EFFECT OF BUNDLING OF MULTIPLE AIRPORTS WITH TRIP-CHAIN FORMATION

Fangzhou XU[1], Shinya HANAOKA[2] and Masamitsu ONISHI[3]

[1]Non-member, Dept. of Transdisciplinary Science and Engineering, Tokyo Institute of Technology
(2-12-1-Ishikawadai 4, O-okayama, Meguro-ku, Tokyo 152-8550, Japan)
E-mail: xu.f.ad@m.titech.ac.jp

[2]Member of JSCE, Professor, Dept. of Transdisciplinary Science and Engineering, Tokyo Institute of Technology
(2-12-1-Ishikawadai 4, O-okayama, Meguro-ku, Tokyo 152-8550, Japan)
E-mail: hanaoka@ide.titech.ac.jp

[3]Member of JSCE, Associate professor, Disaster Prevention Research Institute, Kyoto University
(Gokasho, Uji, Kyoto 611-0011, Japan)
E-mail: onishi.masamitsu.7e@kyoto-u.ac.jp

In this study, an optimization model is developed to simulate air transport market in different situations. In the model, objectives of market participant, involving airports, airlines and passengers are formulated and interactions between them are simulated. Decisions of each participant are optimized by payoff maximization endogenously and final outcome of the market is evaluated. Trip-chain passengers with multiple destinations to visit during one journey are specifically considered, their possible moving modes are generated by a shortest path sub-model. Airport bundling in Hokkaido, a plan that will be carried out with 2020, is taken as an example for case study. The effect is analyzed and discussed through comparison between market participants' decision-making and final outcome before and after bundling.

Key Words : *airports bundling, airports privatization, trip-chain*

1. INTRODUCTION

Airports were traditionally owned and operated by public sectors. However, since the first major case took place in the United Kingdom in 1987, airport privatization has become a worldwide trend[1)]. Take Japan for example, since the first privatization that took place in Narita airport in 2004, until now, 5 airports have been fully or partially privatized and more future privatizations have been planned[2)].

In Japan, airport privatization is expected to have positive ripple effect. Financial independence and integrated operation of aeronautical and non-aeronautical facilities allows revenue allocation inside airport, improves economic health and enables the levy of lower airport usage fee. Lower airport usage fee strengthens competitiveness of airport and attracts the establishment of more airways and flights. Increasing demand then promotes the development of local economy.

Among privatization cases and schemes of Japanese airports, Hokkaido scheme draw more attention. The integrated privatization of multiple distant airports in one region is called bundling. In addition to the mentioned positive effect, enlargement of flights and airways inside region and increase of trip-chain travel demand are also expected. Bundling allows coordination of price setting between airports and stimulate airlines to employ friendlier airway pattern, airfare and frequency inside the region for travelers, thus it is considered to raise the trip-chain demand, create more local consuming and make greater contribution to the local economy.

However, expected positive effect of privatization will not always come. There are some examples of failure and argument about privatization from various perspective haven't stopped from the beginning. Moreover, there are few studies focusing on bundling case. Thus, this study aims to analyze the effect of airport bundling involving: (a) How will airports optimize their strategy when their decision-making modes change? (b) How will airlines and travellers respond and change their decision according to the modified strategy of airports? (c) Will these changes eventually benefit the whole industry and region? To clarify these effects theoretically, an optimization model is developed to simulate interaction between and decision-making of each participant and obtain final outcome of the air transportation market. The proposed model is then used to analyze possible effect of airports-bundling in Hokkaido, an actual plan that will be carried out within 2020, through the comparison of simulated decisions of market participants and outcome before and after bunding.

2. METHODOLOGY

(1) Basic configuration

a) Air transportation market

In this study, air transport market is modelled to be composed of three types of participants: airports, airlines and passengers. Each participant has its own objective. Each participant attempts to achieve its objective by making decision, but desired outcome of objective cannot be realized independently, for the outcome of each participant is not only affected by its own decision, but also by decisions of others. Thus, outcome is determined by the interactions between participants: how one is affected by others' decisions and how one's decisions affect others. Airports, the up-stream leader of market, will make decision at first, they set charge to airlines and passengers considering their reaction for the purpose of profit or social surplus maximization. Receiving charge from airports, the mid-stream follower, airlines, will set airway pattern, airfare and frequency for the purpose of profit maximization, considering passengers' acceptance. At last, as down-stream followers, considering charge from airport and tactics of airlines, potential passengers decide their destination choice, airline choice and route choice. (**Fig.1**)

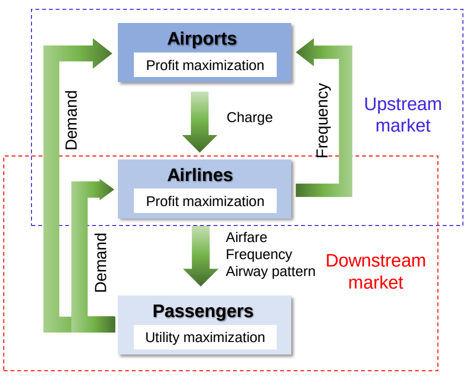

Fig.1 Diagram of air transport market

b) Assumptions

General settings

Every market participant is rational and attempts to maximize its payoff. Demand for flight service is independent from commercial activities[3] and consumer surplus derived from commercial activities is not taken into account.

Airports

There are public and private airports. Charges of public airports are predetermined by government, the charges exactly cover the operating cost to ensure airports' minimum necessary operation. Charges of private airports are set to maximize profit or social surplus in some cases.

Airlines

There are multiple airlines competing with each other with collusion. Airlines have the freedom to adopt any kinds of airway pattern, airfare and frequency only between distant airports.

Passengers

There are two types of passengers/travellers: one-way travellers and trip-chain travellers. One-way travellers have fixed origin and destination. Trip-chain travellers will determine their destination based on travel utility. They can visit multiple destination during one journey and return to origin. Both type of travellers will only choose paths with fewest sections (e.g. if there are direct routes between A and B, travellers setting out from A visiting B will not transit in other sites). Land transportation is available when distance between origin and destination is not so long.Ignore the factor of congestion cost.

c) Framework

The model simulates interactions between and derives optimal decisions of each participants in a backward thinking, regarding the market as a Stackelberg competition. Each participant makes decision considering possible optimal response of its follower. The general description of the model is shown in **Table 1**.

Table 1 General description of the model

Input parameter	
Demand	Number of potential demand, passengers' sensitivity parameter of monetary and time cost, log-sum
Airline	Operating cost, attribute of aircrafts
Airport	Operating cost, concession revenue per passenger
Others	Attribute of sites, air routes and land routes, parameter of logit model, attractiveness value of destinations
Variable	**Optimization problem**
Demand $\mathbf{x}$ Airfare $\mathbf{p}$ Frequency $\mathbf{f}$ Charge $\mathbf{T}$	Airports $\max_{\mathbf{T}} \gamma(\mathbf{T}, \mathbf{f}_i, \mathbf{x}_i(\mathbf{p}_i, \mathbf{f}_i, \mathbf{T}))$ Where $\mathbf{p}_i = [\mathbf{p}_h \ \ \mathbf{p}_{-h}] \ \ \mathbf{f}_i = [\mathbf{f}_h \ \ \mathbf{f}_{-h}]$ Airlines $\mathbf{p}_h, \mathbf{f}_h = \arg\max_{\mathbf{p}_h, \mathbf{f}_h} \pi_h(\mathbf{p}_h, \mathbf{f}_h, \mathbf{x}_h(\mathbf{p}_h, \mathbf{f}_h, \mathbf{p}_{-h}, \mathbf{f}_{-h}, \mathbf{T}), \mathbf{T})$
Outcome	
Optimal value of decision variables: demand, airlines' airfare and frequency, airports' charge, profit of airlines, profit of airports, consumer surplus, social surplus	

(2) Model formulation

a) Formation of trip-chains and moving modes

Given a set of sites $V = \{v_1, v_2, \cdots, v_n\}$ and connectivity between each sites pair. For travelers who set out from origin site s, visit a series of sites $R =$

$\{r_1, \cdots, r_m\}$ and then return to s. For one-way travellers, possible moving modes can be derived through Yen's algorithm[4]. For trip-chain travellers, possible moving modes are obtained by following method:

1. Create adjacency matrix A of vertex(sites) set V. Then set value A_{ij} to 1 if site v_i and v_j are connected, otherwise set A_{ij} to ∞.

2. List all possible sites visiting sequences of the journey, by calculating the permutation of all elements of visiting sites series R. Besides, remove sequences symmetric with others. Here, Q and Q' are regarded 'symmetric' if, for all $k \in$ M, the element q_k of sequence vector Q is equal to the element q'_{m+1-k} of sequence vector Q'. For example, when R = {2,3,4}, all possible permutations are {2,3,4}, {2,4,3}, {3,4,2}, {4,3,2}, {3,4,2}, {2,4,3}. Removing symmetric ones, final possible sites visiting sequences are {2,3,4}, {2,4,3}, {3,4,2}.

3. Create dummy graph $\bar{G}$ of V for each sequence Q. The matrix $\bar{A}$ of $\bar{G}$ has a shape of the block diagonal matrix of m+1 A matrices, while all 0 elements are set to ∞ except elements $\bar{A}(q_k + n(k-1), q_k + nk)$ and $\bar{A}(q_k + nk, q_k + n(k-1))$ for all k. For example: when V = {1,2,3,4} , $A = \begin{bmatrix} \infty & 1 & 1 & \infty \\ 1 & \infty & 1 & 1 \\ 1 & 1 & \infty & 1 \\ \infty & 1 & 1 & \infty \end{bmatrix}$, origin site s is 1 and sequence Q is (2,3), the matrix $\bar{A}$ of dummy graph $\bar{G}$ where $\bar{A}(2,6), \bar{A}(6,2), \bar{A}(7,11), \bar{A}(11,7)$ remain as 0 is:

$$\bar{A} = \begin{bmatrix} \infty & 1 & 1 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty \\ 1 & \infty & 1 & 1 & \infty & 0 & \infty & \infty & \infty & \infty & \infty & \infty \\ 1 & 1 & \infty & 1 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty \\ \infty & 1 & 1 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & 1 & 1 & \infty & \infty & \infty & \infty & \infty \\ \infty & 0 & \infty & \infty & 1 & \infty & 1 & 1 & \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty & 1 & 1 & \infty & 1 & \infty & \infty & 0 & \infty \\ \infty & \infty & \infty & \infty & \infty & 1 & 1 & \infty & \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 & 1 & \infty \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 & \infty & 1 & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & 0 & \infty & 1 & 1 & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 & 1 & \infty \end{bmatrix}$$

Fig.2 shows an intuitive expression of the dummy graph $\bar{G}$.

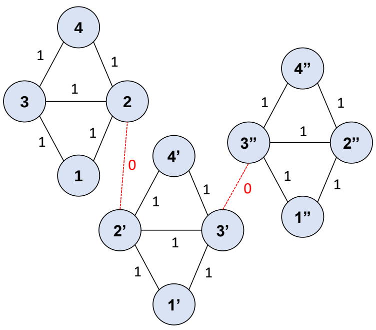

Fig.2 Image of dummy graph

4. Use Yen's algorithm[4] to find out single or multiple shortest paths $P_Q^1, \cdots, P_Q^h$ from origin site s to destination d for each sequence Q. d is actually the clone point of s in the farthest side of dummy graph (e.g. 1'' in figure 1) with a site index $s + nm$. Restore the remaining indexes by subtracting the elements of P that are greater than n repeatly until no elements are greater than n. Remove the overlapping indexes. (e.g. in the example above, untreated shortest path result is P = (1, 2, 6, 7, 11, 9), by restoring, P = (1, 2, 2, 3, 3, 1), by removal, P = (1, 2, 3, 1).)

5. For each path, obtain all possible moving mode, that means, the combination of which transport mode to use in each segment of the path. For each segment p_i-p_{i+1}, generate a vector $\mathbf{t}_{p_i p_{i+1}} = [1,2,\cdots,l]$ of all possible transportation modes including the choice of airline companies. Then, solve the combination problem of taking one element from each vector. Use the example above, if $\mathbf{t}_{12} = [1,2]$, $\mathbf{t}_{23} = [1,2,3]$, $\mathbf{t}_{31} = [1]$, all possible 6 moving modes for path P is listed as:

$d_1^P = (1,1,1)$ $d_2^P = (2,1,1)$ $d_3^P = (1,2,1)$
$d_4^P = (2,2,1)$ $d_5^P = (1,3,1)$ $d_6^P = (2,3,1)$

For each mode d of each path, create a 3-dimensional cost matrix C with l pages (the third dimension) where l is the number of transportation modes for the path. if $d_{ij} = t$, set $C(i,j,t) = 1$, otherwise 0. Note that if a path includes more than one segment between two sites to be visited, and the moving modes (actually airline company) for these segments are same, set corresponding elements of cost matrix to discount rate, which is for connecting flight.

b) Demand function

Logit formulation is adopted to derive the demand of each alternatives[5]. In the case of one-way traveller, based on disutility perception of the trip, there are two phases of decision-making. At first, one needs to decide whether to take the trip (phase i). Then, for travelers determining to take the trip, next decision to make is which airline/route to choose (phase j). V_{OD_j} (Eq. (1)) denotes the deterministic utility of each route w of each OD. p, t, dl, ly denote transport fee, travel time, schedule delay time and lay-over time respectively[6]. Monetary and time cost of each alternative(moving mode) is derived through its 3-dimensional cost matrix C. The demand N_{OD_j} of each route w of each OD is derived as Eq. (2) ~ (4).

$$V_{OD\_j} = -\theta\left(p_{OD\_j} + \alpha t_{OD\_j} + \beta\left(dl_{OD\_j} + ly_{OD\_j}\right)\right) \quad (1)$$

$$\Gamma_{OD\_Y} = \mu \ln\left(\sum_{j^* \in J} \exp\left(\frac{1}{\mu} V_{OD\_j^*}\right)\right) \quad (2)$$

$$N_{OD\_Y} = N_{OD} \exp\left(\Gamma_{OD\_Y}\right) \quad (3)$$

$$N_{OD\_j}=N_{OD\_Y}\frac{\exp\left(\frac{1}{\mu}V_{OD\_j}\right)}{\sum_{j^*\in J}\exp\left(\frac{1}{\mu}V_{OD\_j^*}\right)} \quad (4)$$

In the case of trip-chain travelers, there are four phases of decision-making. At first, one decides whether to join the journey (phase i). Then, for passengers determining to join the journey, they will consider destination then (phase j). After determining destination, they need to think about transportation mode for moving (phase k). Finally, passengers will decide detailed trip-chain (mode) (phase r) for their journey. The demand N_r of each trip-chain r is derived as Eq. (5) ~ (10).

$$V_r=-\sigma\left(p_r+\alpha t_r+\beta(dl_r+ly_r)\right) \quad (5)$$

$$\Gamma_k=\frac{\mu_k}{\mu_j}\ln\left(\sum_{r^*\in R}\exp\left(\frac{1}{\mu_k}V_{r^*}\right)\right) \quad (6)$$

$$\Gamma_j=\frac{\mu_j}{\mu_i}\ln\left(\sum_{k^*\in K}\exp(\Gamma_k)\right)+\frac{1}{\mu_i}At_j \quad (7)$$

$$\Gamma_i=\mu_i\ln\left(\sum_{j^*\in J}\exp(\Gamma_j)\right) \quad (8)$$

$$N_{ijk}=N\frac{\exp(\Gamma_i)}{1+\exp(\Gamma_i)}\frac{\exp(\Gamma_j)}{\sum_{j^*\in J}\exp(\Gamma_{j^*})}\frac{\exp(\Gamma_k)}{\sum_{k^*\in K}\exp(\Gamma_{k^*})} \quad (9)$$

$$N_r=N_{ijk}\frac{\exp\left(\frac{1}{\mu_k}V_r\right)}{\sum_{r^*\in R}\exp\left(\frac{1}{\mu_k}V_{r^*}\right)} \quad (10)$$

As a result, demand of air route ρ of airline company h x_{hl} can be can be derived as shown in Eq. (11). $\delta_{ODjh\rho}$ is a binary variable that equals 1 when trip w of OD contains route ρ of airline h, and 0 otherwise. $\delta_{rh\rho}$ equals 1 if trip-chain r contains route ρ of airline h, and 0 otherwise.

$$x_{h\rho}=\sum_{OD}\sum_{w}N_{OD\_i}\delta_{ODih\rho}+\sum_{r}N_r\delta_{rh\rho} \quad (11)$$

c) Airline's profit maximization

The profit of airline h is defined as profit from flight services, as shown in Eq. (12). In RHS, first term denotes revenue generating from airfare, $\mathbf{p}_h,\mathbf{x}_h$ is the vector of airfare set by airline h and traffic demand of airline h in each airway, respectively. second term denotes aircraft operating cost. $\mathbf{f}_h,\mathbf{s}_h$ is the vector of frequency set by airline h and the seating capacity of aircraft of airline h in each airway, respectively. $\mathbf{D}$ is the diagonal matrix of airway distance of each airway link d_l. c_h denotes unit cost of airline h [7]. Third term denotes charge from airports. $T(\mathbf{wg}_h)$ is the mapping of maximum landing weight of aircraft of airline h in each airway $\mathbf{wg}_h$, denotes the charge that airline needs to pay flying each link, which is the summation of the charge from two end-point airport of the link.

$$\pi_h=\mathbf{p}_h^{\mathrm{T}}\mathbf{x}_h-2c_h\mathbf{f}_h^{\mathrm{T}}(\mathbf{D}\mathbf{s}_h)-\mathbf{f}_h^{\mathrm{T}}T(\mathbf{wg}_h) \quad \forall h\in H \quad (12)$$

Airlines respond to charges from airports and compete in duopolistic airline market, by optimizing their own frequency (airway pattern) and airfare (Eq. (13)). $\mathbf{p}_{-h},\mathbf{f}_{-h}$ are matrixs of airfare and frequency of each link/route of other airlines besides h. $\mathbf{T}$ is the vector of landing fee of each airport. Capacity constraint that, passenger flow on every link should not exceed the total seat capacity offered, needs to be satisfied (Eq. (14)).

$$\max_{\mathbf{p_h},\mathbf{f_h}}\pi_h(\mathbf{p_h},\mathbf{f_h},\mathbf{p_{-h}},\mathbf{f_{-h}},\mathbf{T}) \quad \forall h\in H \quad (13)$$

$$\text{s.t. } f_{hl}s_{hl}\geq x_{hl} \quad \forall h\in H \quad \forall l\in L \quad (14)$$

d) Airport's profit maximization

The profit of airport a is defined as Eq. (15). First term of RHS refers to aeronautical profit generating from landing fee. $\mathbf{f}_a$ is the vector of frequency of each aircraft type landing on airport a. $\mathbf{T}_a$ is the vector of charge to set to each aircraft type landing on airport a. $\mathbf{c}_a$ is the vector of marginal operating cost per flight landing of each aircraft type of airport a. Second term refers to concession profit generating from commercial activities. pt_a and z_a denote the average non-aeronautical profit from per visitor and number of visitors of airport a, respectively.

$$\gamma_a=\mathbf{f}_a^{\mathrm{T}}(\mathbf{T}_a-\mathbf{c}_a)+pt_az_a \quad \forall a\in A \quad (15)$$

When airports are bundled, suppose that the new private operator will optimize charge of each airport for the purpose of maximizing gross profit of all airports subject to slot constraint (Eq. (16) ~ (17)). When setting charge, airport will consider the optimal response of downstream market in order to get maximum payoff.

$$\max_{\mathbf{T}}\sum_{a}\gamma_a(\mathbf{f},\mathbf{x},\mathbf{T}) \quad (16)$$

$$\text{s.t. } \sum_{h}f_{ha}\leq S_a \quad \forall a\in A \quad (17)$$

e) Social surplus function

Social surplus is defined as the summation of profit of airlines, profit of airports and consumer surplus, as shown in Eq. (18). Consumer surplus is shown in Eq. (19) as the summation of consumer surplus of one-way passenger and trip-chain passenger. It is obtained as integral of the demand function with respect to price, from the market price to the maximum reservation price.

$$SS = \sum_h \pi_h + \sum_r \gamma_r + CS \quad (18)$$

$$CS = \sum_{OD} \left(\int_{-(\Gamma_{OD_Y}/\theta)}^{\infty} N_{OD}\, exp(-\theta\omega)\, d\omega \right) + \int_{-(\Gamma_i/\sigma)}^{\infty} N \frac{exp(-\sigma\omega)}{1 + exp(-\sigma\omega)} d\omega \quad (19)$$

(3) Solving procedure

This problem can be regarded as an optimization problem with two sub-level: airport level and airline level[8]. The brief flow chart of the problem is shown as **Fig.3**.

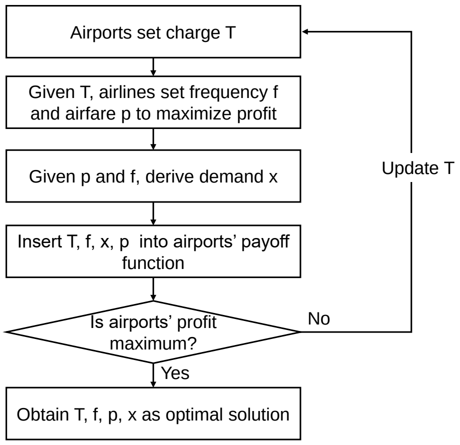

Fig.3 Procedure of optimization

The problem of airline level can be regarded as a competition with non-cooperative collusion, a multi-objective optimization. However, a Nash equilibrium does not necessarily exist[9]. Thus, Non-dominated Sorting Genetic Algorithm is used to obtain pareto solution of airline level[10]. The optimization problem of outer level, airport level is solved by Particle Swarm Optimization (PSO) algorithm.

3. NUMERICAL COMPUTATION

1) Basic scenario

As case study, the effect of airport bundling in Hokkaido will be analyzed by the model. However, the computation complexity will be quite high if we consider all 7 airports involved in the actual plan and airways connecting them. Thus, some simplifications are made: seven airports are categorized into 3 types B, C and D defined in assumption based on their attribute, and each type is imagined as one single airport (**Fig.4**). Suppose there are two airlines with similar market power in the market and only one land transport medthod(bus) is available. Parameters are set based on actual situation if possible.

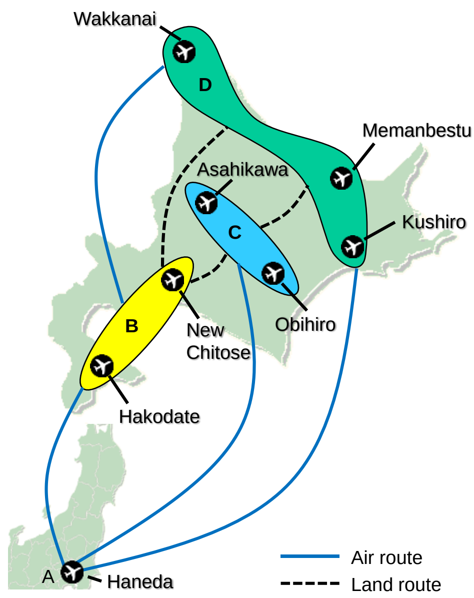

Fig.4 Airport group and network

Decisions of each participant and following outcomes are optimized and simulated by three cases. In case 1, airports are operated and managed by government. Airports' charges are predetermined by MLIT homogenously. In case 2, airports are bundled. The single operator will set charge of each airport integratedly for the purpose of maximizing gross profit. In case 3, a Ramsey price, which is to maximize social surplus subject to a constraint of budget balance, will be set when bundling. Under each case, we try to perform simulations of 5 sub-cases in terms of the proportion of potential trip-chain demand in gross potential demand, from 10% to 50%.

2) Result

Table 2 Optimal airport charge in each case

	Trip-chain	10%	20%	30%	40%	50%
Case 1	T(B)	16	16	16	16	16
	T(C)	16	16	16	16	16
	T(D)	16	16	16	16	16
Case 2	T(B)	1000	1000	1000	1000	1000
	T(C)	1000	828	1000	1000	1000
	T(D)	1000	1000	1000	1000	1000
Case 3	T(B)	0.5	0	0.5	12.2	16.9
	T(C)	2.6	13.6	20.9	0	0
	T(D)	49.1	18	1.7	1.8	0

The results of cases are compared herein. At first, the optimal charge T of each airport is shown in **Table 2**. The pre-determined public charge, which is a piecewise charge with respect to maximum landing weight originally, is turned into the form of dollar per tonne roughly for the convenience of comparison. From the result of case 2, it can be observed that, without any restriction, optimal charges set by profit maximizing airports are extremely high and unrealistic. This is probably because: (a) Through bundling, the new private operator becomes the only participant in local upstream market, it can fully exploit its monopoly power without any competition. (b) Airlines are not sensitive to airports' charges, which does not play a great role in an airline's cost, in the perspective of balance. On average, airport charges represent a relatively small part (typically around 4 percent) of an airline's total operating costs[1]. Flight operation cost usually accounts for more percentage of total operating cost of an airline. Even if airport levy an extremely high charge so that charge becomes main component of an airline's operating cost, it is very possible for airline to ensure a positive balance. For example, when airport B sets its charge to 1000 \$/ton, cost for charge will be \$203200 = \$200*100(\$/ton) + \$3200 when an airline operate one flight on air route (A=B), flight operation cost will be \$53400 = 0.08(\$/km*seat)*890(km)*375(seat)*2. Total cost will be \$256600 = \$203200 + \$53400. Revenue can exceed total cost as long as airline set an one-way airfare over \$342 = \$256600/(375*2) ensuring flight to be fully loaded. In reality, however, when charges go extremely high, an airline might retreat from current market and seek a more profitable market to allocate its resource in a more efficient way, instead of enduring the high charges. While in this study, only one market is assumed, there are no other substitute markets, so airline will hold on as long as it can make profit.

From the result of case 3, it can be observed that optimal charges under Ramsey pricing are generally lower than the public charges predetermined by government. Moreover, pricing coordination between airports in response to different trip-chain demand proportion can be observed: When trip-chain demand becomes higher, charges of airport C and D become lower while charge of airport B becomes higher. That's just the effect expected to be realized through integrated operation. When managed by government, charges of various airports are set to same level despite their distinctive situations. The unreasonable homogenous charging might cause surplus loss sometimes. For example, the charging rules of Haneda, New Chitose and Wakkanai are completely same. Thanks to high demand, Haneda and New Chitose can keep profitable with that charge. The decent financial room generating from profitable operation and the huge potential demand make it possible for two airports to lower charges further. By doing so, higher social surplus from increasing demand can be expected without the concern of deficit. On the other hand, due to low demand, Wakkanai is suffering deficit, and it seems difficult to make some improvement. However, it should be noted that demand of Wakkanai mainly generates from New Chitose and Haneda. If coordination is possible, By lowering charges of New Chitose and Haneda by 10 and raise the charge of Wakkanai by 5 simultaneously, then more traffic demand between them can be attracted because of the lower total charge of the air routes, and the economy of Wakkanai airport can also be improved. Of course, the example above is an ideal case assumed, but the result generally reflects the assumed pricing coordination pattern: lower charge for higher demand, higher charge for lower demand, lower total charge of an air route compared to predetermined one.

Then, as the response of airlines to the optimal charges, the results of airlines airfare and frequency are shown in **Fig.5** and **Fig.6**. From the comparison by case (pricing mode), it can be observed that under profit maximizing charges (case 2), airfares are highest and frequencies are lowest. While under Ramsey pricing charges (case 3), airfares are lowest and frequencies are highest generally.

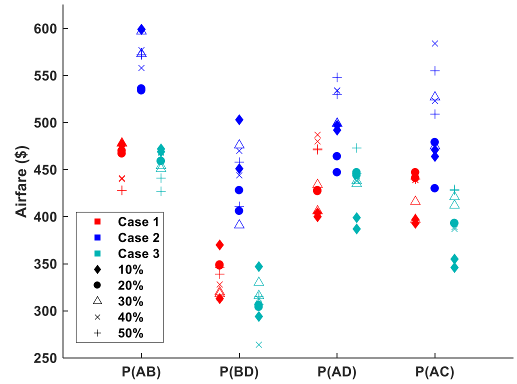

Fig.5 Scatter plot of the airfare

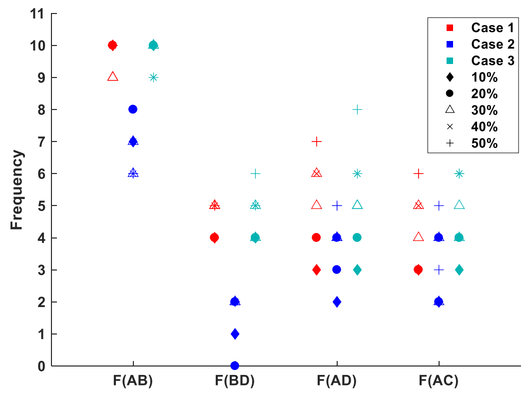

Fig.6 Scatter plot of the frequency

Table 3 Demand, demand visiting multiple sites, consumer surplus, airline profit, airport ptofit and social surplus

Trip-chain		10%	20%	30%	40%	50%
Demand	Case 1	9336	9337	9570	9862	10118
	Case 2	6617	7874	6873	6647	6708
	Change	-29.1%	-15.7%	-28.2%	-32.6%	-33.7%
	Case 3	9675	9778	9897	9972	10201
	Change	+3.6%	+4.7%	+3.4%	+1.1%	+0.8%
Demand visiting multi-destination	Case 1	282	544	865	1170	1511
	Case 2	161	422	527	662	858
	Change	-43.1%	-22.5%	-39.0%	-43.4%	-43.2%
	Case 3	302	591	890	1211	1537
	Change	+7.0%	+8.6%	+2.9%	+3.5%	+1.7%
Consumer surplus (M$)	Case 1	7.09	6.79	6.61	6.57	6.45
	Case 2	5.04	5.72	4.76	4.45	4.23
	Change	-29.0%	-15.7%	-28.0%	-32.3%	-34.4%
	Case 3	7.31	7.09	6.87	6.59	6.49
	Change	+3.1%	+4.5%	+3.9%	+0.3%	+0.5%
Airline profit(M$)	Case 1	6.82	6.83	6.8	6.76	6.75
	Case 2	2.73	2.21	2.15	1.97	1.75
	Change	-60.0%	-67.6%	-68.4%	-70.9%	-74.1%
	Case 3	6.91	6.9	6.87	6.86	6.77
	Change	+1.3%	+1.0%	+1.0%	+1.5%	+0.3%
Airport profit (M$)	Case 1	0	0	0	0	0
	Case 2	3.81	4.55	4.28	4.28	4.48
	Case 3	0.15	0.14	0.14	0.16	0.18
Social surplus (M$)	Case 1	14.11	13.81	13.62	13.54	13.42
	Case 2	11.58	12.48	11.19	10.69	10.46
	Change	-18%	-10%	-18%	-21%	-22%
	Case 3	14.37	14.14	13.88	13.61	13.44
	Change	+1.9%	+2.3%	+2.0%	+0.6%	+0.2%

Table 3 shows the result of market outcome, involving demand, demand visiting multiple-destination, consumer surplus, airlines' profit, airports' profit and social surplus. Under profit maximizing charging when bundling, most outcomes including demand, consumer surplus, airlines' profit and social surplus decline significantly, only airports can achieve great profit in such regime. It's just the consequence that an unrestricted upstream leader fully exploits its monopoly power by setting self-interested charges. In contrast, if charges are set under Ramsey pricing, improvement in demand, consumer surplus, airlines' profit and can be observed. The improvement is considered to be brought by coordination of pricing between airports mentioned above. However, the improvement is not significant. About the modest improvement, a possible explanation is that, since charge in public operating regime is not high, and airline's price sensitivity is low besides, room for improvement is limited.

4. CONCLUSION

This study developed a model to investigate the outcomes of air transportation market. In the model, participants of the market, including airports, airlines and passengers, make decisions to maximize their payoff. Charge of each airport, airway pattern of each airline, airfare and frequency of each route and demand are generated endogenously through optimization. In addition to traditional one-way demand, possible travel patterns of trip-chain passengers who might visit multiple destinations during one journey are also considered. Given the set of sites, all possible trip-chain moving modes is derived and cost of each mode is formulated to the model. The model is used to analyse the effect of airports bundling in Hokkaido, by comparing the possible outcome of market simulated before and after integrated privatization of multiple airports. Some assumptions and simplifications are made to ensure the feasibility and efficiency of simulation.

The result shows that improvement of market outcome, including demand, consumer surplus and social surplus, cannot be achieved by bundling without any restriction. Under such profit maximizing regime, as the leader of upstream market, the private operator will fully exploit its monopoly power to set extremely high charges, leading to great loss in market outcome. However, through Ramsey pricing, outcome loss can be avoided and improvement of demand, airlines' profit, consumer surplus and social surplus can be expected compared to pre-bundling regime. The improvement is considered to be brought by the coordination of pricing between multiple airports and indicates the necessity of pricing regulation when airports are privatized, even though room for improvement may not be large, for the charges set by public sector are not high before bundling. Effect of the introduction of passenger charge is also investigated. Higher improvement might be achieved by levy of both passenger and flight landing charge, but the result can only be regarded as a rough reference due to the instability of simulation caused by increased complexity.

However, the study has several limitations. First, some actual data, such as potential demand, trip-chain behaviours of passengers and attractiveness of each destination cannot be obtained. This makes it difficult to define parameters in passenger's decision-making functions and formulate passenger's travelling pattern correctly. Some regarding survey is desired to collect essential information. Second, airline market simulated is only part of the actual one, some airlines providing low price service are ignored. Third, the simplification that imagines multiple airports to one single airport in numerical computation phase leads to exaggerated potential demand of each air route. These two points cause overestimated airlines' response to airports' charge and affect the accuracy and reliability of final outcome. Fourth, current algorithm for both trip-chain moving modes formation and optimaiztaion is not efficient and stable especially when number of sites(nodes) and variables increases and complexity goes up, the model itself and algorithm still need to be improved.

REFERENCES

1) Graham, A. (2013). Managing Airports 4th edition: An international perspective. Routledge.
2) MLIT. (2016) 空港経営改革について.
3) Zhang, A., and Zhang, Y. (2006). Airport capacity and congestion when carriers have market power. Journal of urban Economics, 60(2), 229-247.
4) Yen, Jin Y. (1971). "Finding the k Shortest Loopless Paths in a Network". Management Science. 17 (11): 712–716.
5) Li, Z. C., Lam, W. H. K., Wong, S. C., and Fu, X. (2010). Optimal route allocation in a liberalizing airline market. Transportation Research Part B: Methodological, 44(7), 886–902.
6) Kanafani, A., and Ghobrial, A. A. (1985). Airline hubbing—Some implications for airport economics. Transportation Research Part A: General, 19(1), 15-27.
7) Swan, W. M., and Adler, N. (2006). Aircraft trip cost parameters: A function of stage length and seat capacity. Transportation Research Part E: Logistics and Transportation Review, 42(2), 105-115.
8) Saraswati, B., and Hanaoka, S. (2014). Airport-airline cooperation under commercial revenue sharing agreements: A network approach. Transportation Research Part E: Logistics and Transportation Review, 70(1), 17–33.
9) Adler, N. (2005). Hub-spoke network choice under competition with an application to Western Europe. Transportation science, 39(1), 58-72.
10) Deb, K., Agrawal, S., Pratap, A., and Meyarivan, T. (2000, September). A fast elitist non-dominated sorting genetic algorithm for multi-objective optimization: NSGA-II. In International Conference on Parallel Problem Solving From Nature (pp. 849-858). Springer, Berlin, Heidelberg.

(Received April 26, 2018)