FORMULATION AND APPLICATION OF M-GATS ALGORITHM IN DESIGNING THE OPTIMAL HUB AND SPOKE STRUCTURE FOR CHINA'S PASSENGER AVIATION MARKET

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Abstract

From 1980s, China aviation market has developed significantly due to the rapid economic growth and deregulation process. During 1986-1995, China built 13 new airports, rebuilt 7 airports and expanded more than 30 airports. Currently, Civil Aviation Administration of China (CAAC) is seeking to improve its aviation network to hub and spoke network. In CAAC 10th Five-Year Plan (2001-2005) for airport improvement and expansion, CAAC designated Beijing, Shanghai and Guangzhou to be mega hub airports and improve airports in Shenyang, Wuhan, Chengdu, Kunming, Xian and Urumuqi to serve as medium hub airports. However, there is still a need to develop a scientific model that can aid China aviation policy maker in designing changes in its aviation network.

This paper presents the development of a methodology that can help decision maker in choosing an optimal hub and spoke structure for China's passenger aviation market. Our research aim to determine which airports among 121 airports in China should be enhanced to become inter-regional and medium size hub and how to route the flow from feeder airports to the hub airports.

Keywords: Hub-and-spoke network; Aviation; China's domestic airport
Topic Area: A3 Airports and Aviation

1. Introduction

Since Chinese economic reform began in early 1980's, China's aviation industry has undergone dramatic administrative and regulatory reforms. In the first reform stage (1980-1986), the government separated civil aviation from the air force, and re-introduced business aspects of the airline industry. In addition, the six regional civil aviation bureaus became profit centers, and were given more autonomy in making operational decisions. The second stage separated the Civil Aviation Administration of China (CAAC) role as administrator and regulator from that of operator and CAAC assumed a purely administrative and regulatory role from 1987. CAAC established a system of six state-owned semi-autonomous trunk carriers to provide domestic and international services. The reforms also separated airport operations from airline operations, and established an airport decentralization policy. In addition, independent local and regional carriers, funded by local governments or large enterprises, were encouraged to enter the market.

With the vigorous economic growth and aviation industry deregulations, China's airline industry has experienced dramatic development since the early 1980s. Between 1980 and 1998, air passenger traffic carried by Chinese airlines increased 16-fold. Domestic air traffic in China was growing at an estimated 20 per cent per year during the 1980-1996 period, And according to IATA (International Air Transport Association), total international scheduled passenger traffic to and from China increased from 1.9 million in 1985 to 8.3 million in 1993, an average annual growth rate of 20.5 percent (IATA, 1995).

Over the past decade, China's economic growth has stretched the nation's air transport system beyond capacity, even though the system was growing around 20 per cent annually during the 1980s and the first half 1990s. A restrictive factor in China's air transportation growth is its inadequate infrastructure, particularly its airports and air traffic control systems. China built 13 new airports, rebuilt 7 and expanded more than 30 airports during 1986-1995. At present, China has 121 civil airports. The density of China's airports averages one in every 79,000 square kilometers, far less than other developed countries. China plans to build 20 feeder airports by the year 2010. CAAC is also seeking for evolving the hub and spoke network for the air transport. Hub and spoke network not only reduces the number of links required to connect the OD pairs but economy of scale in the hub-to-hub links also provide major incentive. The airline operators on the hub to hub links can employ larger aircraft fleet with more frequent service. This give rise to the problem of how to decide which airport should be improved to serve as a regional hub and trans-national hub, and also, how to design the whole network structure, to optimize the efficiency of the entire network.

In this paper, we present the development of a methodology that can help decision maker in choosing an optimal hub and spoke structure for China's passenger aviation market. Our research aim to determine which airports among 121 airports in China should be enhanced to become regional and trans-national hub and how to route the flow from feeder airports to the hub airports.

We formulate our problem as multilevel hub location problem (referred to in this paper as the MHLP). The MHLP problem is a location-allocation decision problem. We are given a set of nodes $N=\{1,\ldots,n\}$ with constant OD flows (W_{ij}). The generalized per unit cost (C_{ij}) can be computed from the distance between node pare and formulated to reflect both transportation cost and travel time cost. The goal of MHLP problem is to find the optimum location of the hubs in each hierarchical level among the set of nodes and allocate the non-hub nodes to a hubs such that it minimizes the total network cost.

This paper is structured as follows. In Section 1, we discuss the current situation of China's aviation industry. In Section 2, we provide our MHLP formulation as a quadratic integer model. Since it is proven that even the single level hierarchical formulation is NP-hard problem (O'Kelly, 1987), we adopted an algorithm namely Multilevel Genetic Algorithm-Tabu Search (M-GATS), which is a hybrid heuristic model between genetic algorithm (GA) and tabu search (TS) to solve the formulated problem. The algorithm of M-GATS is discussed in detail in Section 3. In Section 4, we provide extensive calculation results of M-GATS, when apply to China's aviation network. Discussions and conclusions are provided at the end of this paper.

2. Current situation of China's aviation industry

China's aviation industry has grown at a rate of 20 percent every year for the past decade, putting tremendous pressure on its airports. At present, China is undergoing an unprecedented airport construction period. Figure 1 shows the investment of airport construction and expansion projects from 1980-1990. In this figure, we can see the latter half of the 1990s is the peak of the airport construction and expansion projects.

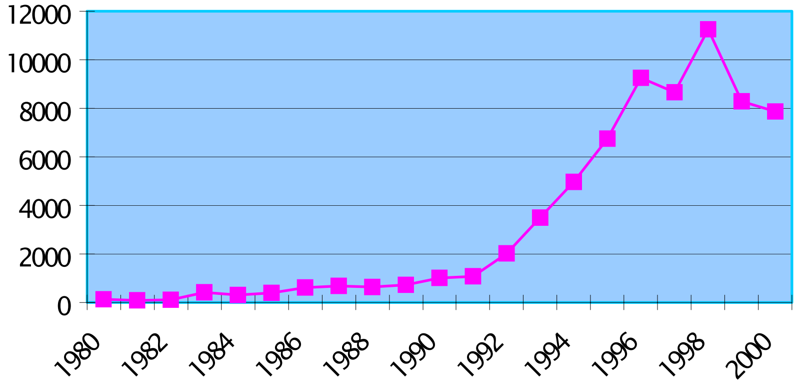

Figure 1 - Investment of airport construction and expansion projects from 1980 to 2000 (unit: Million Yuan)

When the People's Republic of China was founded in 1949, there were only 36 airports available. The Chinese government began to construct the new airports and expand the existing airports from the first five-year national development plan. By 1978, there were 78 airports in China, among these airports, only Beijing Capital International Airport, Shanghai Hongqiao Airport and Guangzhou Baiyun Airport can support B747 take-off and landing.

In 1978, Chinese government opened its door to the world and was beginning to reform its economy. It stimulated the China air transport greatly. China has enjoyed dynamic growth in air transport during the past two decades. China built 13 new airports, rebuilt 7 and expanded more than 30 airports during the 1986-1995.

According to the report of CAAC, there are 121 airports in China at present. The number of the airport, which can support B747 take-off and landing, is increasing from 3 in to 19. However, the density of China's airports averages one in every 79,000 square kilometers, far less than other developed countries. As an effort to meet the needs of the rapid development of the national economy, international trade and foreign exchanges as well as tourism, China plans to build 20 feeder airports by the year 2010 and seeking for evolving the hub-spoke network for the air transport.

At present, the airports in Beijing, Shanghai, Guangzhou take 35% share of passengers handled and 50% cargo handled. In the 10th Five-Year Plan period (2001-2005), CAAC made its new aviation network development plan. In this plan, the airports of Beijing, Shanghai and Guangzhou will be further enhanced as the trans-national hub of China air transport, while construct the airports of Shenyang, Wuhan, Chengdu, Kunming, Xi'an, and Urumuqi as the regional hub airports. Also the total of 164 trunk airports will be constructed or upgraded during these five years. Meanwhile, the airports currently administered by the CAAC will be transferred to local governments. This includes responsibility of airport assets, debt ad staff.

Regarding the geographical distribution of airports, the number of the airports in Eastern region is much larger than that in the Western region of China. For example, Guangdong Province has 16 airports, but for many western provinces, each province just has only one or two airports. This is mainly due to the regional economical disparity. The distribution of airports and flight in China is shown in figure 2.

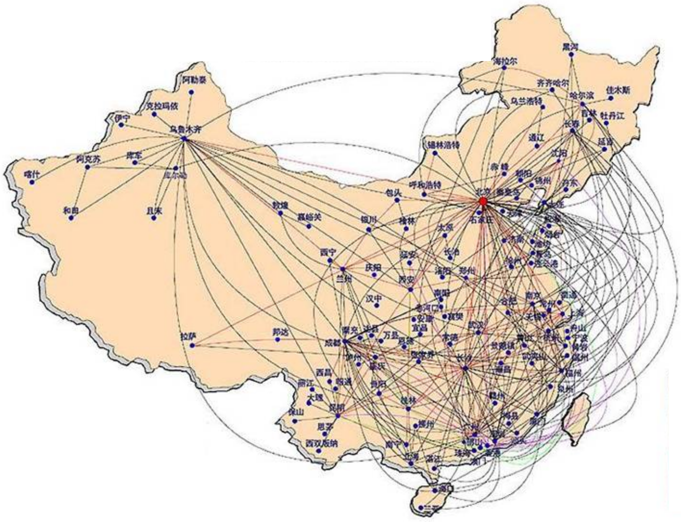

Figure 2 – China's domestic air transportation network in 2000

Although some trans-national hub airports are facing very heavy congestion, but around 65% regional airports are losing money in successive years. One reason is that every local government hopes to build the airport to enhance the development of local economy, but they often overestimated the demand. Thus the airport construction was over-capacity. Huge maintenance cost becomes a very heavy fiscal burden for the local government. Therefore, a tool that can provide a scientific solution on how to design and allocate the hierarchical structure of the aviation network is greatly needed.

3. Formulation for MHLP

The formulation for multilevel hierarchical network considered in this study is classified as multilevel hub location problem (MHLP). The problem is assumed that for a given set of n nodes, we must identify nodes to act as hubs in each level of hierarchy. Once the hubs are determined, we shall allocate those non-hub nodes to the hub. This process of location and allocation must be done such that the total generalized transport cost for the whole network is minimized. O'Kelly (1992) formulated the single level hub location problem as a quadratic integer program. Inspired by his formulation, we develop the formulation for multilevel hub location problem. MHLP is applicable to many types of hierarchical transportation network, especially to the postal, freight and express parcel service carrier.

It is assumed that we are given a set of current or projected amount of OD demand for all nodes represented by W_{ij}. The model also requires a set of generalized transport cost which include both actual transport cost and travel time cost between all node pairs denoted as C_{ij}, while F_j^K is the incremental fix cost for establishing a hub at node j and $\alpha^K, \beta^K, \delta^K$ represent different factor for economy of scale for different level of hierarchy.

The hubs are assumed to be "uncapacitated" which, means that there is no limit to the capacity of hubs both in term of connected nodes and flows. Actually this assumption is not quite unrealistic as it seems. This is because this formulation is a tool to assist decision making in long term planning. This model can give the decision maker the overview of what is need to be done to achieve the optimized network, including the need for enlargement of a certain hubs to serve as the regional consolidation point.

An example of simple hierarchical network is shown in Figure 3.

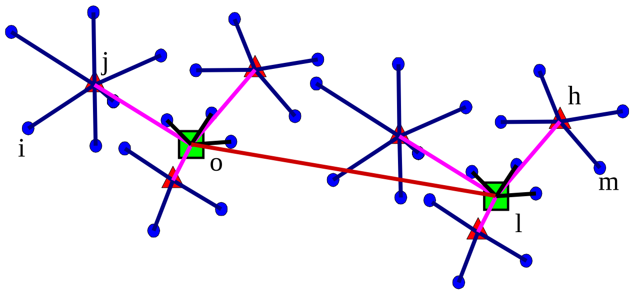

Figure 3 - Simple multilevel hierarchical network

The formulation for MHLP can be stated as follows:

Let K represent the level of hierarchy $K \in \{1,2,3,...K_{\max}\}$, variable X_{ij}^{K} is equal to 1 if node i is assigned to hub j at hierarchical level K and zero otherwise. X_{jj}^{K} is the hub assignment variable. If node j is a hub at level K then X_{jj}^{K} is equal to 1 and zero otherwise. Let W_{ij} represent the flow from node i to node j while C_{ij} is the generalized transportation cost from node i to node j. $|N_K|$ and $|H_K|$ is the dimension of the set of nodes and hubs at level K.

<u>MHLP</u>

$$\text{Min} \quad \sum_{K=1}^{K_{\max}-1}\sum_{i_K}^{|N_K|}\sum_{h_K}^{|H_K|} X_{ih}^{K}\beta^{K}C_{ih}\sum_{j_K}^{|N_K|}W_{ij} + \sum_{K=1}^{K_{\max}-1}\sum_{j_K}^{|N_K|}\sum_{m_K}^{|H_K|} X_{jm}^{K}\delta^{K}C_{jm}\sum_{i_K}^{|N_K|}W_{ij} + \sum_{h_{K_{\max}}}^{|H_{K_{\max}}|}\sum_{m_{K_{\max}}}^{|H_{K_{\max}}|} X_{jj}^{K_{\max}}W_{ij}\,C_{ij}\,\alpha^{K_{\max}} + \sum_{K=1}^{K\max}\sum_{j} X_{jj}^{K} f_{j}^{K} \qquad (1)$$

subject to

$0 \le X_{jj}^{K} \le 1$ and integer for all j,K (2)

$0 \le X_{ij}^{K} \le 1$ and integer for all i, j,K (3)

$X_{ij}^{K} \le X_{jj}^{K}$ for all i, j,K (4)

$|H_K| = |N_{K-1}|$ for all K (5)

The first and the second term in the objective function represent the cost for transport from the feeder airport to the hub airport on the departure leg and the arriving leg. The third term represents the cost for transport on a hub-to-hub link for the highest level hub. Lastly, the fourth term represents fix cost for operation of hubs, which includes plan change, administrative cost, lost time cost, etc.

Constraints (2) and (3) restrict X_{ij}^{K} and X_{jj}^{K} to 0 and 1. Constraint (4) enforces that any node may not be assign to location j unless it is a hub of the same level of hierarchy K. Constraint (5) requires that the set of nodes at level K+1 is the same as the set of hubs at level K.

4. M-GATS Heuristic

In order to solve the proposed MHLP, we developed a hybrid heuristic namely Multilevel Genetic Algorithm and Tabu Search model (M-GATS model). M-GATS consists of two main components, which are Genetic algorithm (GA) and Tabu search (TS). The GA component determines the optimal number of hubs as well as its location; while TS determines the allocation of non-hub nodes to the hubs.

The reason that we combined these two meta-heuristic procedures together is to compliment the strength and weakness of each heuristic in solving this two stages problem. Even though GA can be very efficient in finding optimal hub candidates since the coding can be done effectively by using a string of binary with length n, the bit value 1 represent a hub node while 0 represent a non-hub node. The solution will give both the optimal number of hubs and their location. However, using GA to solve the allocation part of the problem will present many difficulties. First, the coding will have to be a string of real variables of length n, which raise the complexity of the problem up to n^n possibilities. Even though there are many researches proposing the methods to enhance GA to overcome the real bit coding, but it would greatly increase the calculation time.

In the other hand, while TS is very efficient in finding a better assignment of each spoke to hubs from the distance based assignment by exploring different hubs reassignments an avoiding local optima entrapment, but TS is not suitable for the hub location part. The reason is that in using TS in hub location part, we need to first specify the number of hubs then use TS to relocate the hubs to find the most suitable location. Thus since we also need to determine the optimal number of hubs, we will need to run TS n times for each number of hubs to determine both the optimal number of hubs and their location.

The algorithm of M-GATS is described in Subsection (1) and brief description of GA and TS are given in Subsection (2) and (3). For principles of GA and TS in a broader sense, please refer to Goldberg (1989) and Glover (1997)

4.1. M-GATS algorithm

Our M-GATS algorithm starts from using GA to find the optimal hub candidates and their location. Then TS is called to find the optimal node allocation for each GA candidates. The search will terminate when GA's solution is converged. After that, the second level hubs calculation will start by consolidate the flow to the hubs and remove all the nodes. Then consider all 1st level hubs as nodes and start the 2nd level hubs calculation. This consolidation will continue until there is no further improvement in objective value to gain from further consolidation. The algorithm of M-GATS is described in steps below and the flowchart for M-GATS is described in figure 4.

Step 0. Initialize: Acquiring the nodal flow, nodal coordinates and other parameters.

Step 1. Calculate cost matrix: From the nodal coordinates, calculate the generalized transportation cost from any node i to any node j.

Step 2. Call GA: Call genetic algorithm subroutine to evaluate the hub locations and the number of hubs for each population.

Step 3. Call TS: Call tabu search subroutine to evaluate the allocation for the best individual in each generation of population in GA.

Step 4. Repeat GA and TS: The process of GA and TS is repeated until the iteration reach maximum genetic iteration, then the location-allocation matrix for the best population is recorded.

Step 5. Restart: Restart step 2-4 with a new seed, until restart reach maximum restart. The best solutions obtained from each restart is compared and the best solution is reported.

Step 6. Node consolidation: From the location -allocation matrix obtained in step 5, consolidate the flow to the hub nodes and consider these hub nodes as regular nodes in the second level hierarchy calculation and extract the required link cost form the cost matrix.

Step 7. Start second level calculation: Repeat steps 2-5 again and record the best solution found for the second level hub location-allocation.

Step 8. Determine higher level location-allocation: Repeat steps 6-7 for the higher level hierarchy until the additional hierarchy does not improve the overall transportation cost.
Step 9. Terminate: Return the location-allocation matrix and the overall transportation cost.

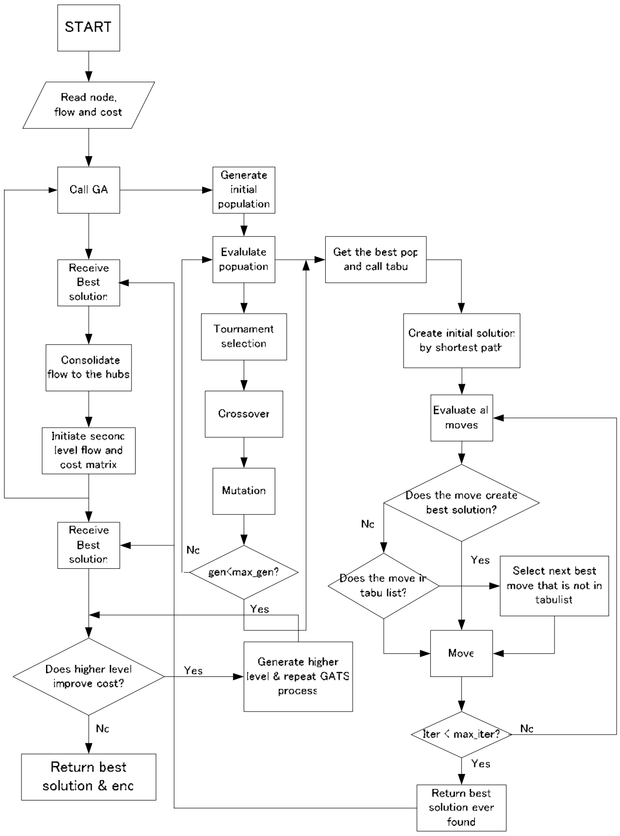

Figure 4 - Flowchart for M-GATS heuristic

4.2. Genetic algorithm

Genetic algorithm is a search algorithm which inspired by a Darwinian evolution theory. The algorithm starts from a randomly generated set of solutions (referred to as individuals) called populations. Then these set of individuals undergo the process of selection, crossover and mutation as in natural evolution. The new solutions are formed from the good solutions form the previous populations, which are selected according to their fitness, the more suitable they are, the more chance they have for reproduce. By this process, the individuals with low fitness will eventually die off and new individual with good fitness will be encountered. After the population pass thru several iterations, the optimal solution will survive in the population as in the nature rules of survival of the fittest.

In this model, we represent each feasible solution by a string of n binary bits called "individual". Each of the bit represent the hub status of the corresponding node: 1 as a hub and 0 as a node. For example, an individual in a 5 node system, which represent as 01001, means that in this individual node 2 and node 5 will act as a hub and the rest is a node and will be assigned to these two hubs.

Our Genetic algorithm is described in steps as follows.

Step 1. Initialize: Initiate a set of random initial solutions called "population" as a string of 1 and 0, by random number generator, to represent hub node and non-hub node. Each solution in the population is referred to as individual.

Step 2. Evaluate fitness: The fitness of each individual is evaluated by first, from the hub location in each individual, allocating the nodes to the hubs according to least cost rule, then the individual's fitness can be calculated according to the one-level objective function established in equation 1 as:

$$\sum_i \sum_h X_{ih} \beta\, C_{ih} \sum_{j_K} W_{ij} + \sum_{h_x} \sum_{m_x} X_{jj} W_{ij}\, C_{ij} \alpha$$
$$+ \sum_j \sum_m X_{jm} \delta\, C_{jm} \sum_i W_{ij} + \sum_j X_{jj}^K f_j^K \tag{6}$$

Step 3. Tournament selection: Randomly pick a pair of individual from the population pool and the individual with higher fitness will win with some probability (experimentally determined) and transferred to mating pool.

Step 4. Crossover: From the mating pool, a pair of individual will be randomly selected to "mate". The offspring is formed by taking the bits after the random crossover point in the first parent string and combine it with the bits before the crossover point form the second parent string, and vise versa. This is repeated until the offspring filled new population set.

Step 5. Mutation: The bits in each individual from new population undergo mutation (randomly change form 0 to 1 and 1 to 0) with some low probability.

Step 6. Evaluate fitness: (as in step 2).

Step 7. Record best solutions: The individual with the best fitness is selected and call tabu search subroutine to evaluate the allocation. The best solution's fitness and location-allocation is recorded.

Step 8. Evolution: Repeat step 3-7 is repeated until the iteration reach maximum genetic iteration.

Step 9. Termination: Return the best recorded individual along with its cost and location-allocation matrix.

By the process mentioned above, the individuals with low fitness will eventually die off and new individual with good fitness will be encountered. After the population pass thru several iterations, the optimal solution will survive in the population as in the nature rules of survival of the fittest.

4.3. Tabu search

Tabu search is a meta-strategy for guiding known heuristics to overcome local optimality. The overall approach is to avoid local optimum entrapment by forbidding or penalizing moves that will take the solution in the next iteration to points in the solution space previously visited (hence the name "tabu").

Tabu search begins by identifying a neighborhood of a given solution which contains new solutions that can be reached in a single iteration. A transition from a feasible solution to a transformed feasible solution is referred to as a move. As tabu search guiding the solution toward local optima, a move may either result in a best possible improvement or a least possible deterioration of the objective function value. To insure that the moves do not reverse to the solution visited before, the method records recent moves in tabu lists and prevent those moves for a number of iterations. Thus, this insures that new regions of a problems solution space will be investigated, while of avoiding local minima and ultimately finding the global optimal solution.

In our model, TS component receive the number of hubs and it's location from the best solution in each population of the GA component. The initial allocation solution will be assigned by the least cost rule, which all nodes will be assigned to the closest hubs. This initial solution is not optimal since the least cost rule does not consider the amount of traffic between the nodes. According to the single allocation constraint, all nodes must be assigned to only one hub. Thus the neighboring solution will be the solution that differs from the current one by one non-hub node allocation. The size of this neighborhood is equal to (n-p)(p-1), since for each of the non-hub nodes (n-p), there will be (p-1) choice of reallocation.

The objective value of the initial solution will be determined according to the objective function in equation (7). The first move is chosen from the best possible move that decrease the objective function the most. Once a node is reallocated, it will be place in the "Tabu list" which will prevent the node in this list from reallocate for a certain number of iterations (Tabu duration). The next move will be selected from the best possible non-Tabu move in the neighborhood. The key idea of keeping this Tabu list for Tabu duration is that the chosen move in each iteration is not necessarily be the improving one. The non improving move can guide the search to the unexplored solution and escape local optima entrapment. The existence of Tabu list also prevents the problem from cycling around the solution loop. However, the Tabu status can be override if choosing the move that currently in the Tabu list would lead to a new solution that is better than the best found solution. This is referred to as the "aspiration criteria".

In our algorithm, the TS components are described in steps as follows

Step 1. Initialize: Acquire hub location obtained form the best solutions in each generation of GA and assign all nodes to the hubs according to the least cost rule.

Step 2. Generate neighborhood set: The neighbor- hood set is a set of all solutions that can be obtained by reallocate one node to other hubs.

Step 3. Evaluate all moves: Evaluate all moves in the neighborhood set.

Step 4. Move: Choose the solution with the maximum improvement in objective value or the least non-improvement one that is not in tabu list.

Step 5. Tabu: Place the moved node in the tabu list to prevent that node from moving again for a certain iteration (tabu duration).

Step 6. Continue search: Repeat step 2-5 until the iteration is exceed maximum iteration.

Step 7. Termination: Terminate the search and return the best solution found.

5. Calculation results of china's aviation network

5.1. Parameters preparation

The first task before we carry out our calculations by M-GATS, is to set the parameters used in both genetic algorithm and Tabu search. In this section, we provide all parameters that were used in our experimental study. All these parameters were initially set as suggested in the literature Skorin-Kapov (1996), Abdinnour-Helm (1998), Goldberg (1989), and Glover (1997). Then we performed several initial experimental calculations in a randomly generated dataset to adjust these parameters to suit our specific problem.

It is found that, since the solution space of our hub location is quite large, instead of using a conventional tournament wining probability of 0.9, we choose the lower probability of 0.7. This is to prevent premature convergence and guide the search to explore more solution space. Our empirical study also suggest that even if we use just the conventional parameters i.e. Tournament wining probability = 0.7~0.95, Crossover probability = 0.6~0.95, Mutation probability = 0.005~0.01, Tabu list size = number of nodes*(0.1~0.2), the search would also be able to find the optimal solution. However, it will need more iteration and genetic restart. The adjusted parameters for GA and TS are as follows:

Genetic algorithm

Maximum genetic restart = 10
Maximum genetic iterations = 300
Population size = number of nodes*2
Tournament wining probability = 0.7

Crossover probability = 0.7
Mutation probability = 0.005

Tabu search

Maximum iterations = 200 (or 50 consecutive iterations if there is no improvement in objective value)
Tabu list size = number of nodes*0.1
Tabu duration = tabu list size

Calculation results

We obtained the data set for China's aviation network from China aviation statistic yearbook (2000) published by CAAC. The data set consists of OD data and coordinates of all 121 airports. The locations of all airports are shown in figure 5.

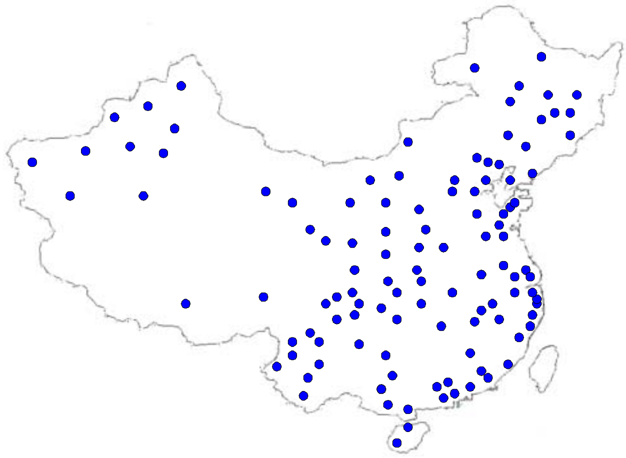

Figure 5 – China's airport location (121 airports)

This data set contains the OD data on major trunk routes and distance for all flight routes. However, OD data on small feeder links were unavailable. Therefore, we used gravity model to estimate the OD flow of the feeder links.

$$V_{ij} = K \frac{(P_i P_j)^a (G_i G_j)^b}{D_{ij}^c} \tag{7}$$

Where D_{ij}: distance between two airports (km)
G_i, G_j: GDP of the zone i and j (yuan/person/year)
P_i, P_j: population of the zone i and j
K, a, b, c : regression coefficients.

We carried out regression analysis to determine the regression coefficients. The results of our regression analysis were determined as follows: K=0.182, a=0.52, b=0.35, c=0.85 with the coefficient of determination R^2=0.803

We compare our calculated results with the network arranged according to CAAC's 5 years plan. In this plan, the airports of Beijing, Shanghai and Guangzhou will be enhanced as the trans-national hub of China air transport, while construct the airports of Shenyang, Wuhan, Chengdu, Kunming, Xi'an, and Urumuqi as the regional hub airports. The calculation results are shown in Table 1 and the example of network arrangement according to our calculation is shown in figure 6.

Table 1 Calculation results for China's aviation network

Case	δ_1	β_1	β_2,δ_2	α	F_j^1	F_j^2	number of M-GATS 1st level hub	number of M-GATS 2nd level hub	M-GATS O.V.	CAAC's arrangement O.V.	% diff.
1	2	3	0.75	0.2	1000	2000	24	5	118974	12882	3.28
2	2	3	0.75	0.2	2000	3000	17	5	143487	151877	5.85
3	2	3	0.75	0.2	3000	4000	13	4	163377	168302	3.01
4	2	3	0.75	0.1	1000	2000	24	6	110081	122848	11.60
5	2	3	0.75	0.1	2000	3000	17	5	136897	150743	10.11
6	2	3	0.75	0.1	3000	4000	13	5	162302	168302	3.70

*Calculation time =98050 sec. (27 hr 14 min 10 sec)

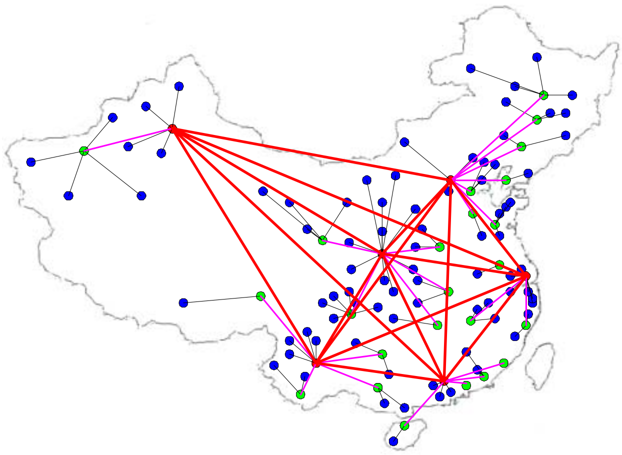

Figure 6 – Calculated result for China's aviation network, case 4

From the result in table 1, it is shown that our M-GATS results can reduce the total transportation cost from CAAC's plan in all cases. In case 4, the cost reduction is up to 11.6 %, which is the largest among all cases. In this case, our calculation determined that the airports in Beijing, Shanghai, Guangzhou, Kunming, Xi'an, and Urumuqi should be developed as the trans-national hub. Also another 24 airports should be developed to become regional hub airports. When comparing this result to CAAC's 5 years plan, it is shown that China still need to improve its hub-and-spoke structure. The construction and improvement of the existing system will lead to further cost reduction and also travel time saving for the entire network.

It is also observed that the parameters for economy of scale and fixed cost for establishing hubs has considerable effects on the hub location and allocation. Therefore, in the application of this model to the actual decision making, the estimation of these cost parameters is very crucial and should be done with acceptable accuracy.

6. Conclusions

In this paper, we developed a heuristic model based on GA and TS namely M-GATS to solve China's domestic aviation network problem. We presented the application of M-GATS to design an optimal hub and spoke structure for China's aviation network. From our results, it is shown that China still need to develop its airports further both in term of regional and trans-national hubs. The model suggested that, apart from Beijing, Shanghai, and Guangzhou, CAAC should develop Kunming, Xi'an, and Urumuqi to become new trans-national hubs.

The future work for this research should focus on increase the accuracy of the cost and OD parameters. The model should also take into account the increase in future demand due to the change in network structure.

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References

Abdinour-Helm, S.,1998. A hybrid heuristic for the uncapacitated hub location problem. European Journal of operation Research, 106, 489-499.

CAAC, 2000. China aviation statistic yearbook. CAAC press.

Ernst, A.T., 1996. Efficient algorithms for the uncapacitated single allocation p-hub median problem, Location Science., 4, 139-154.

Ernst, A.T. and Krishnamoorthy, M., 1998. Exact and heuristic algorithms for the uncapacitated multiple allocation p-hub median problem. European Journal of operation Research. 104, 100-112.

Glover, F. and Laguna M., 1997. Tabu search. Kluwer Academic Publishers, Boston.

Goldberg, D.E., 1989. Genetic algorithms in search, optimization, and machine learning. Addison-Wesley Pub. Co., New York.

Ieda, H., 1997 Modeling and solving of hierarchical transport systems such as hub-spokes /point-to-point and/or consolidated /direct delivery in the uniform boundless plane. Journal of Infrastructure Planning and Management. Japan Society of Civil Engineering, 14, 733-782.

Kijmanawat, K. and Ieda, H., 2004. Multilevel Hierarchical Network Design: Formulation and development of M-GATS algorithm. Journal of Infrastructure Planning and Management. Japan Society of Civil Engineering, 751/IV-62, 139-150.

O'Kelly, M.E., 1987. A quadratic integer program for the location of interacting hub facilities. European Journal of operation Research. 32, 393-404.

O'Kelly, M., 1992. Hub facility location with fixed costs. Papers in Regional Science: The Journal of the RASI., 71, 293-306.

Skorin-Kapov, D. and Skorin-Kapov, J.,1994. On tabu search for the location of interacting hub facilities. European Journal of operation Research. 73, 502-509.

Skorin-Kapov, D., Skorin-Kapov, J. and O'Kelly, M., 1996. Tight linear programming relaxations of uncapacitated p-hub median problems. European Journal of operation Research. 94, 582-593.

Zhang, A., 1998, Industrial reform and air transport development in China. Journal of Air Transport Management, 4, 155-164.