ANALYSIS OF THE IMPACT ON DOMESTIC AIR PASSENGERS' FLOW BY 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 constructed airport is constructed. The domestic air passenger's flow can be regarded as the resultant equilibrium of gaming between the airlines and the passenger in the transportation market. The model formulates the equilibrium based on so called as Stackelberg Problem. It is applied to analyze the impact on domestic air passenger's flow by the construction of New Chubu International Airport in Japan, and discusses the optimal service routes and service frequency by airlines, and the change of passengers' flow.

1. 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 flights. The flight number of both airports reaches almost the limit of the capacity, and that of Kansai International Airport (henceforth called as KIX) opened in 1994, is also estimated to be saturated in the near future. Thus, New Chubu International Airport is being planned. Under these situations, it is needed to develop the suitable and easy tools 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 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 researches 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, that is not so useful because it needs the huge size of computation. Taking these into account, the present paper aims to develop an easier analytical tool to make clear the equilibrium flow in the transportation market.

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. These situation of the government, the carrier and the user can be regarded as the gaming so called as Stackelberg Problem. Under these understandings, the present paper develops a model to obtain the Stackelberg equilibria among carriers (airlines and railways) and passengers under given inter-regional O.D. distribution of demand, and analyzes the impact of the construction of New Chubu International Airport on the air passengers' flow.

2. MODEL FORMULATION

As discussed previously, the equilibrium of the behavior of the carriers and the users can be regarded as the Stackelberg equilibria of the Non Zero Sum - Non Cooperative - Two Person Game in the transportation market. The Stackelberg problem is characterized as follows;

1) There are two types of players in the game; the leader and follower.
2) The leader has the perfect information about the follower's behavior, and 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 competitive to the air transportation. The structure of the problem is shown in Figure 1.

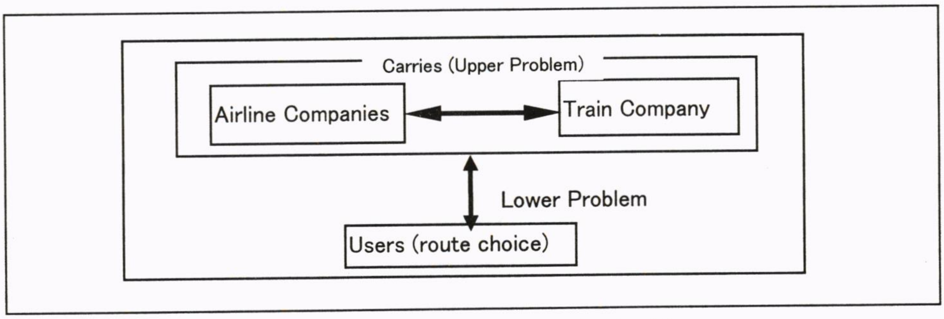

Figure 1 The Structure of the Problem

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 in the domestic transportation market, the railway company is not treated as the leader even if it is considered as an alternative transportation mode.

2.1 Premises and Assumptions

In modeling of the behavior of the airline and the passenger, followings are assumed and premised;

1) Airport locations and its capacities are a priori given as the policy scenario by the government.
2) The railway network including that of the bullet train and the train schedule are given, and the railway company does not change its train schedule and fare.
3) The capacity of train is assumed to be large enough to carry all the passengers between any origin and destination.
4) Railway stations are assumed to locate at the centroid of each zone.
5) 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.
6) 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.
7) Passengers can choose whichever the railway or the airway.
8) Competition among air carriers is not explicitly treated, but implicitly considered by introducing a load factor.
9) 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.
10) The purpose of the airlines is assumed to maximize their net revenue, while the passengers behave to minimize the total travel time. This assumption is introduced from the recent research results by K. Kuroda and M. Takebayashi (1996).
11) At the hub airport, the necessary connecting time for transit passengers is assumed constant. This means the flight schedule is planned to satisfy this constraint.

2.2 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 and terminal facilities. Thus, referring to Figure 2, the objective function of the airline and their constraints are given by

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

$$\text{s.t.} \quad \sum_{l \in La} \sum_m \delta_h^l \cdot y_m^l \leq CAP^h \qquad (for \quad \forall h \in Ha) \quad (2)$$

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

$$y_m^l \geq 0 \quad (4)$$

$$\text{and} \quad \boxed{\text{passenger's behavior}} \quad (5)$$

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 the link 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: air fare per person for the link l.

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

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

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.

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

δ_h^l : Kronecker's delta defined as

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

CAP^h: capacity of terminal h, expressed by maximum flight number.

H: a set of terminals.

Ha: a set of airports ($Ha \in H$).

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

2.3 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 these by railway companies. 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 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 adopts this criterion. It is formulated as follows;

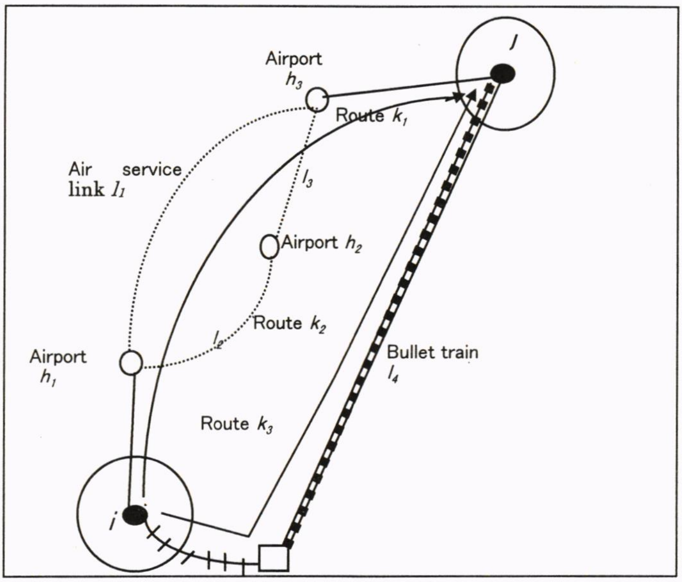

Figure 2 Concept of Transportation Network

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

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

$$+ \delta_k^R (\sum_{l \in L} \delta_k^l \cdot t^l + \sum_{l \in L} \sum_h \sum_m \delta_{2k}^{\,l} \cdot \delta_{2h}^{\,l} \cdot \frac{OT}{2 \cdot \sum_m y_m^l})\} \tag{6}$$

$$\text{s.t.} \quad \sum_k x_{ijk} = X_{ij} \tag{7}$$

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

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

where

x_{ijk}: passengers' volume from zone i to zone j using route k.

X_{ij}: the volume 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 (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).
$\lambda_m{}^l$: the load factor of the craft of size m at the link l.
$\delta_{2k}^{\,l}$:Kronecker's delta defined as

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

$\delta_{3k}^{\,l}$:Kronecker's delta defined as

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

$\delta_{2h}^{\,l}$: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 Eq.(7) means that the summation of passengers using all routes between the zone i and j must be equal to its O.D. volume of passengers, and Eq.(8) gives the constraint that the air passengers at any air transportation link must be less than equal to its total capacity, and Eq.(9) gives the non-negative constraint for the variable x_{ijk}.

3. MODEL TEST BY PASSENGER BEHAVIOR

3.1 Numerical Conditions

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

OD Zones and OD Distribution of Passengers
Prefecture governmental unit is employed as the OD zones, and each of the OD pair of

passengers between every two prefectures is used by the data of 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 noticed that the volume of air passengers, that is, air demand, is, of course, influenced by the air line policy.

Airports and Service Route Network

Since, in Japan, the airline policy is more or less regulated by the central government, the airway routing and service frequency might not be optimal for air carriers. Thus, the comparing with the existing airway routes and frequency and 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 3. It is noticed in the figure that Kansai International Airport (KIX) was opened in 1994, and extension of Tokyo International Airport (TKY) will be completed in 1997 which will supply more capacity than the present. 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 1 is listed the capacity of main airports.

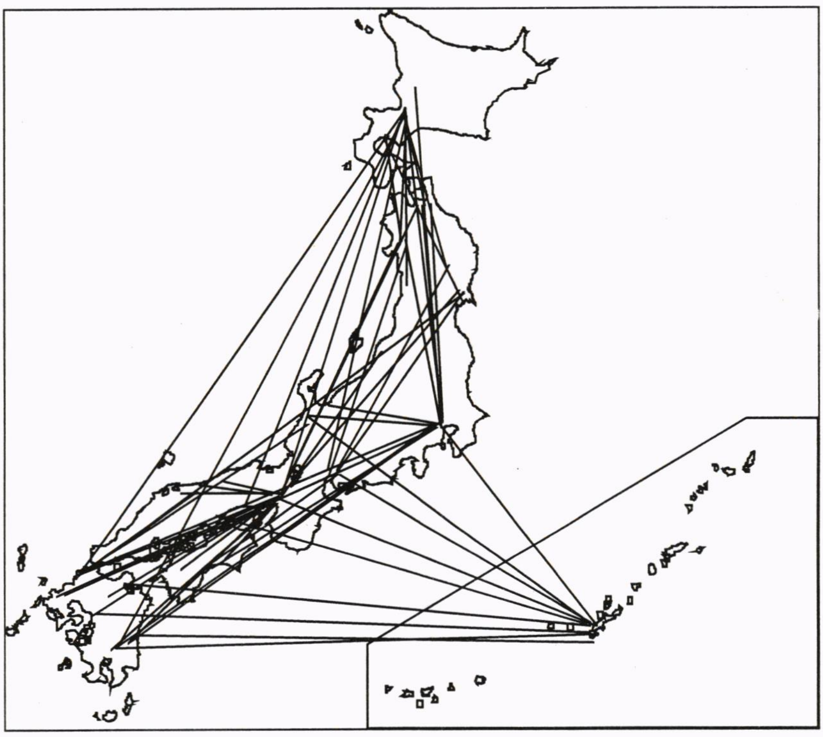

Figure 3 Air Service Routes

Table 1 Capacity of Main Airports

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

Aircraft and Costs

The aircraft type used for the domestic service, their capacity and their operation costs are listed in Table 2. 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 as an average value. The airport charge of all the airport considered is the same. This is 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.

Table 2 Capacity, Operational Cost and Airport Charge

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

3.2 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). The air passengers' volume of all service routes estimated by the model and those by the statistics are shown in Figure 4.

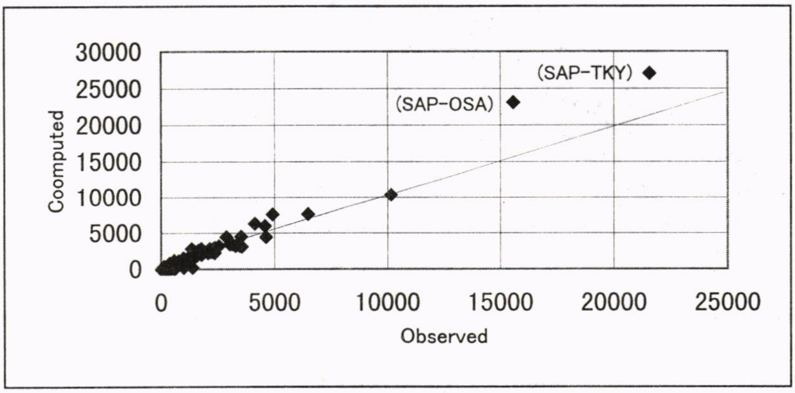

Figure 4 Comparison of Air Passengers Volume

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 which can not be explained by the model. Those routes are concentrated in the local routes connecting with local airport whose flight service frequency is relatively small than the main routes. The small service frequency results in the long interval time at the airport which is defined as the average waiting time in the model. Therefore passengers of those regions associated with those airports choose the railway. The model should be improved to diminish this point in future.

As already discussed, the model test is carried out under the given air service routes which are considered to be regulated more or less by the government. Then in order to investigate how much is the difference of air carrier's behavior between the computed and the real. The results are shown in Figure 5. As can be seen in this figure and Figure 3, 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.

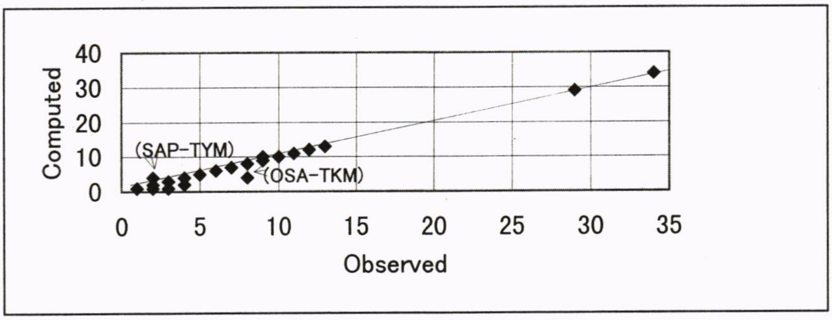

Figure 5 Comparison of Service Flight Frequency

4. SIMULATION OF AVIATION POLICY SCENARIOS

As stated in the previous chapter the extension of Tokyo International Airport (TKY) will be completed at the beginning of the 21st century, 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, 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 location are not so far from existing Osaka and Nagoya International Airports, respectively. Corresponding to 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 the 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 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, and the 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. The O.D. matrix in 2010 is estimated with this annual growth ratio and the present OD matrix. Four cases of scenario for discussion are considered as listed in Table 3.

Table 3 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

The first scenario is Case 1 which 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 which assumes that OSA is closed and NCB is opened and extension of KIX is finished. The last scenario is Case 4 which assumes that NCB is not opened yet but others are same as Case 3.

4.1. Influence 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 present Nagoya International Airport (NGY), no influence will be considered but only change will be shift of present function of NGY to NCB. It is true when we see Table 4 which lists the computed results of four cases.

Table 4 Impact of the Construction of Chubu New International Airport

Case	Carrier's Net Revenue	Total Aviation Passengers (thousand person)	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

Comparing with Case 1 and Case 2, the influence of NCB on carrier's net revenue, total volume of air passengers and average travel time of passengers can not be seen. This can be also concluded by Figure 6 which shows the total volume of air passengers of each airport.

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

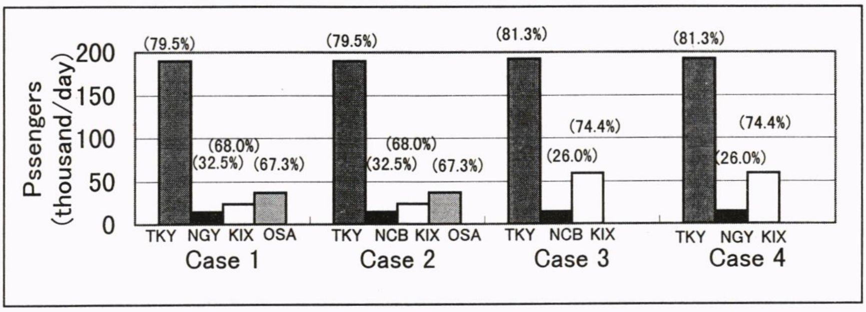

Figure 6 Comparison of Total Volume of Air Passengers at Each Airport

Figure 6 teaches us that construction of NBC and close of NGY gives no influence at all on air market. In Figure 4 it is also notable that TKY will invite much more air passengers than other airports on the background of greater OD volume and transit passengers which is shown in Figure 7.

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

4.2 Influence of Close of Osaka International Airport

Influence of close of OSA can be examined by comparing with Case 1 and Case 3. From Table 4 it will be estimated that close of OSA will result in increase of net revenue of airlines and decrease of average travel time of passengers. Comparing with Case 2 and Case 3, only change induced by close of OSA is the shift of function of OSA to KIX. When OSA is closed passengers using OSA may shift to KIX, and KIX will be functioned as Hub airport more than the present as can be seen in Figure 7.

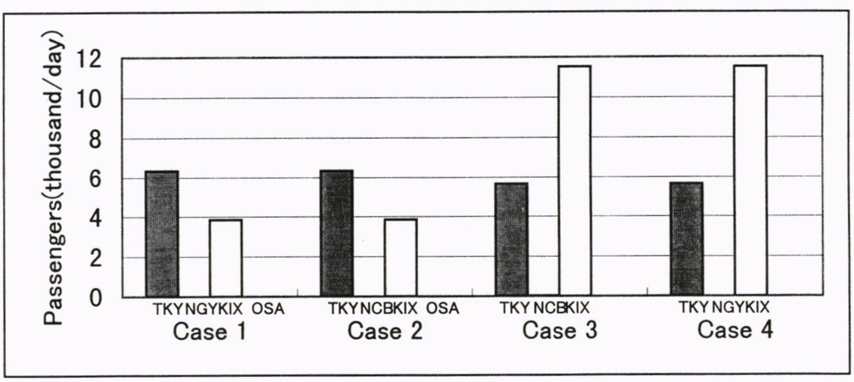

Figure 7 Comparison of Transit Passengers at each Airport

From these it is concluded that close 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 article.

4.3 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 article this is suggested. In fact, the results of Case 4 shown in Table 4, Figure 6 and Figure 7 say that the extension of KIX will invite all airlines to KIX from OSA in order to make 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 for global alliance. However in the real market each of airlines may behave to maximize his own net revenue if 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 by the present paper.

5. CONCLUDING REMARKS

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, construction of New Chubu International Airport, and close if 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 present model, special computation algorithm should be developed. Another point improved is 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 landing cost and terminal rental fee and so forth.

The model also does not consider the international air passengers behavior because of lack of data of the origin and the destination of foreign passengers in Japan. This is the issue for future analysis of this study.

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