AIR FREIGHT NETWORK OPTIMIZATION

RUEY-MIN WANG
Associate Professor
Dept. of Transportation Management
Toko University
Pu-Tze City, Chiayi County, Taiwan 613
Fax: +886-5-3622899
Email: rmwang@mail.toko.edu.tw

CHUN-HAO CHEN
Graduate Research Assistant
Dept. of Transportation Engineering and Management, Feng-Chia University
Taichung City, Taiwan 40724
Fax: +886-4-4522032
Email: g8912854@knight.fcu.edu.tw

Abstract: The hub-and-spoke network can make use of the economy scale to reduce transport cost. This research considers both the characteristics of airfreight and total transport cost in the hub-and-spoke network. The research formulation also thinks about the relationship among distances, types of aircraft, and transport cost. The research looks for the optimal route in the hub-and-spoke network via mathematical programming. The airfreight can employ the optimal route to reduce operation cost, as well as to improve the satisfaction of customers. The research reviews related literatures, which concentrated to the hub-and-spoke network of the airfreight in the past. The mathematical programming is the tool used to solve for the target problem. The research takes advantages of related literature to establish the initial proposed model of the hub-and-spoke network. At the end of this paper, sensitivity analysis was conducted to prove the feasibility of proposed method.

Keyword: hub-and-spoke network, mathematical programming, economy scale, optimal route

1.INTRODUCTION

The growth of global trade and worldwide economy for the demand of reliable in-transit air cargo services has resulted in a fast development of air cargo service. To be competitive, an air carrier needs to supply both satisfactory services and reasonable prices to cargo owner in order to get business.

Since the deregulation in 1978, the hub-and-spoke network started to develop in the USA. The hub-and-spoke network system has the capability to gather passengers and goods in an efficient way, that dramatically reduces the average operating cost. Hub-and-spoke network is recognized with higher transport elasticity and mobility that will enhance working efficiency to reduce transport cost. Time issue of air cargo is less urgent than passenger transport, so air cargo can be handled more easily. For example, the Federal Express Company was able to guarantee to provide door-to-door service overnight in American, by taking the advantages of their sophisticated air network and their complete transshipment system. Therefore, the airline operator can easily utilize the advantage of extended capability in the hub-and-spoke network system that dramatically cut time and cost simultaneously to increase competition capability.

To reduce cost and make profits to attain the satisfactory level from customers is the most important topic to study. This research takes total transport cost into account, which is based on the characteristic of a specific airfreight case. Besides, the relationship among distances, types of aircraft, and transport cost are also considered in the research. The research also refers to the related references in the past. The proposed model is formulated by mathematical programming to minimize cost, and simultaneously determines the optimal route in the hub-and-spoke network. At the end, the research will use a real airline cargo network to prove the feasibility of proposed model. This research expects to use the optimal route to construct the choice behavior of airfreight route.

2.RESEARCH GOALS AND FLOW CHART

The research capitalizes on the concept of economy scale. It considers both the airfreight's characteristics and the transport cost. In addition, transport efficiency is regarded as important issue in the research. The research tries to solve for the best route choice that can lower total cost by taking the advantage of the hub-and-spoke network. Research steps are depicted as followings

1. Define the purpose of research

   The step defines the research purpose and scope. The hub-and-spoke network is directed at the airfreight network.

2. Literature review

   The research reviews the correlative literatures about hub-and-spoke network. Due to the hub-and-spoke network is the 0-1 integer programming, literature reference also covers method related to definite problem solving techniques.

3. Parameters and variables

   Define the parameters and variables used in the mathematical model.

4. Formulation

   The research considers the relationship of mileages, types of aircraft, and operation cost. To minimize the total cost is the object of model in this research. Mathematical programming was used to determine the optimal route.

5. Experiment results

   The research simulates the real airfreight network and uses CPLEX program to solve for the problem. It also conducts a sensitivity analysis to test the reliability of proposed model. The research illustrates the discrepancy by the sensitivity analysis.

6. Conclusions

   The research brings up the important conclusions that obtained from the experiment. It will provide the helpful suggestion for the follow-up researches to fit within the real world's condition.

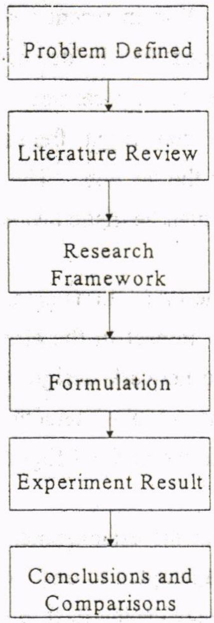

Figure.1 、Research Flow Chart

3.LITERATURE REVIEW

The research reviews the foregoing literatures that are related to the hub-and-spoke network. Most of the past studies regarding airline network design are focused in developing mathematical programming models or designing solution algorithms. In general, most of methods are seeking the minimum cost or the maximum benefit. These objectives are subject to transport time, value of freight, types of aircraft, and transport cost. Therefore, the research combines the above-mentioned objects to construct the proposed model. Normally, the hub-and-spoke network problem is formulated as NP-Hard problem or large-size 0-1 integer programming. Lagrangian relaxation method and simplex method are used mostly to solve the problem.

Hsu and Wang (1997) developed a model to route an air shipment through a hub to destinations. The logistics cost functions are formulated by considering relevant expenses in shipping process, and compared to make the optimal route choice. Their model had showed how the time value of shipment with spatial distribution of origin, destination and hub airports could affect the overall shipping costs and route choices. For each link with specific flow and distance, there were procedures in their model to find the optimal type of aircrafts, which yields the minimum cost. The sensitivity analysis of their model displayed that routing via a cargo hub could be more essential when time value of the airfreight rises.

Yan and Hwung (1996) mentioned that planning of aircraft routes and flight frequencies are both important for airline operations. Their model was formulated as a network flow problem. Due to the airline deregulation in recent years, the market demand significantly grew for airline carriers. It is expected that the demand will increase in the future. They aimed to develop a systematic model to help carriers to minimize their operating costs for determining optimal aircraft routes and flight frequencies regarding the operations of multi-fleet and multi-stop flights for the air hub. The Lagrangian relaxation accompanied with network simplex method, lagrangian heuristic and subgradient method was developed to solve the problems.

Hsu and Lee (2000) remarked that the interactions among airline cargo demand, route flight frequency, and aircraft type are very impact in the airline cargo network problems. They studied the airline cargo demand and network design problem via constructing models and economic theory to reflect the demand-supply interaction in a competitive air cargo market. They developed a model to determine the optimal flight frequency and aircraft type for each routes.

Yan and Tseng (1999) mentioned that the establishment of timetables and crew scheduling always affect the efficiency. They attempted to develop an integrated model using solution algorithm to help carriers simultaneously decide fleet routes and suitable schedules. In order to manage the interrelationships between trip demand and flight supply, they applied a time-space network model to formulate the movements of aircraft and passenger flows. Mathematically, the model was formulated as a special multiple commodity network flow problem. They developed a Lagrangian-based algorithm to efficiently solve the problem.

4.REASEARCH METHOD

Primarily, this research is trying to use the mathematical programming to investigate the airfreight transshipment problem in a hub-and-spoke network. It considers the characteristics of the airfreight and total transport cost. Figure 2 is the model's architecture.

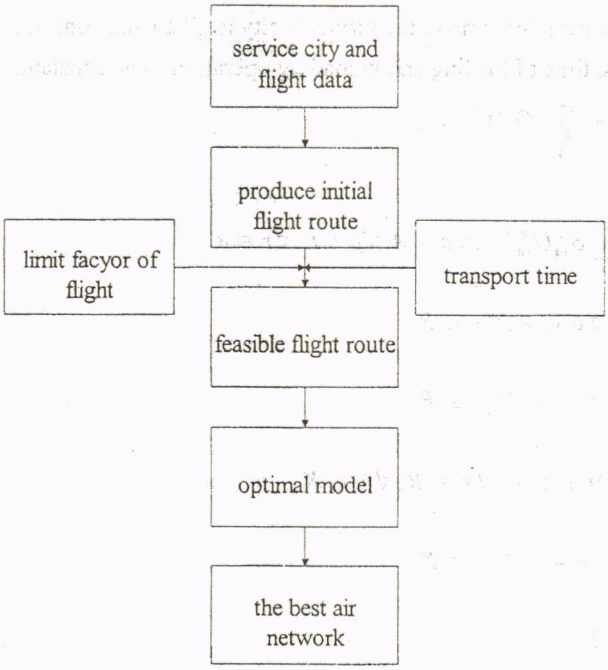

Figure.2 、Model's architecture

Before using the optimal model to solve, the research considers the time's limit and the navigation's constraint. It also considers the types of airplane when to find the flight's route. These restrictions can avail against reducing the influence of variables. The research sets up the freight network model under the restrictions. Under the time limit and navigation's constraints, the study results all flight's routes from every city to the hub. According to the types of the airplane, the study separates the wrong routes from all flight's routes. The study uses the mathematical programming to solve for the freight network problem.

In the process of producing freight's route, the research takes account of these restrictions to produce the initial routes. The available route can be separated from the preceding routes. It can ensure that all adopted route is available. At the same time, the research takes account of the route's capacity to be sufficient for the restriction of the arrival time. The research uses the commercial software CPLEX to solve the problem. It looks for the optimal freight network in the feasible transit's routes. By way of the sifting process, it reduces the number of variables in the solving process.

The research refers to Lin's (2000) mathematical model. The model is the initial framework of the hub-and-spoke network. The objective of the research is to minimize total cost. The constraints consider the relationship of distances, types of aircraft, and transport cost in the realistic demand. It also considers the service time as one of constraint. The basic assumptions of the model is following:

1. Suppose the location of the hub and service's city is given.

2. Suppose the received time in the service's city is given and constant.
3. Suppose the time of loading and unloading operation to be constant.

$$Min \sum_r C_r^k Y_r^k + \sum_p Q_p^n C_s X_p^n \tag{1}$$

s.t

$$\sum_p Q_{pa}^n X_p^n \le \sum_r \delta_{ra}^k U_{ra}^k Y_r^k, \forall a \in A, \forall p \in P, \forall r \in R \tag{2}$$

$$\sum_r \delta_{ra}^k Y_r^k \le 1, \forall a \in A, \forall r \in R \tag{3}$$

$$\sum_p X_p^n = 1, \forall n \in N, \forall p \in P \tag{4}$$

$$\sum_r \delta_r^n Y_r^k \le 1, \forall n \in N, \forall r \in R, \forall k \in K \tag{5}$$

$$\sum_r Y_r^k \le B^k, \forall r \in R, \forall k \in K \tag{6}$$

$$T_0 + \sum_p T_p X_p^n \le T^r \tag{7}$$

$$X_p^n \in (0,1), Y_r^k \in (0,1) \tag{8}$$

Related parameter's definitions：

A ：A set of all links, represent a.
P ：A set of all transit's route, represent p.
R ：A set of all air routes, represent r.
N ：A set of all nodes, represent n.
K ：A set of all type of airplanes, represent k.
δ_r^n ：The air route r that pass through city n is 1 ；otherwise 0.
δ_{ra}^k ：The airplane's type k that use link a in the freight's route r is 1 ；otherwise 0.
δ_{pa}^n ：The transit's route p that use the link a of the city n is1 ；otherwise 0.
Q_{pa}^n ：The origin's city n use the transit's route p, a flow of the link a.
U_{ra}^k ：The maximum flow of the airplane's type k in freight's route r.
B^k ：The maximum number of the airplane's type k.
C_s ：The handling cost of cargo.
Q_p^n ：The export volume of the origin's city n use the transit's route p.

C_r^k : The transport cost of the airplane's type k in freight's route r.

T_p : The time window of the transit's route.

T^r : The maximum time window of the freight route.

Decision variables :

Y_r^k : Use the airplane's type k in the freight's route r is 1 ; otherwise 0.

X_p^n : Use the transport route p of the city n is 1 ; otherwise 0.

Model (1) is the minimum cost of all freight's routes that consider the transport cost of airplanes and the handling cost. The restriction (2) hedges about the link volume. It limits that the flow of any link not to be greater than the maximum volume of single airplane in all freight's routes. The restriction (3) hedges about that single airplane flies in one route. The restriction (4) hedges about the single transport route. It limits that every city only has one transport route. The restriction (5) hedges about the freight's route. It limits that every city is only passed through the single freight's route. The restriction (6) hedges about useful volume of the types of airplanes. The restriction (7) hedges about the service hours. It limits that the goods is delivered on the time that is stipulated. The restriction (8) hedges about that the decision variables including freight's routes and transport routes of goods are the 0-1 integer programming. Minimum cost is used as the objective of formulation. The research determines the optimal hub-and-spoke network in the conditions. The airways can use the hub-and-spoke network to raise the working efficiency.

5.EXPERIMENT RESULT

The research makes use of the real data to build the airfreight network included five cities in Taiwan, and uses CPLEX program to solve for the hub-and-spoke network problem. First, it collects the volume of the cargo, which transported between the five cities. Second, it collects the type of available aircraft including characteristics of maximum voyage, maximum load, freight cost, and their quantity. In addition, this research assumed that the handling cost of cargo is NT$10/kg. The research uses the foregoing data to derive the minimum total cost. At the end, sensitivity analysis is conducted to test the reliability of proposed model. This research divides into two parts. In the first part, it chooses different locations to be the hub center. From that, changes of total cost for the difference hub's sites can be understood. In the second part, the volumes of cargo were varied to test the transport efficiency. The change of overall cost for the various volumes can be analyzed. Figure.3 is the geographical distribution of various airfreight networks. Table 1 is shown the volume of the cargo shipped among cities. Table 2 is shown the available aircraft types and related characteristics. Table 3 is shown the total cost without the hub.

Table 1 、The volume of the cargo between the cities

O-D	City 1	City 2	City 3	City 4	City5
City 1		4420	3169	4327	16979
City 2	2938		289	340	1464
City 3	1690	210		214	885
City 4	3075	476	328		1503
City5	13230	3443	2825	3398	

P.S. 1. The unit is "kg"

2. The handling cost of cargo is NT$10/kg

Table 2 、The available aircraft type and related characteristics

Aircraft type	Max. Voyage (Km)	Max. Load (Kg)	Cost ($/km)	Quantity
TYPE I	3426	2400	525	1
TYPE II	3426	3600	225	3

Table 3 、the total cost without the hub

The volume of cargo	Total cost
The original	5,015,000
Increase 5%	5,215,000
Increase 10%	6,875,500
Increase 15%	7,383,600
Increase20%	7,584,500
Increase 30%	7,750,500

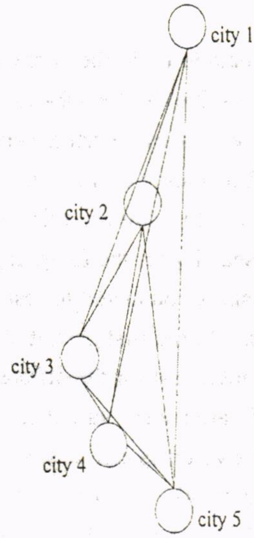

Figure.3 、The layout of network

Phase1.

When the volume of cargo is original without the hub, the total cost is NT$5,015,000. The research chooses the city 2 as the hub center in this project. Figure.4 is the network of layout phase. All cargo must be unloaded in the hub before delivery to other places. Both freight route and the transport route are chosen as decision variables of the research. The research uses the above-mentioned data and CPLEX program to solve for the problem. When the volume of cargo is original with the hub, the total cost is NT$5,214,100. The cost with the hub is higher than without the hub. Then, the sensitivity analysis is conducted to test the reliability of proposed model. Fist, the volume of the cargo is increased to 5%. The transport cost stays the same. The handling cost of goods is only increased by the volume of cargo rising. In the part, the total cost with the hub is higher than without the hub. Second, the volume of cargo is increased to 10%. The transport cost and handling cost are simultaneously heightened. The total cost with the hub is still higher than without the hub. Third, the volume of cargo is increased to 15% and 20%. Their transport costs are the same as 10%. Their handling costs are still increased by the volume of cargo rising. In the part, the total cost with the hub is lower than without the hub. Final, when the volume of cargo is increased to 30%, the total cost is an unfeasible solution (see the table 4). Figure.5 is the tendency of the sensitivity analysis.

Table 4、The sensitivity analysis in the phase 1

The volume of cargo	Transport cost	Handling cost	Total cost
The original	4,930,600	283,500	5,214,100
Increase 5%	4,930,600	309,340	5,239,940
Increase 10%	6,830,600	335,180	7,165,780
Increase 15%	6,830,600	361,020	7,191,620
Increase20%	6,830,600	386,860	7,217,460
Increase 30%	-	438,540	-

P.S."-" is unfeasible solution

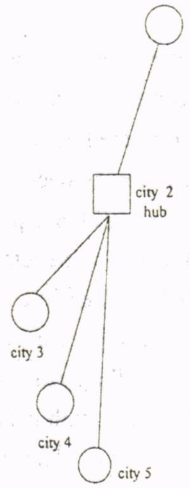

Figure.4 、The test network 1

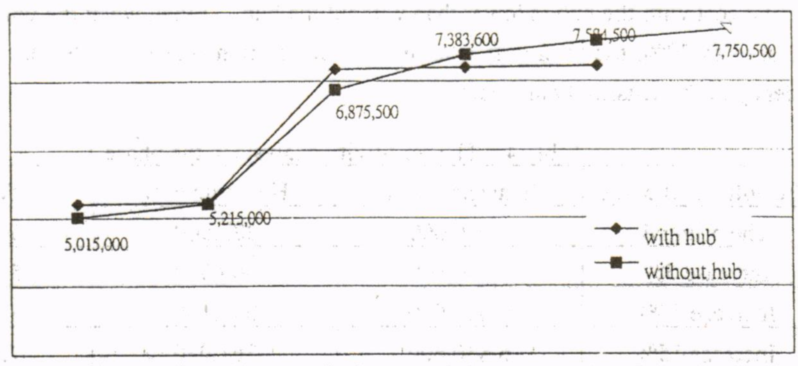

Figure.5 、The result of sensitivity analysis

Phase 2.

When the volume of cargo is original without the hub, the total cost is NT$5,015,000. The research chooses city 3 as the hub center in this phase. Figure.6 is the test network of phase. All cargo must be unloaded in the hub to be delivered to other places. The solving process is similar as in phase 1. When the volume of cargo is original, the total cost is NT$5,554,100. The cost with the hub is higher than without the hub. Then, the sensitivity analysis is conducted to test the reliability of proposed model. Fist, the volume of the cargo is increased to 5%. The transport cost stays the same. The handling cost of goods is only increased by the volume of cargo rising. In the part, the total cost with the hub is higher than without the hub. Second, the volume of cargo is increased to 10%. The transport cost and handling cost are simultaneously heightened. The total cost with the hub is still higher than without the hub. Third, the volume of cargo is increased to 15% and 20%. Their transport costs are the same as 10%. Their handling costs are still increased by the volume of cargo rising. In the part, the total cost with the hub is lower than without the hub. Final, when the volume of cargo is increased to 30%, the total cost is an unfeasible solution (see the table 5). Figure.7 is the tendency of the sensitivity analysis.

Table 5 、The sensitivity analysis in the phase 2

The volume of cargo	Transport cost	Handling cost	Total cost
The original	5,270,600	283,500	5,554,100
Increase 5%	5,270,600	309,340	5,579,940
Increase 10%	6,820,600	335,180	7,155,780
Increase 15%	6,820,600	361,020	7,181,620
Increase 20%	6,820,600	386,860	7,207,460
Increase 30%	-	438,540	-

P.S."-" is unfeasible solution

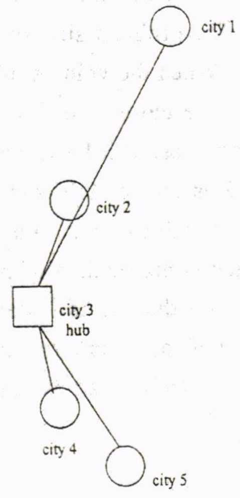

Figure.6 、The test network 2

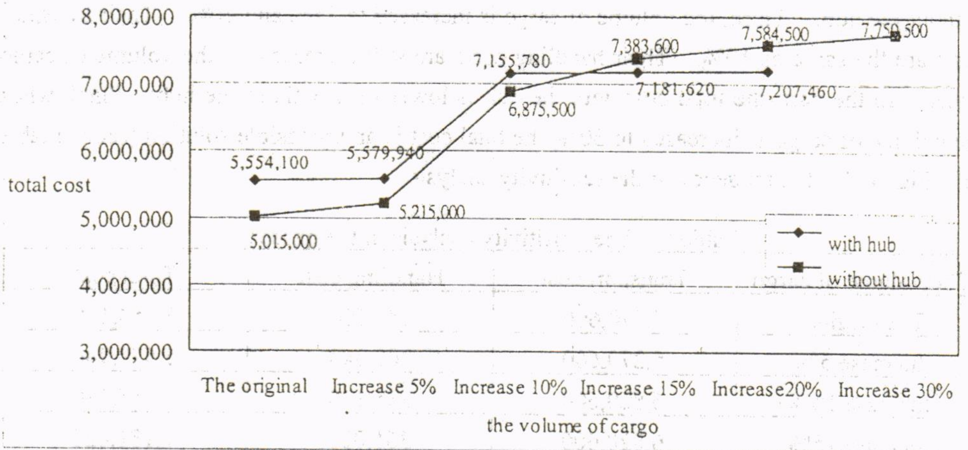

Figure.7 、The result of sensitivity analysis

From the shown test results, the two phases can give the study the total cost. Because the cost of city 2 case is less than city 3 case under the original volume of cargo, city 2 as the hub center will be better than city 3. The different sites of hub can affect the total cost in the hub-and-spoke network operation. When the volume of cargo is increased more than 15%, the overall cost of city 3 case will be close to city 2 case. When the volume of cargo conforms to economy scale, the total cost will be lower and close to the optimal. In the higher volume of cargo, the city 2 is the feasible site of hub. In addition, the research compares the total cost using the hub with using no hub. When the volume of cargo is less than 15%, the total cost with the hub is higher than without the hub. When the volume of cargo is more than 15%, the cost with the hub is lower than without the hub in the more volume of cargo. When the volume of cargo conforms to economy scale, the hub-and-spoke network will be suited to use. The airfreight can use the hub-and-spoke network to reduce operation.

6. CONCLUSIONS

The planning of aircraft routes is very important in airline operations. It can affect the working cost of airfreight and the service level. To reduce the cost and improve the service level are important for the planning of airfreight. The hub-and-spoke network system dramatically cuts the time and cost simultaneously to increase competition ability. The airfreight can use the optimal route of the hub-and-spoke network to reduce their operation cost.

The hub-and-spoke method of mathematical programming was chosen as the methodology that used to solve for the problem. This research uses the 0-1 integer programming techniques to set up the network model. The object is to achieve the minimum total cost of all freight's routes by considering the transport cost of the airplanes and the handling cost. It simultaneously considers the freight's route, transport route, and types of aircraft to arrange the optimum route. Under the time limit and the navigation constraints, the research results all flight's routes. According to the types of the airplane, the study sifts the wrong routes from all flight's routes. By way of trial-and-error testing, the research obtains that the city 2 is the better site of hub. Because the fleet's restriction can affect the range of solving, the more volume of cargo results the unfeasible solution in the experiment. From the experiment, the hub-and-spoke network can be still used in the small area. The hub-and-spoke network is effective for the airfreight.

Future research can be done in following aspects :

1. The follow-up research will establish the quick solving process. The quick solving process can suffice the time reaction in the competitive market.
2. According to the experiment result, the location choice of hub is important. The follow-up research should increase the number of hub and use a large network for testing. It will enhance the accuracy of the experiment.
3. In the future, the study also considers detailed handling cost and other expenses in the airport. It will make the complete experiment.
4. Because the fleet's restriction can affect the range of solving. The follow-up research will vary the size of fleet to understand the change of cost. The number of fleet can help the airfreight to decide the operation policy.
5. Human factor (including the aviator, etc.) is not considered in the study. The human factor can influence the operation cost in the realistic circumstance. In the future, the problem can be considered to fit in with the real condition.

REFERENCE

Hsu, Chaug-Ing and Wang, Chih-Ching (1997) Direct versus terminal routing on a hub-and-spoke air freight network, **Transportation Planning Journal, Vo1.26, No.1,** 95~118

Yan, Shang-yao and Hwung, Wu-Chung (1996) Planning of aircraft routes and flight frequencies for the air hub, **Transportation Planning Journal, Vo1.25, No.4**, 681~708

Yan, Shang-yao and Tseng, Chih-Hwang (1999) An integrated study on single-fleet routing and flight scheduling, **Transportation Planning Journal, Vo1.28, No.4**, 635~658

Lin, Cheng-Chang and Jyh-Yeuan Liou (1999) The delivery network design problem of time-definite freight delivery common carries, **Transportation Planning Journal, Vo1.28, No.4**, 535~564

Lin, Cheng-Chang (2000) The singular path constrained freight routing planning of time-definite freight delivery common carriers, **Transportation Planning Journal, Vo1.29,** No.1, 1~32

Lin, Cheng-Chang and Joan C. W. Hsu (1999) The ground network design problem of the same day express service, **Journal of the Chinese Institute of Transportation, Vol.11, No.2,** 61~86

M. E. O'kelly, O. Bryan, D. Skorin-Kapov, J. Skorin-Kapov (1996) Hub network design with single and multiple allocation: a computational study, **Location Science, Vol.4, No.3,** 125~138

Turgut Aykin (1995) The hub location and routing problem, **European Journal of Operational Research 83**, 200~219

Lin, Cheng-Chang and Lin, Yu-Jen (2000) Air network design for express integrated common carriers, **Master Thesis**, Department of Transportation & Communication Management Science, National Cheng Kung University, Taiwan

Hsu, Chaug-Ing and Lee, Jin-Thin (2000) The Study on Flight Frequency and Aircraft Type for Airline Cargo Routes, **Master Thesis**, Department of Transportation Engineering & Management, National Chiao Tung University, Taiwan