1. INTRODUCTION

Airport management in multiple airports region needs to consider both airline's strategy and air passenger's demand carefully. Air Passenger traffic in a multiple airports region is affected by air fare, flight frequency, access transport condition and so on. Therefore, the spatial characteristics of the hinterland influence airport management as well as the economic climate such as cost structure and the price elasticity.

Airport pricing studies have been tackling congestion problems and a regional monopoly problems for a long time. Those studies produced a lot of fruitful knowledge and become one mainstream of the airport research field. The recent researches are developing the modeling of the vertical structure and oligopoly structure of the market (Brueckner (2002), Pels and Verhoef (2004), Zhang and Zhang (2006), Basso and Zhang (2007) and so on). These results contributed to a suggestions of the economic solutions.

On the other hand, administrative regulation is implemented in practice (even if it is clearly inefficient) when the economic (pricing) approach is difficult (de Neufville and Odoni (2003)). Slot control, perimeter limitation, aircraft size regulation in a specific airport and restrictions of number of landings are examples of the administrative regulations, and in fact, some airports implement such policies. The analysis of the influence by the policies in the real transport network by economic equilibrium models is in general difficult even if the model treats such a variable explicitly. Quantitative constraint in mathematical model means the existence of the corner solution essentially. Therefore, it is difficult to get analytical solution in the large-scale network problems.

Engineering based transport demand estimation models traditionally treat large scale network problems (for example, Kanafani and Ghobrial (1985), Hansen and Kanafani (1989), Hansen (1990), Ghobrial and Kanafani (1995)). Since the principal purpose of transport demand estimation model is accurate estimation of traffic volume, theoretical framework of the model is sometimes not consistent with economic equilibrium. When benefit analysis of the policy is necessary, this point becomes a problem.

Thus economic equilibrium models and transport demand estimation models have strong and weak points respectively. We have attempted to integrate the advantages of the models in order to analyze policy effects in actual network size. Ishikura (2007) defined a multi-layered zoning system and proposed a model which combined Cournot equilibrium model and a transport route choice model based on Takebayashi (2005). Although Ishikura (2007) presented formulation and validation of parameters, model performances such as sensitiveness and robustness are not checked yet. This paper applies the model to the multiple airports region in Japan and discusses the validity of the model by some scenario analysis.

2. THE MODEL

2.1 METHODOLOGY AND ASSUMPTIONS

We firstly represent the model framework which follows Ishikura (2007). We start by defining the market and zone classification. The model describes basically one OD pair market which includes several airports and air transport network within the OD market. The OD market assumes to be Cournot equilibrium. Furthermore we assume that air transport is substitutive to other transport modes such as bullet train; this assumption is common and empirically valid in Japan. We define the Cournot equilibrium model of the OD market as the first layer model. The first layer model derives equilibrium air fare and equilibrium demand. Note that the supply of airlines in the first layer model is the number of passengers but not the number of the flight.

The second layer model describes the optimal flight allocation problem considering the passenger's choice behavior. Each region of the first layer model has subregions. Airport access transport condition should be different between subregions even if the subregions are within same region of the first layer. The difference of airport access condition is an important factor of airport choice for passenger in multiple airports region.

Flight frequency is another critical factor of the choice behavior. The airport where more frequent flights are served is more convenient and attractive for travelers. Therefore flight allocation between airports in multiple airports region itself can affect to passenger travel pattern. The number of flights of each route can be variable which influences to demand and load factor of routes. Our second layer model assumes that airlines optimize the level of load factor of the flights by adjusting their flight allocation among flight routes in an OD market. Air fare and operation cost are predetermined by the first layer model and don't change in the second layer model. In one OD market, the lengths of the flight routes are almost same even if each region has multiple airports. Therefore we assume that marginal cost is same in one OD market.

The assumptions mean the second layer model does not treat economic matters. When airport pricing system in a multiple airports region is the discussion point, economic modeling approach should be adopted. However our interest is mainly in the administrative airport management policies such as direct slot control, aircraft size regulation and so on. We design the model structure so as to analyze the influences by such policies; in other words, our model handles above policy issues as explicit constraints.

Cost minimization is achieved only if airline's resource is utilized efficiently. Our second layer model is interpreted as a technological choice problem from an economic viewpoint. We regard passenger load factor as the index of efficient use of aircraft in the model. The model assumes that each airline has its desirable level of load factor and minimizes the gap between the target load factor and the expected load factor. Airlines can control the flight allocation between the routes, namely the number of flights of the airport-pairs, in an OD market. Since flight allocation itself affects passenger's airport choice behavior, airlines have to consider passenger's reaction. The second layer model is formulated as an optimization problem which has constraints about passenger behavior and the technological conditions.

The relationship of the two layers and whole structure of the model are shown in **Figure 1**. Finally the model derives the flight frequency and passenger demand of each flight route in the OD market. The

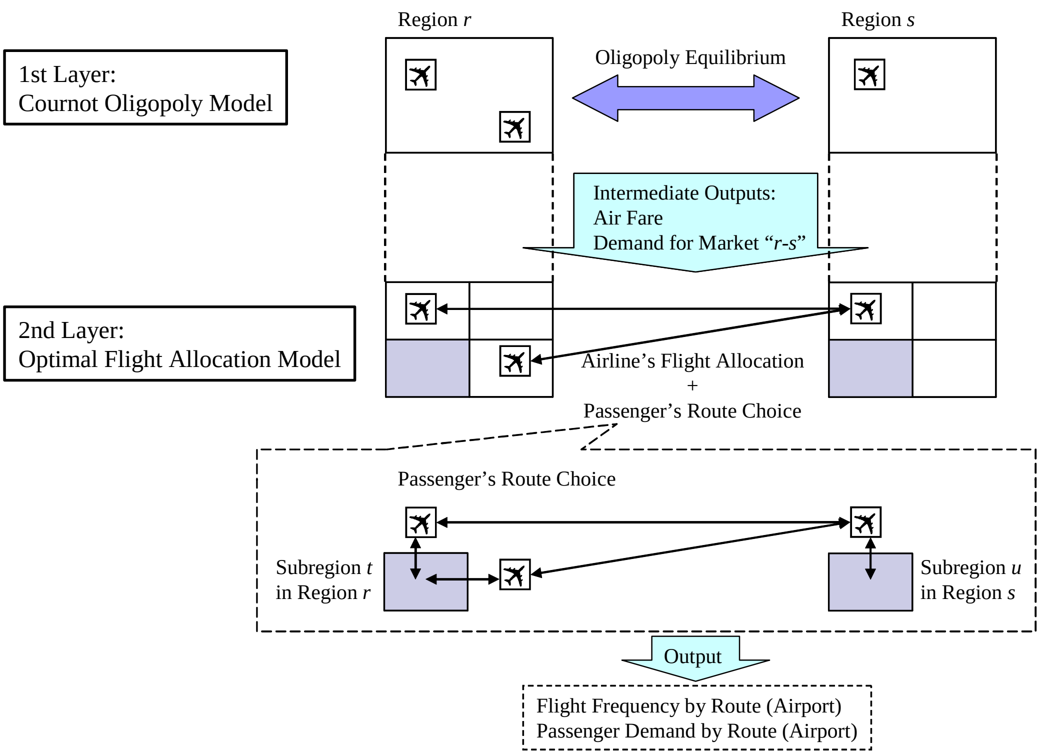

Figure 1 Whole Structure of the Model

following sections present the detail formulation of the model.

2.2 OD MARKET MODEL: FIRST LAYER

We consider here a simple Cournot equilibrium for an OD market. Generalized form of the model was built by Ishikura (2007). This paper provides the identified functional form of the model, having in mind of the application in the later chapter.

Let Q_{rs} denote the demand function of OD market between region r and region s. The demand depends on travel time indices of air and rail as well as standard variables, air fare and the income index. $t_{rs}{}^{air}$ and $t_{rs}{}^{rail}$ denote representative flight time and rail transport time respectively. When the OD market has the multiple airports in either (both) regions, flight time will differ among the flight routes. Therefore the representative flight time should be defined. We assume the specific (gravity type) demand function as follows.

$$Q_{rs} = e^{\beta_0} \left(t_{rs}^{air}\right)^{\beta_1} \left(p_{rs}\right)^{\beta_2} \left(t_{rs}^{rail}\right)^{\beta_3} \left(Y_r\right)^{\beta_4} \left(Y_s\right)^{\beta_5} \quad (1)$$

Where Y_r and Y_s denote regional income indices, gross regional products, of origin r and destination s respectively, and p_{rs} denotes air fare.

Airline i's cost function is denoted $C_{rs}{}^{i}$ and assumed to be the following linear function of passenger kilometers:

$$C_{rs}^{i} = \alpha \cdot l_{rs}^{i} \cdot Q_{rs}^{i} \quad (2)$$

where $l_{rs}{}^{i}$ denotes the length of the representative flight route and $Q_{rs}{}^{i}$ denotes passenger demand of airline i. The sum of the demand of airlines which enter the OD market rs is equal to the OD demand.

$$Q_{rs} = \sum_{i} Q_{rs}^{i} \quad (3)$$

The profit maximization under the Cournot competition market is written as the following expression:

$$\max_{Q_{rs}^{i}} \ \pi_{rs}^{i} = p_{rs} \cdot Q_{rs}^{i} - C_{rs}^{i} \quad (4)$$

First order condition (FOC) is given by the following simultaneous equations system:

$$\frac{\partial p_{rs}}{\partial Q_{rs}^{i}} \cdot Q_{rs}^{i} + p_{rs} - \frac{\partial C_{rs}^{i}}{\partial Q_{rs}^{i}} = 0 \quad \forall i \quad (5)$$

By solving the equations we can obtain equilibrium OD demand and airfare. The outputs of the above first layer model are inputs of the second layer model as the predetermined variables.

2.3 FLIGHT ALLOCATION MODEL: SECOND LAYER

This section illustrates the second layer model which describes the optimal flight allocation behavior by airlines. In the model, the objective of the airline is to utilize the seat resource efficiently. The vacant flight means the excess seat capacity and there will be a possibility of improving the aircraft utilization by reducing flight frequency. On the other hand the too high load factor may cause a kind of inefficiency. The average load factor is in general less than 80% even in congested flight routes because the flight schedule is relatively fixed comparing with demand fluctuation. Hence the airline must be losing the latent customers, if the flight of a route is always fully occupied. We assume that there exists the appropriate average load factor of flight routes and, hereafter call it target load factor.

The optimization problem of airline i is written as follows:

$$\min_{f_{rs}^{ik} \in F_{rs}^{iK}} \sum_{k \in K} \left(B_{rs}^{ik} \cdot f_{rs}^{ik} - q_{rs}^{ik} \right)^2 \quad (6)$$

s.t.

$$B_{rs}^{ik} = S_{rs}^{ik} \cdot L_{rs}^{ik} \quad (7)$$

$$\sum_{k \in K} q_{rs}^{ik} = Q_{rs}^{i} \quad (8)$$

$$S_{rs}^{ik} \cdot f_{rs}^{ik} - q_{rs}^{ik} \geq 0 \quad (9)$$

$$q_{rs}^{ik} = \sum_{t} \sum_{u} \left(q_{tu}^{i} \cdot Prob_{tu}^{ik} \right) \quad (10)$$

$$Prob_{tu}^{ik} = \frac{\exp\left(V\_k_{tu}^{ik}\right)}{\sum_{k \in K} \exp\left(V\_k_{tu}^{ik}\right)} \quad (11)$$

$$\begin{aligned} V\_k_{tu}^{ik} &= \phi_1 \cdot t_{rs}^{air} + \phi_2 \cdot p_{rs} \\ &\quad + \phi_3 \cdot \ln\left(f_{tu}^{ik}\right) + \phi_4 \cdot ACC_{tu}^{ik} \end{aligned} \quad (12)$$

The objective function (6) expresses that airline i

minimizes the gap between target load factor and the actual load factor by controlling f_{rs}^{ik} which denotes the number of flights in route *k*. B_{rs}^{ik} denotes the target seat allocation per flight in route k defined by the product of the seat capacity of the aircraft S_{rs}^{ik} and the target load factor L_{rs}^{ik} in (7): where S_{rs}^{ik} and L_{rs}^{ik} are given exogenously. q_{rs}^{ik} denotes the airline *i*'s passenger demand using flight route k and the sum of for all *k* must be equal to the predetermined equilibrium demand of the OD market Q_{rs}^{i} as expressed in (8). Aircraft seat capacity constraint is represented by (9).

Constraints (10), (11) and (12) express the route choice behavior of passenger who will travel from subregion *t* in region *r* to subregion *u* in region *s*. $Prob_{tu}^{ik}$ denotes the probability that passengers traveling from *t* to *u*, denoted by q_{tu}^{i}, choose the flight route *k*. The choice behavior is represented by a Logit Model expressed as (11) and (12). We adopt the Logit Mode which was used in the long run air demand forecast implemented by Ministry of Land, Infrastructure, Transport and Tourism Japan. In indirect utility function (12), t_{rs}^{air} denotes the flight time and p_{rs} denotes the air fare given by the first layer model. ACC_{tu}^{ik} denotes the accessibility index for passenger traveling from subregion *t* to subregion *u* using route k. ACC_{tu}^{ik} is defined by the Logsum variable calculated by the airport access transport choice model and ACC_{tu}^{ik} for every subregion-airport is given exogenously[1]. The utility function (12) includes the flight frequency f_{rs}^{ik} which is control variable of airline *i*. Therefore airline's flight allocation behavior affects passenger's choice behavior.

Finally, we must know q_{tu}^{i} in order to solve the problem. We assume that the demand share s_{tu} given by current actual travel pattern is unchanged and that s_{tu} is equivalent between airlines. Hence q_{tu}^{i} can be calculated by the following (13) and (14).

$$s_{tu} = \frac{q_{tu}}{\sum_{t \in r} \sum_{u \in s} q_{tu} \left(= Q_{rs}\right)} \tag{13}$$

$$q_{tu}^{i} = s_{tu} \cdot Q_{rs}^{i} \tag{14}$$

3. APPLICATION TO TOKYO-OSAKA MARKET

3.1 OVERVIEW OF THE MARKET

This chapter applies the model to a real market and analyzes the influence of some policy scenarios. We chose the transport market between Tokyo's peripheral region and Osaka's peripheral region; both regions have multiple airports system. The two regions are the largest regions in terms of economic and population level in Japan, and the volume of transport demand is also the largest. Currently Tokyo region has two airports for domestic civil aviation use: Haneda (HND) which is located on the almost center of the region and Narita (NRT) which is located on the northeast of the capital and mainly used for international hub. In the center of Osaka region, there are three airports to which domestic regular flights are served from Tokyo region. Osaka Int'l (ITM) is the closest airport from the Osaka's urban area and the largest airport in the region in terms of domestic passenger demand. Kansai Int'l (KIX) is the second largest international hub airport of Japan and located on the southwest of the Osaka's downtown.

Regarding both regions, the domestic hub airport (HND and ITM) is closer to the core urban area of the region than the other airports. The number of flights reaches almost the limit of the runway capacity in HND and ITM. Although HND's capacity will be expanded

[1] The detail of formulation of the choice models, definition of accessibility index and the parameters are published on the web of National Institute for Land and Infrastructure Management (http://www.ysk.nilim.go.jp/kakubu/kukou/keikaku/juyou.html (*in Japanese)).

by adding the new runway planned in 2010, it is almost impossible to increase the capacity of ITM. Furthermore due to the noise problem and environmental problem, aircraft type regulation at ITM is argued.

In Osaka region one new airport Kobe (UKB) opened in 2006. UKB is located on Kobe City whose population volume is over one million and which is the second largest city in the region in terms of the economic scale. Since Kobe City is near the center of Osaka metropolitan area, UKB's open influenced the air passenger's travel pattern and the competitive situation between ITM flight route and UKB flight route. Airway for UKB partially overlaps to airway for KIX, therefore the number of flights at UKB is restricted because of the safety from a viewpoint of air traffic management. The variation of the regulations regarding UKB's flight capacity will therefore be an important factor which affects the passenger travel pattern. However, our database is developing to include the level of service data of UKB's access transport and the passenger travel data currently. This analysis, unfortunately, does not include UKB, and we will treat it in future research work.

3.2 INITIAL CONDITIONS AND SCENARIO CASES

This section sets up the parameters of functions and the basic initial conditions for the application analysis. The parameters of demand function (1) are given by Ishikura (2007) which estimated by using cross sectional data of domestic air transport market of Japan and shown in **Table 1**. We assume two homogenous airlines enter the OD market; marginal cost is equivalent between them. Marginal cost parameter alpha is 0.91015 (JPY per passenger kilometer) given by following Ishikura (2007) as well as demand function. The paremeters of utility function of the logit model is imported as mentioned in section 2.3 and represented in **Table 2**.

There are two airports (HND and NRT) in Tokyo region and three airports (ITM, KIX and SHM(Nanki Shirahama)) in Osaka region; SHM is a small airport located on south of Osaka region. The second layer model treats the four regular flight routes between Tokyo-Osaka OD market; NRT-ITM, HND-ITM, HND-KIX and HND-SHM.

Table 1 Parameters of Demand Function

Parameter	Value
β_0	-11.716
β_1	-1.587
β_2	-0.849
β_3	1.745
β_4	0.894
β_5	0.899

Table 2 Parameters of Utility Function

Parameter	Value
ϕ_1	-2.355E-02
ϕ_2	-2.948E-04
ϕ_3	7.523E-01
ϕ_4	7.599E-01

The type of aircraft flown in each route is exogenously given and only the seat capacity is the characteristic of the aircraft in the model. Initial setting of the seat capacity by flight route is shown in **Table 3** and the pattern will be changed in the policy scenario cases. Furthermore we assume that target load factor is 70% for all routes.

The current political matters argued actually are aircraft size restriction of ITM and the airport capacity constraints. We prepare 5 virtual cases which illustrate the exogenous change of aircraft size and the limitation of the maximum number of flights in the specific routes as summarized in **Table 4**. Case 1 and Case 2 illustrate the policy scenarios that aircrafts flying from/to ITM are downsized by the regulations. Case 3 and Case 4 illustrate the scenarios that the maximum number of flights in HND-ITM and NRT-ITM are limited due to the airport capacity limitation. Although airport capacity means the capacity of the node, we treat the link capacity as an alternative index of the airport capacity. It is because our model treats one OD market, however multi OD model will be possible by rewriting constraints of the second layer model.

Table 3 Number of Seats per Aircraft by Flight Route

NRT-ITM	HND-ITM	HND-KIX	HND-SHM
400	400	350	160

Table 4 Scenarios by Case

	Case 0 (Base)	Case 1	Case 2	Case 3	Case 4	Case 5
Seat capacity of the aircraft of NRT-ITM	400	350	300	400	400	350
Seat capacity of the aircraft of HND-ITM	400	350	300	400	400	350
Maximum number of flight of NRT-ITM (per day)	unlimited	unlimited	unlimited	6	6	6
Maximum number of flight of HND-ITM (per day)	unlimited	unlimited	unlimited	18	15	15

3.3 RESULTS

Firstly we state the accuracy of the model system. Statistical fitting index cannot be applied in order to evaluate the model accuracy because our model is not a sort of regression model. Therefore, we show the fitting performance of the model by the mapping of the relationship between the estimated passenger demand and the actual passengers of inter-subregion as presented in **Figure 2**. The result shows that the model can estimate overall characteristics of the demand distribution, however in some subregion the residual is large.

The analysis results regarding the flight routes are represented in **Table 5**, **Table 6** and **Table 7**. The results of Case 0 mean that HND-ITM route has a competitive advantage to other routes basically. When aircraft size regulation is implemented as Case 1 and Case 2, airlines will increase the number of flights in HND-ITM routes and reduce the supply in other routes. If the aircraft size is restricted to small size and the flight frequency is not limited, the airline has incentive to remain the volume of seat supply of larger demand routes by adding the number of flights. As a result, choice probability of the route like HND-ITM rises and the competitive route like HND-KIX loses the demand.

The regulation of supply at ITM will influence the competitive situation within the Osaka region's market drastically.

In Case 3 and Case 4, the constraint of the number of flight of HND-ITM is effective.

The number of flights of NRT-ITM route is constrained as well as HND-ITM in Case 5 which assumes that the maximum number of flights and the aircraft size are simultaneously regulated. The combination of aircraft size regulation and the upper bound of the flight frequency strongly restricts the supply at ITM in Case 5. However, the passenger demand in HND-ITM is the largest because of the advantage of accessibility.

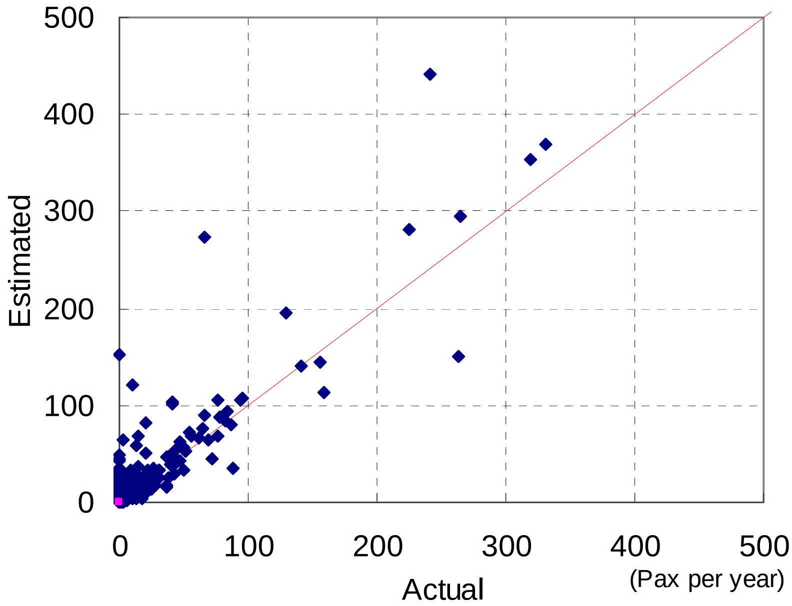

Figure 2 Fitting of the Model in Terms of Passenger Demand Between Subregions

Table 5 Number of Flights by Route (/year)

	NRT-ITM	HND-ITM	HND-KIX	HND-SHM
Case 0	974	7,116	4,980	817
Case 1	1,171	9,065	3,992	816
Case 2	1,799	10,950	3,395	812
Case 3	1,229	6,570	5,344	814
Case 4	1,593	5,475	6,102	811
Case 5	2,190	5,475	6,259	809

Table 6 Number of Passengers by Route (/year)

	NRT-ITM	HND-ITM	HND-KIX	HND-SHM
Case 0	272,728	1,992,657	1,220,079	91,486
Case 1	286,856	2,220,906	978,113	91,385
Case 2	351,910	2,333,091	801,333	91,147
Case 3	321,129	1,879,559	1,284,802	91,357
Case 4	390,254	1,665,315	1,429,809	91,213
Case 5	467,488	1,606,575	1,411,502	91,040

Table 7 Passenger Load Factor by Route

	NRT-ITM	HND-ITM	HND-KIX	HND-SHM
Case 0	70.0%	70.0%	70.0%	70.0%
Case 1	70.0%	70.0%	70.0%	70.0%
Case 2	65.2%	71.0%	67.4%	70.1%
Case 3	65.3%	71.5%	68.7%	70.1%
Case 4	61.2%	76.0%	67.0%	70.3%
Case 5	61.0%	83.8%	64.4%	70.3%

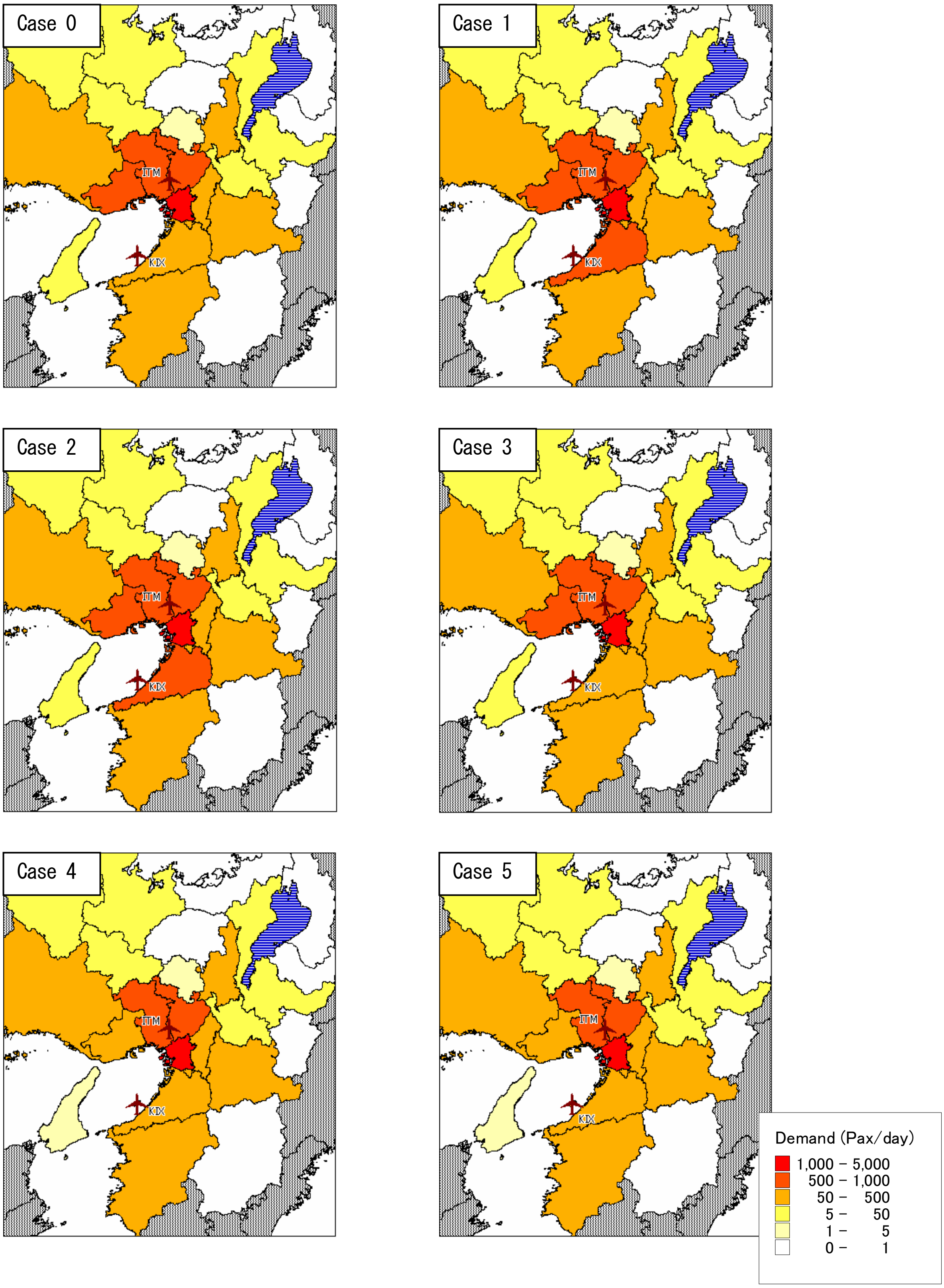

Figure 3 Passengers Using HND-ITM Route by Subregion

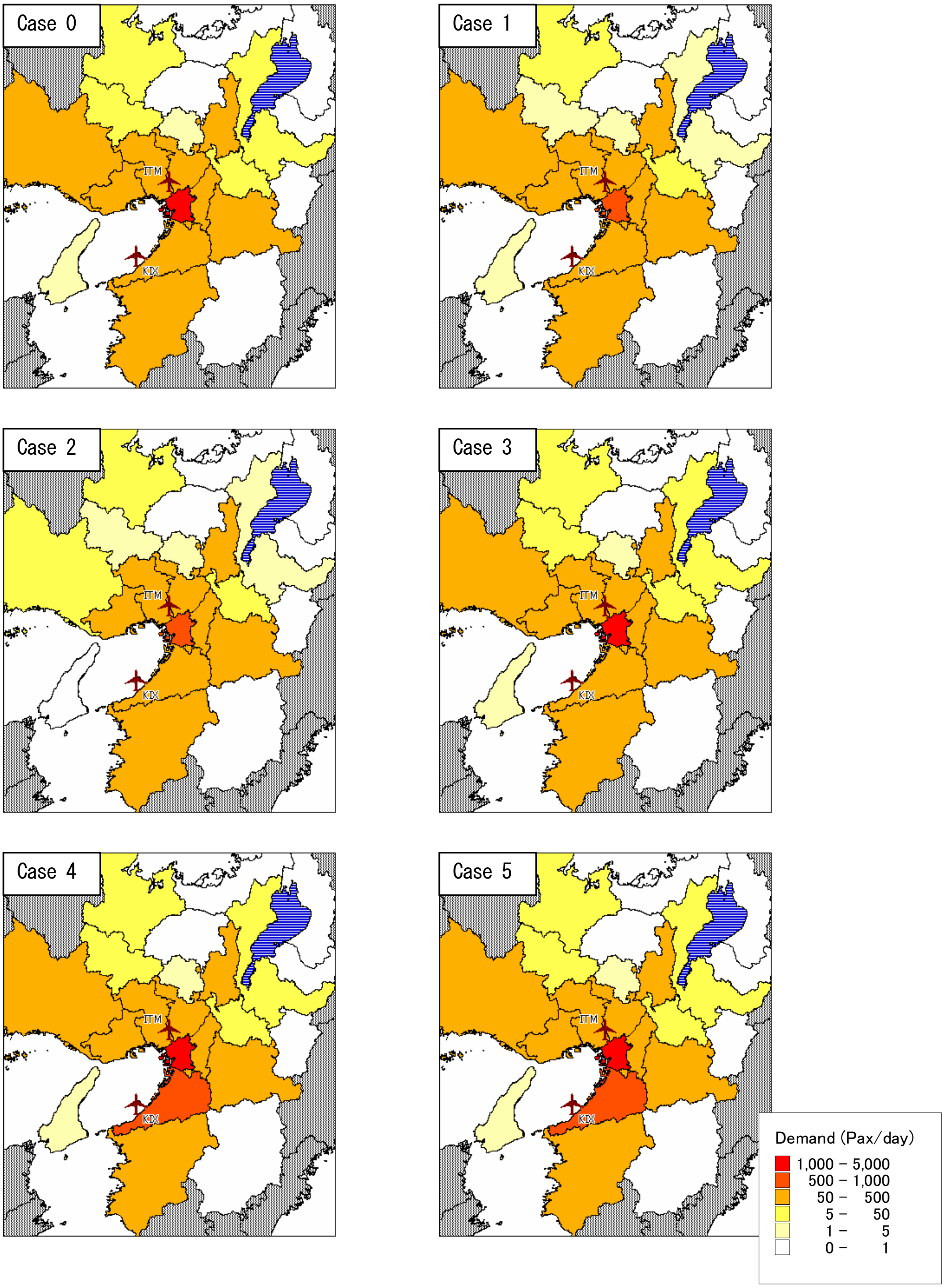

Figure 4 Passengers Using HND-KIX Route by Subregion

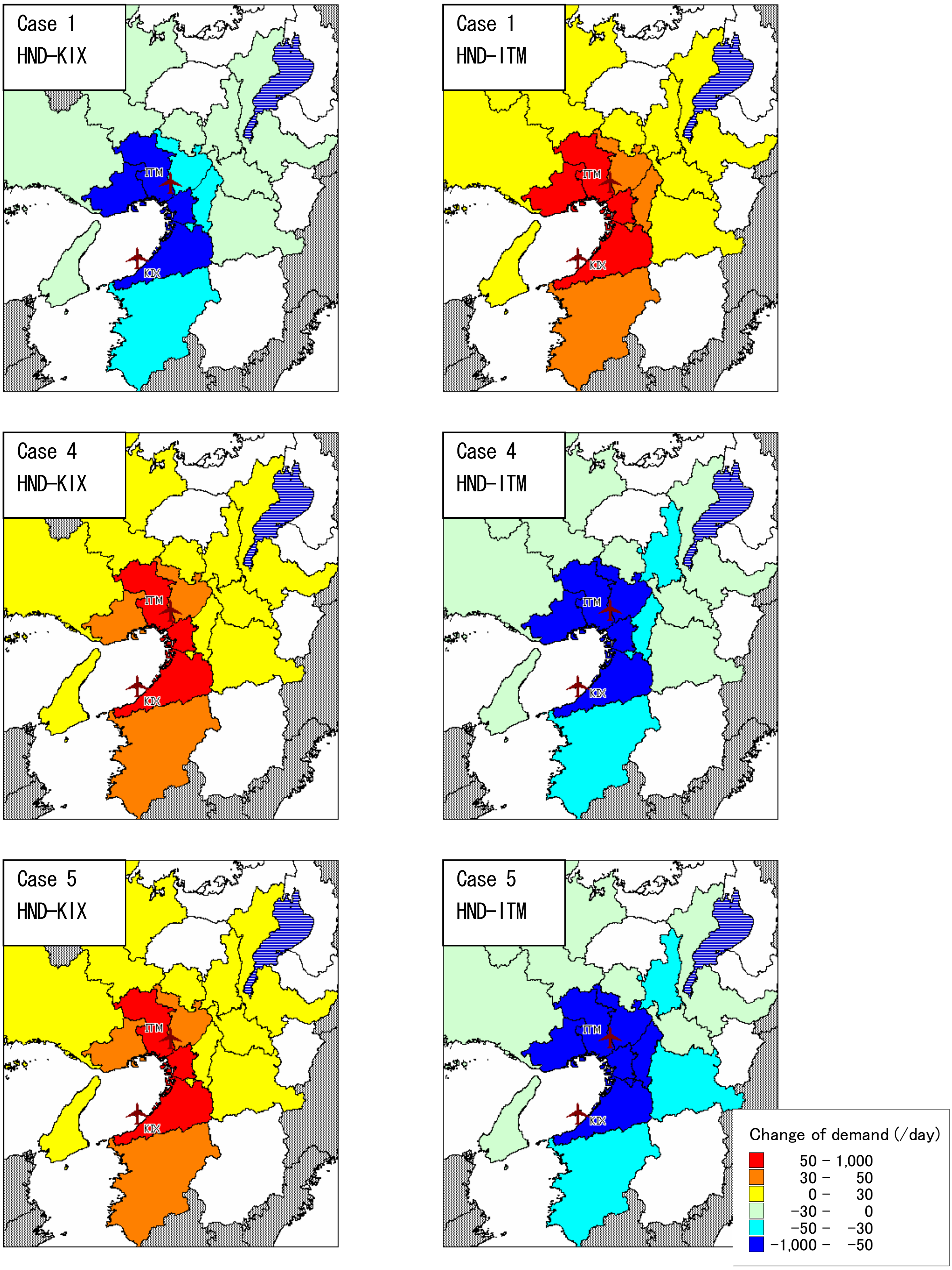

Figure 5 Change of Passengers from Case 0

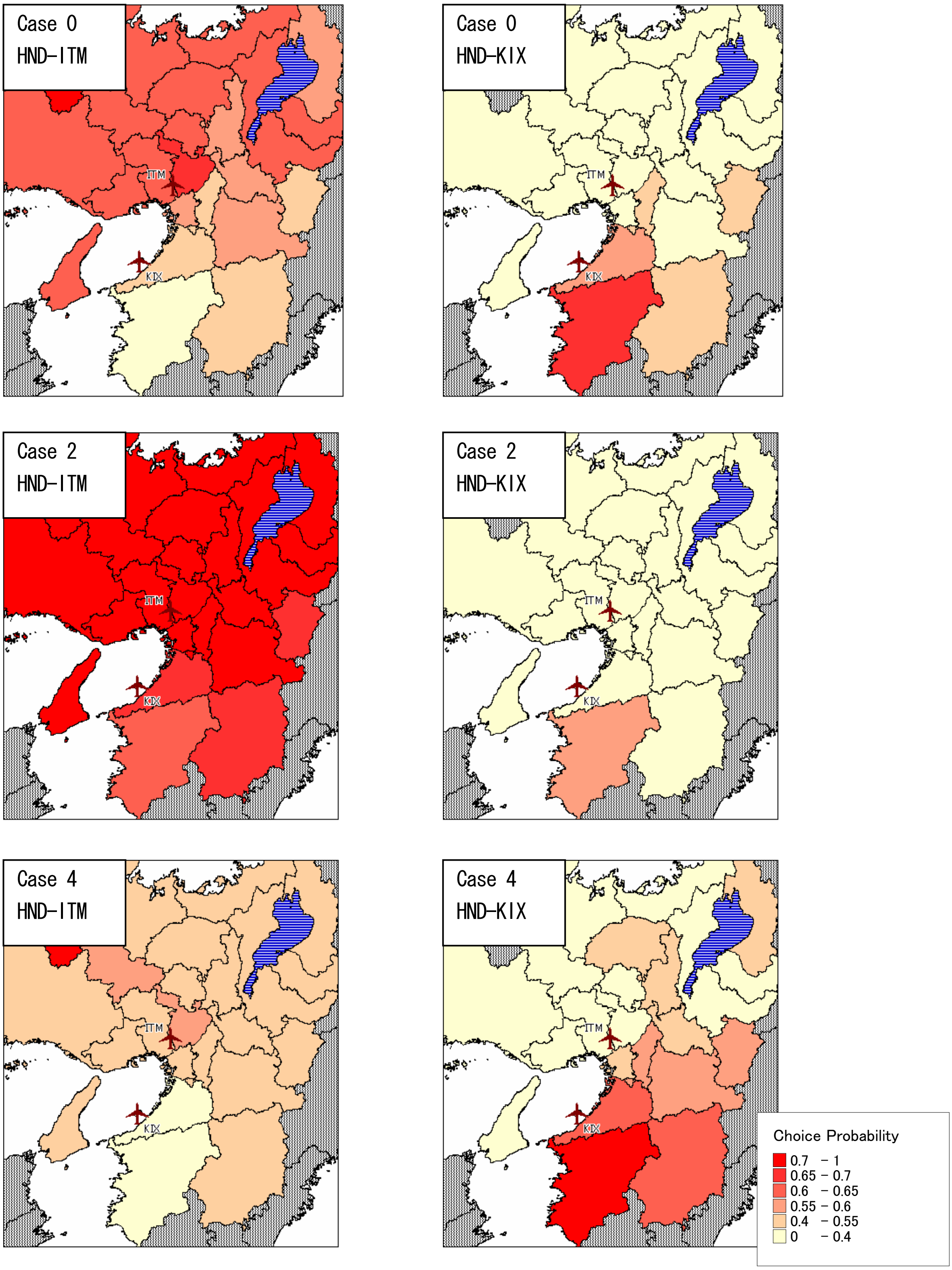

Figure 6 Choice Probability

Figure 3 and **Figure 4** show the spatial distribution of passenger demand of each subregion using HND-ITM route and HND-KIX route respectively. The change from Case 0 of the passengers using HND-KIX and HND-ITM in some selected cases is expressed in **Figure 5**, and it shows that subregions around Osaka Bay are influenced largely. The volume of the change of the passenger demand by the route depends on total air passenger volume of the subregion. The result implies that the administrative regulations or restrictions may affect mainly Osaka Bay area in terms of the aggregated flow of the demand.

Figure 6 represents the distribution of the choice probability by the route in Case 0, Case 2 and Case 4. In Case 2 which assumes the aircraft size regulation at ITM, HND-ITM route is more attractive choice alternative for the passengers of most subregions. On the other hand, in Case 4, HND-KIX route becomes the better choice for the passengers of the southeast part in Osaka regions. In terms of passenger behavior, the influence on the southeast sub regions may be relatively large.

4. CONCLUDING REMARKS

This paper has shown the methodological framework of a layered model in order to analyze administrative policies in multiple airports market with detailed zoning. We have illustrated the formulation based on Ishikura (2007), and applied the model to the real Tokyo-Osaka market. In the application study, we have examined some administrative policies about aircraft size and upper limit of the maximum number of the flights and obtained the basic prospects and implications.

Our model emphasizes the airport choice behavior of passengers and airlines, and economic aspects such as cost function are simplified. The development of the first layer's oligopoly model is the first direction of the improvement of the research. Although our current model treats single OD market, it is necessary to consider multiple ODs in order to argue the matters regarding airport slot capacity. The improvement to multi ODs framework is another important future work.

（Accepted November 14, 2008）

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