OPTIMIZATION OF NEW AIRPORT LOCATION AND AIRLINE RATE
IN TERMS OF BENEFITS FOR SUPPLY AND DEMAND SIDES

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Abstract: A model for locating new airports is built aiming to minimize the total expenses of regional air transport. Two factors in the model namely airport choice probability and airlines average rate are analyzed in detail. For the former, a sub-model to simulate the users’ behavior for choosing airports is built, and for the later a sub-model to analyze the market scale of regional air transport is developed based on the model calculating the market scale of single airline. The study integrates the airline average rate setting, airport choice behavior and new airport location closely and considers the benefits of both passengers and the new airports simultaneously. Due to the interaction, an iterative calculation algorithm is designed to solve the model, in which a GAs is used to simulate the relationship between the two factors and the equilibrium solution is obtained. Finally, a numerical test is done to validate the method.

Key Words: Airport Location, Airline Average Rate, Airport Choice Behavior

1. BACKGROUND

As the nodes of air transport network, airports determine the accessibility and the served space of air transport and thus determine the being utilizable extend. Due to the huge investment, it is necessary to analyze the demand and the distribution of the existing airports in a region when locating new airports in the region rationally. The aim of this study is not only to make the newcomer obtain an enough passengers but also to avoid the vicious competition. Therefore, when making a decision of building a new airport, two key issues should be considered, i.e. locating the newcomer rationally to make it cooperate with the existing ones, and making sure the newcomer be used efficiently.

Studyies on airport location have been done by many researchers. Hokey et al. (1997) proposed a dynamic, multi-objective, mixed integer programming model tending to optimize the location of an airport under capacity and budgetary constraints. Meantime, Smith (1997) optimized the locations of airport hubs in an air transport network with the quadratic integer programming formulation. He laso demonstrated a mapping onto a Hopfield neural network which guarantees feasibility of the final solution, and is able to escape from local minimum.

Lyman et al. (2001) introduced a simple facility location model for airport by taking London as study region, provided the theoretical and analytical tools to understand the markets based on both airport location and airline access to competing attractions. Van et al. (2003) presented a methodology for making decisions based on uncertain information through the use of an analytical feasibility study of an airport island in the North Sea as an alternative to the present inland airport, quantified several conflicting aspects, including uncertainties, for each of five alternative locations for the new airport. Merino et al. (2004) considered the uncapacitated p-hub median problem with single allocation, where each non-hub node (origin
and destination) must be allocated to exactly one of the p hubs. Lin et al. (2006) applied Fuzzy Analytic Hierarchy Process approach to the international competition level for a competitive analysis of the suitable location mode of each airport, and established the competitive criteria for the location mode of the airport. Besides, Mikio (2006) studied the management policy in the multiple airport system in Japan and provided the comprehensive market model consists of three types of equilibrium-equilibrium between airlines, between passengers, and between airlines and passengers. From the aspect of air transport economics and policy, Yang (2006) studied the pricing method for air tickets based on the data surveyed in China.

However, there is almost no study on the combination of the airport location, airline rate setting and airport choice behavior. This study aims to optimize the location of the airports and the structure of air transport network for a region. With consideration of airport choice behavior, a model is developed that can optimize the spatial distribution of airports and the airlines average rate (AAR) in the new airport.

2. AIRPORT LOCATION MODEL AND ITS ALGORITHM

Structure of air transport network in a region should be designed with reference to the demand in each city in the region. While the air transport demand, namely trip generation and distribution, is influenced by the structure of the network inversely. Generally, the design of regional air transport network consists of two parts, i.e. locating the airports, which will be the nodes of the network; and arranging the airlines, which will be the links of the network. This study, at the level of strategy, optimizes the location of airports in a region through studying the interaction between the airline rate of a new airport and the airport choice behavior of the passengers.

2.1 Airport location model

It can be said that building a new airports can improve the quality of air transport network, enlarge its covering area and raise the accessibility and service level of air transport. In detail, the aim of building a new airport is to minimize the total expenses of air trip in the region, which can be represented with a model as follows.

\[
Min \quad C = \sum_{i=1}^{I} \sum_{j=J} a_i \times S_i(r_j) \times \rho_j \times x_j \times (c_{ij} + r_j \times d_j)
\]

\[s.t. \quad M_j = \sum_{i=J} a_i \times S_i(r_j) \times \rho_j \geq M_0 \quad \forall j \in J\]

\[\sum_{j \in J} \rho_j = 1 \quad \forall i \in I\]

\[r_{\bar{j}} \leq r_j \leq \bar{r}_j \quad \forall j \in J\]

Here, \(C\) = the total expenses of air trips in the region; 
\(I\) = the set of cities in the region; 
\(J\) = \{existing airport cities\} \(\bigcup\) \{alternative cities for building new airports\}; 
\(a_i\) = the air trip demand in city \(i\), related to social-economic and demographic conditions; 
\(r_j\) = the AAR of airport \(j\); 
\(S_i(r_j)\) = the modal split of air trip in city \(i\); 
\(\rho_j\) = the probability of passengers in city \(i\) using airport \(j\);
\[ c_{ij} = \text{the expenses of a passenger in city } i \text{ access to airport } j; \]
\[ \bar{d}_{ij} = \text{the average flight distance of airlines operated in airport } j; \]
\[ x_j = 0-1 \text{ variable, i.e. } x_j = \begin{cases} 1 & \text{if city } j \text{ has an airport} \\ 0 & \text{else} \end{cases}; \]
\[ M_0 = \text{the minimum turnover of passengers in an airport;} \]
\[ r^{-}, r^{+} = \text{lower and upper limits of AAR.} \]

The model simulates the situations of various passenger distributions in alternative air transport networks in a region. In the model, \( r_j \) and \( \rho_{ij} \) interacts each other, and their optimal solution can be obtained through solving the programming problem. The two variables and the equilibrium resulted from the interaction between them are illustrated as follows.

### 2.2 Probability of airport choice \( \rho_{ij} \)

Probability of airport choice reflects the airports choice behavior of users, and is affected by several factors. The airport choice behavior follows the rule by which users choose service facilities and consume the services. The Huff gravity model, MNL model and the MCI (Multiplicative Competitive Interaction) model are common choice behavior models. Among them, the MCI model is the most widely used to build the model for consumers to choose shopping destination. Different from gravity model, MCI model includes various variables that affect the choice behavior of the consumers. Its structure can be described as follows.

\[
\rho_{ij} = \left( \prod_{k=1}^{J} A_{ij}^{\beta_k} \right) \left( \prod_{e=1}^{r_j} B_{eij}^{\beta_e} \right) / \left( \sum_{j \in J} \left( \prod_{k=1}^{J} A_{kj}^{\beta_k} \right) \left( \prod_{e=1}^{r_j} B_{ekj}^{\beta_e} \right) \right)
\]

Here, \( \rho_{ij} \) is the probability of user \( i \) choosing facility \( j \);
\( A_{ij} \) is the \( k \)-th attribute of facility \( j \), it is independent of users;
\( B_{eij} \) is the \( e \)-th attribute of facility \( j \) for attracting user \( i, e = 1,...,r \), representing the opinion of users on the facility;
\( \beta_k, \beta_e \) are the sensitivity indices, denoting the sensitivity degree of users to the attributes;
\( J \) is the set of facilities being selected.

Hess et al. (2005) thought that four factors mainly affect the airport choice behavior in a region with several airports. They are: the accessibility from city \( i \) to airport \( j \) (\( A_{ij} \)), the usable airlines in airport \( j \) (\( L_j \)), the travel expenses between city \( i \) and airport \( j \) (\( c_{ij} \)), and the ticket price level in airport \( j \) (\( p_j \)). Here, the ticket price level \( p_j \) can be calculated as the product of the AAR in airport \( j \) by the average flight distance, i.e. \( p_j = r_j \times \bar{d}_j \). Based on the mentioned MCI model, the probability of users to choose airports in a region can be calculated as follows:

\[
\rho_{ij} = \frac{A_{ij} l_j / f(c_{ij}, r_i \times \bar{d}_j)}{\sum_{j \in J} (A_{ij} l_j / f(c_{ij}, r_j \times \bar{d}_j))} \quad \forall i \in I
\]

Here, \( f(c_{ij}, r_j \times \bar{d}_j) \) is the expenses function of user access to the chosen airport.

Ordinaly, it needs to estimate the modal split of each mode (road, railway and ect.) to calculate \( c_{ij} \) first, and then calculates the weighted average access expenses (including money
and time expenses). While, this study creates a railway and road integrated transport network. Based on the integrated network, the generalized travel impedance between any two cities can be calculated with the shortest path algorithm, and then we can select the access expenses $c_{ij}$ from the impedance matrix. Finally, the accessibility from city $i$ to airport $j$ can be calculated with function $A_{ij} = 1/c_{ij}^2(\forall i \in I, \forall j \in J)$.

2.3 Airlines average rate $r_j$

AAR may be determined by air transport service supplyer in an airport. For the determination, the supplier pays more attention to how to set a reasonable rate level to enlarge its market scale and maximize its revenues. Because they are mainly represented by the air ticket income, the revenues depend on the AAR in the airport heavily. If the AAR is too high, the airport will be selected with low probability which will reduce the ticket income. A rate optimization model can be established through simulating the process of supplier pricing and users choice behavior as follows.

$$\text{Max } R(r_j) = \sum_{i \in I} a_i \times S_i(r_j) \times \rho_j \times r_j \times \overline{d_j} \quad \forall j \in J$$

Here, $R$ = the total revenues of supplier in the region. 
$\overline{d_j}$ = the average flight distance of airlines operated by airport $j$.

Respecting to the modal split $S_i(r_j)$, a logit model for the market scale of air transport (KLP) has been built with the price sensitivity measurement (PSM) by Kishi et al. (1999). It can calculate the optimal ticket price at which the airline can realize the largest market scale. In order to generalize the KLP model from for an airline to for the whole air transport network, ticket price variable is divided into two parts, namely $r_j$ and $\overline{d_j}$.

Based on the above method, works for surveying data and solving model will be enormous if the model is calibrated by airline. Therefore, we calibrate the model by airline group rather than by airline. The details are as follows: first, the airlines operated by an airport are grouped according to their rates. The airlines ratio of the $k$-th group to the total airlines ($\alpha_k$) in the cycle of one week is calculated and a representative airline from each group is selected. Secondly, a questionnaire survey is carried out respecting to the representative airlines. And then the obtained cognitive ticket prices are divided into the product of AAR by average flight distance. Due to the difference sensitivity to price, passengers are further divided into business and private ones, i.e. $S_i(r_j) = S_{ik}(r_j) + S_{ip}(r_j)$ . Here the subscript $b$ and $p$ represent the business and private passengers respectively. With KLP model, the surveyed data can be analyzed to get $a_{ik}$ and $b_{ik}$. And then, with considering the average flight distance $\overline{d_k}$ of $k$-th group of airline, the market scale models of business and private users can be built as follows:

$$S_{ik}(r_j) = \frac{1}{1 + \exp(-a_{ik} d_k \times r_j - b_{ik})} - \frac{1}{1 + \exp(a_{ik} d_k \times r_j + b_{ik})}$$

$$S_{ip}(r_j) = \frac{1}{1 + \exp(-a_{ip} d_k \times r_j - b_{ip})} - \frac{1}{1 + \exp(a_{ip} d_k \times r_j + b_{ip})}$$

Thus, the total market scale of air transport in city $i$ can be represented as follows:
Moreover, the average airline distance can be expressed as the weighted average of the average distances of all kinds of airlines operated by airport $j$, i.e. $\overline{d}_j = \sum_k \alpha_k \times \overline{d}_k$.

Till now, KLP model has been generalized from for one airline to for all airlines operated by an airport. Moreover, the model for calculating the revenues of supplier can be obtained with the combination of the market scale model, total trips in a city, AAR and the average flight distance.

We suppose that the users’ sensitivity to the ticket price in the new airports is same as that in the existing airports and the AAR to be set in all the new airports are also the same. Thus, the relationship between the revenues of supplier and AAR in new airports can be induced from the survey carried out in the existing airport. It is the foundation to optimize the AAR in the new airports.

2.4 Optimization of $\rho_y$ and $r_j$

It can be seen from Eq. (3) and Eq. (4) that $r_j$ influences $\rho_y$, and vice versa. As a result, the iterative calculation is needed to simulate the process in which the supplier adjusts $r_j$ based on its revenues and the users’ willingness to pay. The process can be explained as follows:

First, expenses function $f(c_y, r_j \times d_j)$, which influences the users’ choice of airport, can be described as:

$$f^{(k)}(c_y, r_j^{(k-1)} \times \overline{d}) = \begin{cases} c_y, & k = 0 \\ c_y + r_j^{(k-1)} \times \overline{d}, & k \neq 0 \end{cases}$$

Eq. (8) means if the AAR of new airports is equal to that of the existing ones, access expenses will be the main factor effecting users’ choice of airport, i.e. $f^{(0)}(c_y, r_j^{(0)} \times \overline{d}) = c_y$. Then $\rho_y^{(1)}$ can be calculated with Eq. (3) and the corresponding $r_j^{(1)}$ can be obtained from Eq. (4) in current iteration. Because the AAR changes from $r_j^{(0)}$ in the previous iteration to $r_j^{(1)}$ in current iteration, the airport choice probabilities should change correspondingly. Since the current expenses of a passenger in city $i$ using airport $j$ is $f^{(0)}(c_y, r_j^{(0)} \times \overline{d}) = c_y + r_j^{(0)} \times \overline{d}$, thus changed probability ($\rho_y^{(2)}$) and AAR ($r_j^{(2)}$) can be calculated in the next iteration further. The above process will be repeated until $R$ in Eq. (4) does not change or change less than a given threshold.

2.5 Algorithm Design

Genetic algorithm (GAs) is used to solve the optimal model mentioned above. The calculation process is as follows:

**Encoding**

In order to represent the airports distribution by the variables, first, the potential cities are lined up to form a chromosome. And the chromosome is binary coded in which the gene will be either 1 or 0 to represent building an airport in the city or not. For example, chromosome
(1 1 0 1 0 0 0) means that the airports will be built in city 1, city 2 and city 4.

Selection
The objective function of Eq. (1) is taken as the fitness value and the Roulette Wheel Selection method is used to select chromosomes that are taken as the parents for the crossover or mutation operation. The chromosomes are selected probabilistically, according to their fitness value. The less total expenses it makes, the more likely it is to be selected. In addition, the parameter Elitism is used for selection, i.e. the less-expenses chromosomes in the population are automatically copied into the next generation. This is to ensure that the best chromosome generated so far can be passed down to the next generation and to guarantee that the population shall not degrade over the evolution process.

Crossover and Mutation
The crossover operation, the mutation operation, and their outcomes are illustrated as follow:

In order to avoid a completely random search led by frequent application of mutation operation, a low probability is assigned to its activation in this study as 5%.

3. CASE STUDY
To validate the models above, case study is done for Liaoning Province, China. At present, there are two airports in the region, which are located in Shenyang and Dalian respectively. Supposing new regional airports will be built, and then we optimize the locations of the new airports and the corresponding AAR simultaneously with the developed method aiming to construct an optimal air transport network for the region.

3.1 Parameters setting
The set \( I = \{14 \text{ cities in the region}\} \). The numbers of airlines in the new airports are set as \( l_j = 40\% \ l_{Shenyang} = 40\% \ l_{Dalian} \). The accessibility \( A_{ij} \) and expenses \( c_{ij} \) from city \( i \) to airport \( j \) can be calculated with the integrated surface transport network. According to the unit expenses of air trip and the willingness to pay for ticket, the upper and lower limits of AAR are set as \( r_j = 170\text{yuan/hkm} \) and \( r_j = 70\text{yuan/hkm} \) (hkm=100 kilometers) respectively. The minimum trips of passengers needed by a new airport is set as \( M_0 = 750,000\text{trips} \). The current AAR and average flight distance are \( r_{Shenyang} = r_{Dalian} = 134\text{yuan/hkm} \) and \( d_{Shenyang} = d_{Dalian} = 933\text{km} \) respectively.

3.2 Numerical results
As shown in Figure 1, six cities are selected as the potential locations for the new airports. Then the set \( J = \{\text{Shenyang, Dalian, Dandong, Jinzhou, Yinkou, Panjin, Chaoyang, Huludao}\} \).
Based on the hypothesis mentioned above, the data are collected in Dalian airport to represent the relationship between the AAR and air market scale of each new airport. Airlines in Dalian airport are divided into 4 groups and Dalian to Beijing, Dalian to Shanghai, Dalian to Guangzhou and Dalian to Shenzhen are selected as the representatives. Surveys on ticket price of these airlines are carried out in Dalian airport, and then $a_i$ and $b_i$ are calculated. Thus, with the airlines average distance $d_k$ ($k=1,\ldots,4$), business and private market scales can be estimated. Further, the total market scale $S_j(r_j)$ can be calculated with Eq. (7).

With the parameters and the designed algorithm, the model of Eq. (1) is solved, and the solutions tend to convergence after 116 times calculation. Then it is found that only one gene in each chromosomes is 1, which means that only one new airport is needed in the region. Considering the economy level and the transport demand in Liaoning, this result fits the actual situation. Finally, the located airports, their AARs and total expenses of air trips are shown in Table1.

<table>
<thead>
<tr>
<th>Potential Location</th>
<th>Dandong</th>
<th>Jinzhou</th>
<th>Yinkou</th>
<th>Panjin</th>
<th>Chaoyang</th>
<th>Huludao</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAR</td>
<td>116</td>
<td>103</td>
<td>108</td>
<td>105</td>
<td>117</td>
<td>110</td>
</tr>
<tr>
<td>Total Expenses</td>
<td>143.64</td>
<td>100</td>
<td>110.52</td>
<td>102.63</td>
<td>146.33</td>
<td>124.40</td>
</tr>
</tbody>
</table>

Note: Total expenses in the situation of locating a new airport in Jinzhou is set as 100.

It can be understood that if the new airport is located at Jinzhou and $r_j = 103 \text{ yuan/hkm}$, the total expenses of air trip are minimized. The airport choice behavior in the region will change with different AAR, after the new airport is built in Jinzhou. The changing situation of regional passengers selecting Jinzhou airport due to the changing AAR can be shown in Figure 2. This mechanism of the process shows that a new airport adjusts its AAR to enlarge its revenue and cooperate with the existing airports.
Figure 2 Changes of passengers of Jinzhou airport with different AAR

Figure 3 shows the effects of AAR in the new airport on the business and private passengers and further on the revenues of supplier.

It can be found that the market scale of business and private passengers do not reach their maximum at the same AAR. However, the total market scale and the revenues of supplier are the most concerned. When $r_j = 103 \text{ yuan/hkm}$, although the number of private passengers is a little less than its maximum, the business one reaches its maximum and the total market scale and the revenues of suppliers also reach their maximums (57.48% and $34.983 \times 10^6$). Thus, $r_j = 103 \text{ yuan/hkm}$ is the optimized AAR for the new airport.

4. SUMMARIES

The study develops a model to locate new airports aiming to minimize the total expenses of air trip in a region. Two factors namely airport choice probability and airlines average rate in the new airports are analyzed. The former is a choice behavior sub-model simulating the
behavior of user selecting airports, and the latter is a sub-model to calculate the scale of air transport market based on the single airline market share model.

The model integrates the AAR setting, airport choice behavior and new airport locating to emphasize the benefit of both service supplier and consumers. Because AAR and airport choice probability interact, a GAs based iterative calculating algorithm is designed for solution. At last, a numerical test is done to validate the model.

REFERENCES