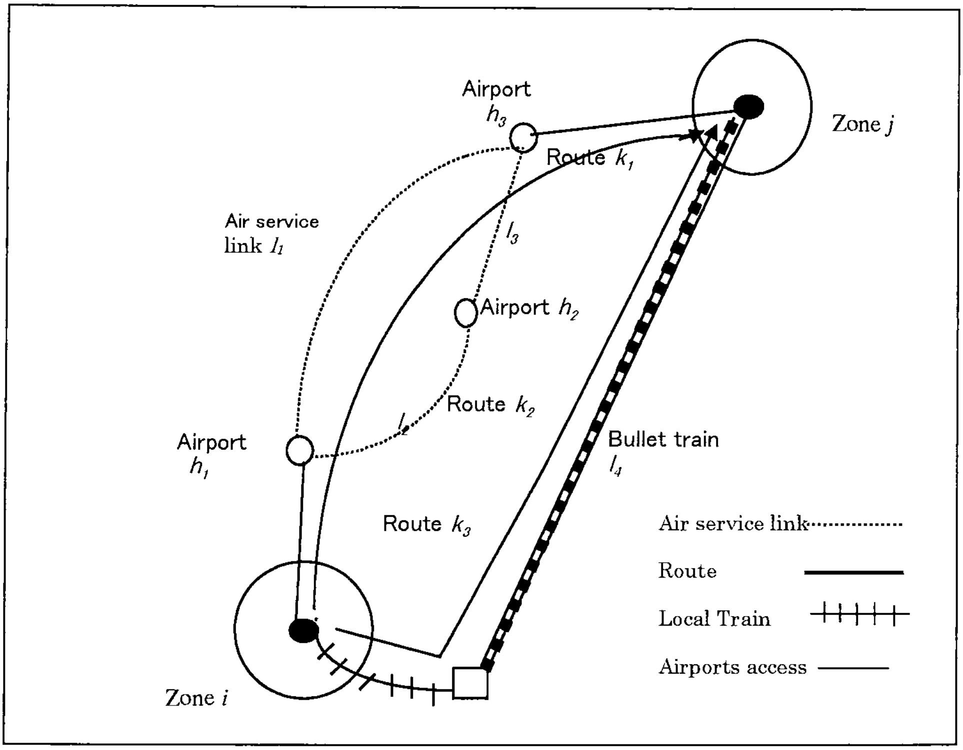

Figure 2 - Concept of Transportation Network

Passengers' Behavior

The passengers can choose either of the airway or the railway consulting their preferences under the flight schedule and the capacity of flight provided by the air-carriers and those by railway companies. The total travel time for aviation passengers considered is shown in figure 3.
The passengers may prefer to minimize (1) the total travel time, or (2) to minimize the total travel cost, or (3) to minimize the generalized cost. K. Kuroda and M. Takebayashi (1996) investigated above three criteria for air passengers, and concluded that the criterion of the minimum total travel time was most appropriate to explain the air passengers' behavior.

Therefore, the present paper employs this criterion. It is formulated as follows;

$$\min T(x_{ijk}) = \sum_i \sum_j \sum_k x_{ijk} \cdot t_{ijk}$$

$$= \sum_i \sum_j \sum_k x_{ijk} \{\delta_k^A (t_{ijk}^{ae} + \sum_{l \in L} \delta_k^l \cdot t^l + \sum_{l \in L} \sum_h \sum_m \delta 2_k^l \cdot \delta 2_h^l \cdot \frac{OT}{2 \cdot \sum_m y_m^l} + \sum_{l \in L} \sum_h \delta 3_k^l \cdot \delta 2_h^l \cdot WT)$$

$$+ \delta_k^R (\sum_{l \in L} \delta_k^l \cdot t^l + \sum_{l \in L} \sum_h \sum_m \delta 2_k^l \cdot \delta 2_h^l \cdot \frac{OT}{2 \cdot \sum_m y_m^l})\} \tag{6}$$

s.t.

$$\sum_k x_{ijk} = X_{ij} \tag{7}$$

$$\sum_i \sum_j \sum_k \sum_m \delta_k^l \cdot x_{ijk} \leq y_m^l . CAP_m^l \cdot \lambda_m^l \tag{8}$$

$$x_{ijk} \geq 0 \tag{9}$$

where

x_{ijk}: passengers' volume from zone *i* to zone *j* using route *k*.
X_{ij}: the volumes of OD passengers between the zone *i* and the zone *j* (person/day).
CAP_m^l: the aircraft's capacity of a craft of size *m* at the airline or railway service route
l (person/ craft).
WT: waiting time for transit at the airport (assumed as a constant value).
δ_k^A :Kronecker's delta defined as

$$\delta_k^A : \begin{cases} 1 : \text{route } k \text{ includes airlines} \\ 0 : \text{others} \end{cases}$$

δ_k^R :Kronecker's delta defined as

$$\delta_k^R : \begin{cases} 1 : \text{route } k \text{ includes railway} \\ 0 : \text{others} \end{cases}$$

t_{ijk}: travel time from *i* to *j* at route *k*.
t_{ijk}^{ae}: the total access and egress time at the route *k* between the zone *i* and the zone *j* (min).
t^l: the line haul travel time at the link *l* (min).
OT: the opened time of the terminal (hrs/day).
λ_m^l: the load factor of the craft of size *m* at the link *l*.
$\delta 2_k^l$:Kronecker's delta defined as

$$\delta 2_k^l : \begin{cases} 1 : \text{link } l \text{ is the first link included in route } k \\ 0 : \text{others} \end{cases}$$

δ_{3k}^{l} :Kronecker's delta defined as

$$\delta_{3k}^{l}: \begin{cases} 1 : \text{link } l \text{ is the second link included in route } k \\ 0 : \text{others} \end{cases}$$

δ_{2h}^{l} :Kronecker's delta defined as

$$\delta_{2h}^{l}: \begin{cases} 1 : \text{terminal } h \text{ is included in the link } l \\ 0 : \text{others} \end{cases}$$

The constraint eqn.(7) means that the total number of passengers using all routes between the zone i and j must be equal to its O.D. volume of passengers, and eqn.(8) gives the constraint that the air passengers at any air transportation link must be less than equal to its total capacity, and eqn.(9) gives the non-negative constraint for the variable x_{ijk}.

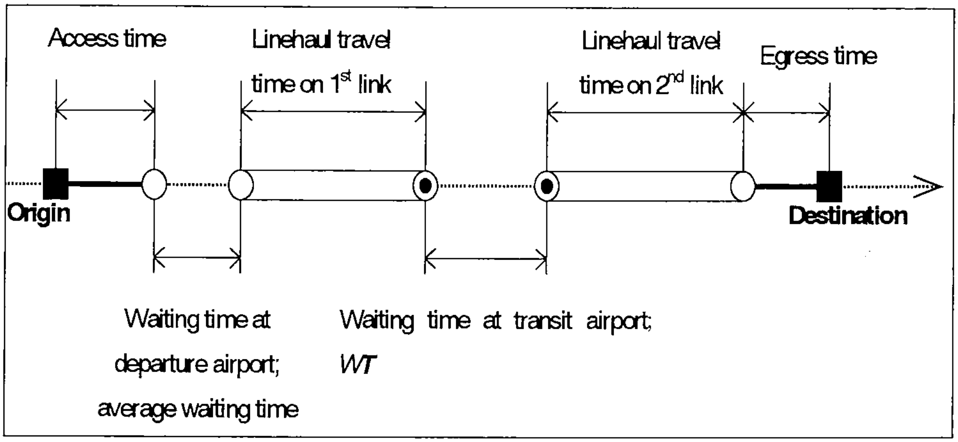

Figure 3 - The Content of Aviation Passengers' Travel Time

MODEL TEST BY PASSENGERS' BEHAVIOR

Numerical Conditions

Kuroda and Takebayashi (1996) discussed the model performance by applying it to domestic transportation network in Japan, and concluded that the minimum travel time criterion can well explain the behavior of passengers. However, they suggested that the constant waiting time for transit passengers assumed in their model has given a discrepancy for local line passengers. Then, in the present paper, the passenger behavior model is appropriately modified as discussed previously. Therefore the present paper again discussed the modified model performance for estimation of passengers behavior. In numerical computations, following data are used;

OD Zones and OD Distribution of Passengers

Prefecture governmental domain is employed as the OD zones (Table 1), and each of the OD pair of passengers between every two prefectures is used as the data based on the Survey of Passengers Movement by the Ministry of Transport of Japan in 1991 (Ministry of Transport, 1991). This OD distribution is assumed not to be influenced by the charge of the airline policy, because the OD distribution is mainly determined through socio-economic activities in the region. It is, however, noticed that the volume of air passengers, that is, air demand, is, of course, influenced by the air line policy.

Table 1 - OD Zones

1	2	3	4	5	6	7	8	9
Hokkaido	Aomori	Ibaragi	Toyama	Shiga	Tottori	Tokushima	Fukuoka	Okinawa
	Iwate	Tochigi	Ishikawa	Kyoto	Shimane	Kagawa	Saga	
	Miyagi	Gunma	Fukui	Osaka	Okayama	Ehime	Nagasaki	
	Akita	Saitama	Gifu	Hyogo	Hiroshima	Kochi	Kumamoto	
	Yamagata	Chiba	Shizuoka	Nara	Yamaguchi		Oita	
	Fukushima	Tokyo	Aichi	Wakayama			Miyazaki	
		Kanagawa	Mie				Kagoshima	
		Niigata						
		Yamanashi						
		Nagano						

Airports and Service Route Network

Since, in Japan, the airline policy is more or less restricted by regulation of the central government, the airway routing and service frequency might not be optimal for air carriers. Thus, the comparison of the existing airway routes and frequency with computation results by the model is nonsense. Therefore, in the present paper only passengers behavior is examined under the existing policy of airlines. Airports considered in computation are the first and the second class airports regulated in Japan, those and airline service routes are shown in Figure 4. It is noticed in the figure that Kansai International Airport (KIX) was opened in 1994, and extension of Tokyo International Airport (TKY) is completed in 1997 which can supply more capacity than the past. Therefore the model test was carried out for the condition before KIX was opened. However, simulation of airport policy scenario in the succeeding chapter is carried out after KIX is opened and extension of TKY is finished. In Table 2 is listed the capacity of main airports.

Aircraft and Costs

The aircraft type used for the domestic service, their capacity and their operation costs are listed in Table 3. The airport charge is also listed in the same table. The operation cost of aircraft is referred to the Airline Statistics in 1991 (Ministry of Transport, 1991), and it includes the redemption cost of aircraft as an average value. The airport charge of all the airport considered is the same. This is also referred to the Airline Statistics in 1991(Ministry of Transport, 1991). Load factor of all crafts is assumed as 0.7, which is considered as average value in all service routes.

Examination of Passengers' Behavior

As previously mentioned, model test is carried out only for passengers' behavior under the air service network in 1991. The computation results by the model are compared with the Airline Statistics in 1991 (Ministry of Transport, 1991).

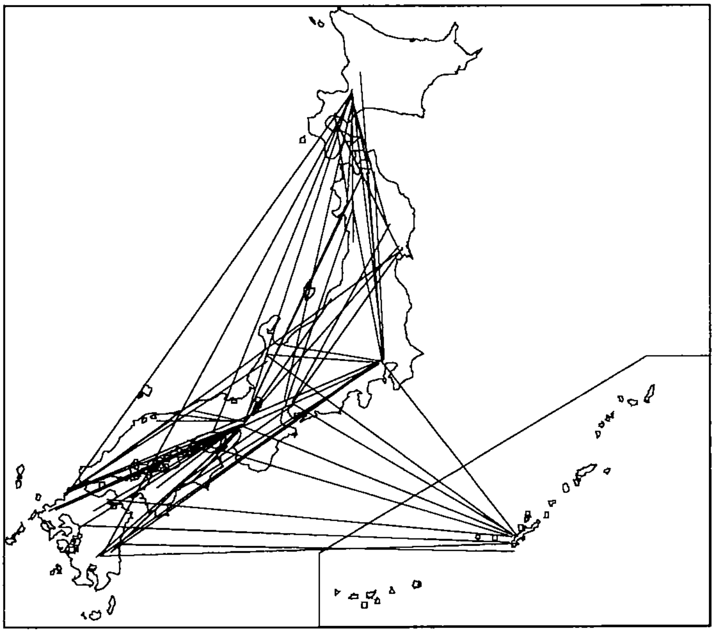

Figure 4 - Air Service Routes

Table 2 - Capacity of Main Airports (1991)

Airport	Capacity (craft /day)
TKY	400
OSA	300
NGY	240
SAP	300

Table 3 - Capacity, Operational Cost and Airport Charge

Type	Capacity (person/ craft)	Operational Cost (thousand yen/ flight)	Airport Charge (thousand yen/ flight)
B747	569	6,037	475
DC10	318	4,750	374
B767	288	2,815	221
A300	308	3,187	251

The air passengers' volume of all service routes estimated by the model and those by the statistics are shown in Figure 5.

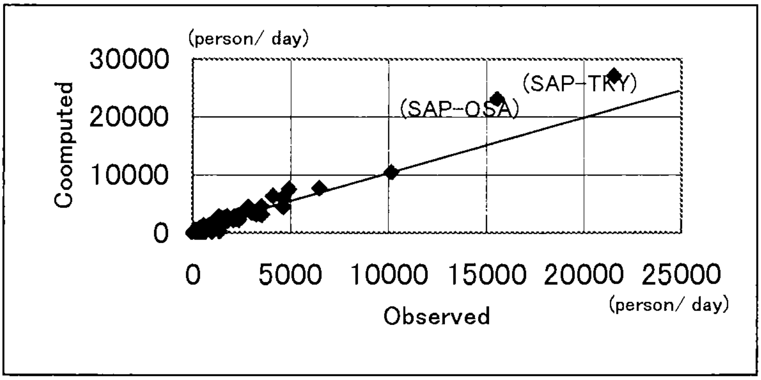

Figure 5 - Comparison of Air Passengers Volume

The figure shows the model can well explain the behavior of passengers who chose the air transportation. The correlation coefficient is 0.984. However, it can be seen that there are some local service routes that can not be explained by the model. Those routes are the local to local route whose flight service frequency is relatively small than the main routes. The lower service frequency results in the longer interval time at the airport, which is defined as the average waiting time in the model. Therefore, the model estimates that passengers of the region, whose airport has relatively lower frequency service, choose the railway. The model should be further improved to diminish this point in the future. As already discussed, the model test is carried out under the given air service routes which are more or less regulated by the government. Then in order to investigate how much is the difference of air carrier's behavior between the computed (assumed non-regulated free market) and the present is compared. The results are shown in Figure 6. As can be seen in this figure and Figure 5, the real service routes in 1991 employed by the airlines were almost optimized in the sense that they maximized their net revenue. These results may suggest that if air transportation market is completely deregulated, air carriers may withdraw from these local service routes. This will be further discussed in the succeeding chapter.

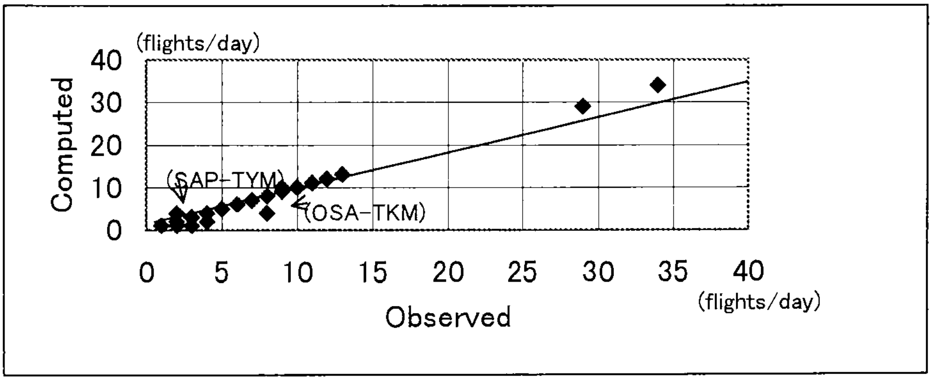

Figure 6 - Comparison of Service Flight Frequency per Day

SIMULATION OF AVIATION POLICY SCENARIOS

As stated in the previous chapter the extension of Tokyo International Airport (TKY) has been completed and extension of Kansai International Airport (KIX) is now being extended, and further a new international airport is planned to open in 2010 in Chubu Region which is the central part of main island of Japan, instead of closing of existing Nagoya International Airport. This is temporally called as New Chubu International Airport (NCB). KIX and NCB are the offshore airports and their locations are not so far from existing Osaka and Nagoya International Airports, respectively. Corresponding to the extension of KIX, there is some opinion of closing of OSA Airport which is located at the urbanized area in Kinki Region, because serious noise problem has been induced in its surrounding area.

Under these circumstances, this chapter discusses the influence of these plans and opinions on the air carrier's strategy in the domestic transportation market and on the flow of air passengers by scenario simulation using the proposed model. In the scenario simulation complete deregulated air transportation market is assumed and the crafts' capacity employed and costs are also assumed as same as the present, but the estimated OD distribution of passengers in 2010 is used. In numerical computations, the annual growth ratio of the domestic O.D. passengers from 1991 to 2010 is assumed as 1.0% according to the Air Statistics (Ministry of Transport, 1991). This leads the total of domestic O.D. passengers in 2010 as 108.83 millions (Figure 7). The O.D. distribution in 2010 is estimated based on this annual growth ratio and the present OD patterns. Four cases of scenario are considered as listed in Table 4.

The first scenario is Case 1 that assumes that extension of TKY is finished but KIX's extension is not finished and others are same as the present situation. The second scenario is Case 2 which assumes that Case 1 plus New Chubu International Airport (NCB). The third scenario is Case 3 that assumes that OSA is closed and NCB is opened and extension of KIX is finished. The last scenario is Case 4 that assumes that NCB is not opened yet but others are same as Case 3.

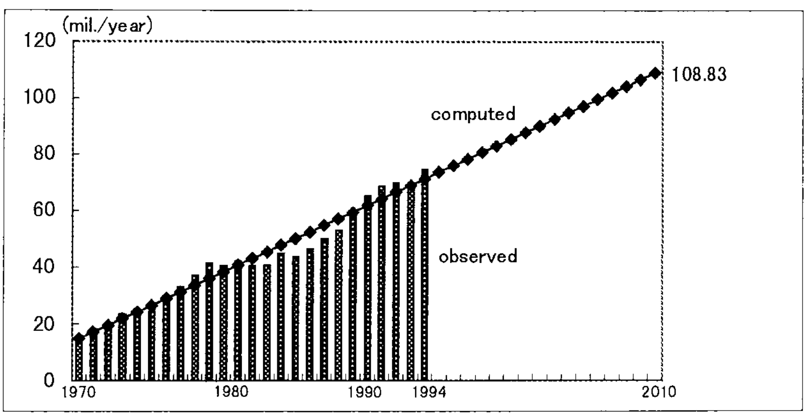

Figure 7 - Comparison of Total Volume of OD Passengers from1970 to 2010

Table 4 - Conditions of Airport Capacity

Case	TKY	OSA	KIX	Chubu
Case 1	800(extended)	300(present)	200(present)	None
Case 2	800(extended)	300(present)	200(present)	300(constructed)
Case 3	800(extended)	None	500(extended)	300(constructed)
Case 4	800(extended)	None	500(extended)	None

Table 5 Impact of the Construction of Chubu New International Airport

Case	Carrier's Net Revenue	Total Aviation Passengers (thousand person/ day)	Average Travel Time (min./person)
Case 1	100	276.2	222.94
Case 2	100	276.2	222.94
Case 3	110	278.1	219.86
Case 4	110	278.1	219.86

Influence of Open of New Chubu International Airport

Since New Chubu International Airport (NCB) is planned to be constructed at the offshore island where is not so far from the present Nagoya International Airport (NGY), no influence on other airports is anticipated but only change will be shift of the function of the present NGY to NCB. It is true when we see Table 5 that lists the computed results of four cases. In this table, carriers' net revenue is normalized based on Case 1.

Comparing with Case 1 and Case 2, no influence of NCB on the carrier's net revenue, the total volume of air passengers and on the average travel time of passengers can be seen. This can be also concluded from Figure 8, which shows the total volume of air passengers of each airport.

Figure 8 teaches us that the construction of NCB and in Fig. 8 and Fig. 9 the close of NGY gives no influence at all on the air market. It is also notable that TKY will invite much more air passengers than other airports reflecting the greater increase of OD volume of its hinter region and the transit passengers.

This means that airlines prefer to take the strategy of Hub-and-Spoke type network of their service route in the free market for more cost-effectiveness.

Influence of Closing of Osaka International Airport

Influence of closing of OSA can be examined by comparing with Case 1 and Case 3. From Table 5 it will be estimated that closing of OSA will result in the increase of net revenue of airlines and the decrease of average travel time of passengers. Comparing with Case 2 and Case 3, only change induced by closing of OSA is the shift of function of OSA to KIX. When OSA is closed, the passengers using OSA may shift to KIX, and KIX will be functioned as the Hub airport more than the present as can be seen in Figure 9.

From these it is concluded that closing of OSA will improve not only the net revenue of airlines but also the average travel time of passengers by strengthening the Hub-function of KIX. This conclusion may suggest that the extension of KIX will invite change of airlines' routing strategy so as to collect their network from OSA to KIX in the regulation free market because this change is better for both of airlines and passengers. In order to examine this hypothesis, Case 4 is carried out. Results are discussed in the next section.

( ) shows the ratio of landing frequency to airport capacity.

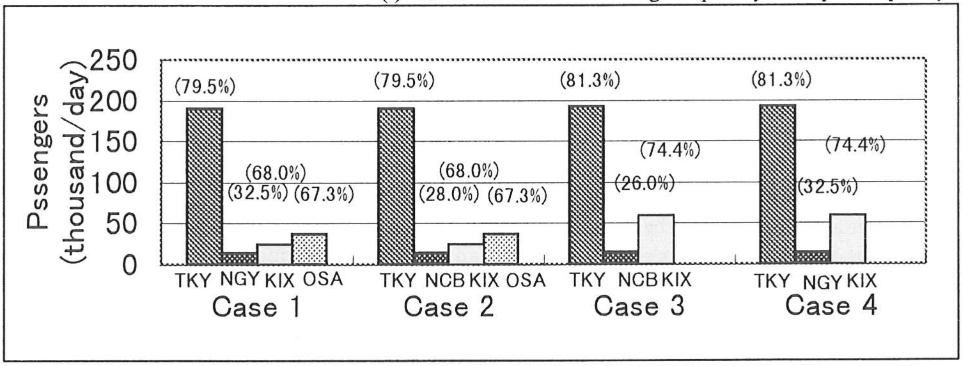

Figure 8 Comparison of Total Volume of Air Passengers at Each Airport

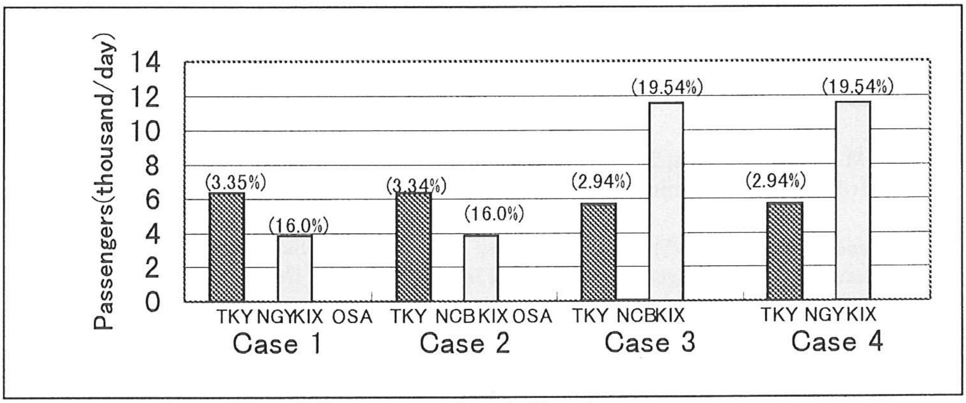

Figure 9 Comparison of Transit Passengers at each Airport

Influence of Extension of Kansai International Airport

It is easily anticipated that the extension of KIX will at least influence on existing Osaka International Airport because those are located very closely. In the previous section this is suggested. In fact, the results of Case 4 shown in Table 5, Figure 8 and Figure 9 say that the extension of KIX will invite all airlines to KIX from OSA in order to make the Hub-and-Spokes type network which is more cost-effective for airlines and consequently it gives more convenient service for passengers. This may be true if regulation free market is accomplished and airlines are assumed to make consortium. However, in the real market, each of airlines may behave to maximize his own net revenue if the independent service is more profitable than making consortium. Therefore, some airlines may serve at OSA and others at KIX even if KIX is extended. Unfortunately the present paper do not analyze so-called Nash-type Equilibrium between airlines. This is the future problem remained in the present paper.

CONCLUSION

The present paper proposes a tool to analyze so called as Stackelberg equilibria between air carriers and passengers in the domestic transportation market, and examines the model for passengers' behavior by comparing with observed volume of passengers and the computed ones by the model. The results say that the model can well explain the passengers' behavior.

The paper also analyzes the influences of some aviation policy scenarios, which include the extension of Tokyo and Kansai International Airports, the construction of New Chubu International Airport, and the closing of Osaka International Airport. Even the present model gives much information about future conditions under those policy scenarios, these are based on some assumptions and premises which must be improved. One of those is the assumption of non-competitive situation among airlines in the market. When this is considered in the model, a special computation algorithm should be developed. Another improvement is about the cost function of airlines. The present model does not give the detail cost function, which makes us impossible to analyze the change of airport management policy such as the landing cost and the terminal rental fee and so forth.

The model also does not consider the international air passengers' behavior because the structure of international aviation market is supposed not to be the same as the domestic one. Therefore, a different approach to the international aviation market is needed. This is the issue for future analysis of this study.

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