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Air Cargo Decision Support System

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Abstract

Businesses around the world are being connected due to the advancement in information system. The airline cargo transportation system is a large and complex service system. Nowadays, this system shows its importance by playing a crucial role in the global economy. Whether it is through shipment planning by providing expedited service, express transportation for valuable goods, or utilizing the aircraft space while generating the most profit, the air cargo industry serves as a key engine of economic growth and development. In this research, a decision support system for air cargo scheduling is proposed. The system consists of several practical components that can be used to maximize the revenue from the operation. The main contribution of this research is to develop a scalable decision support system that takes into consideration of practical data. The computational results with practical data were used to evaluate the system performance.

Key Words: Airline cargo reservation system, Decision support system, Airline cargo scheduling

1. Introduction

In air cargo business, the transportation of goods is normally initiated by shippers once they received orders from customers. As of today, businesses all over the world are being connected with the expanding of e-commerce via the internet. The traditional supply chain, from supplier to manufacturer then to customer, is still maintained but changed in details. One of the changes is freight transportation. Physical goods can be transported using ship, rail, surface transportation, and the newest player-air cargo. Air cargo industry has been playing a significant role for transporting light-weight and high value goods since its beginning after World War I. Cargo carrier can be classified into three types which are cargo-only carrier, combination carrier, and integrator.

Cargo-only carrier normally uses freighters which are aircrafts specifically altered for cargo operation with no seat or windows in the main cabin and generally have wide body. Most freighters are equipped with rollers in order to facilitate the loading of large shipments. Approximately 10 to 15 percent of world air cargo is handled by cargo-only carrier. Combination carrier primarily focuses on passenger transportation but uses available belly space to transport cargo. Typically, more than 50 percent of international cargo is transported by using combination carrier. Examples of carriers with this type are Lufthansa, British Airway and KLM. Integrator, in contrast, offers its logistics solution directly to shippers. It offers a complete integrated transportation to customers with door to door service. As a result, the integrator normally acts both as a forwarder and a carrier and has its own ground and air transportation to provide service to customers. The major air freight integrators are FedEx, UPS, TNT and DHL. Fig. 1 shows the air freight value chain.

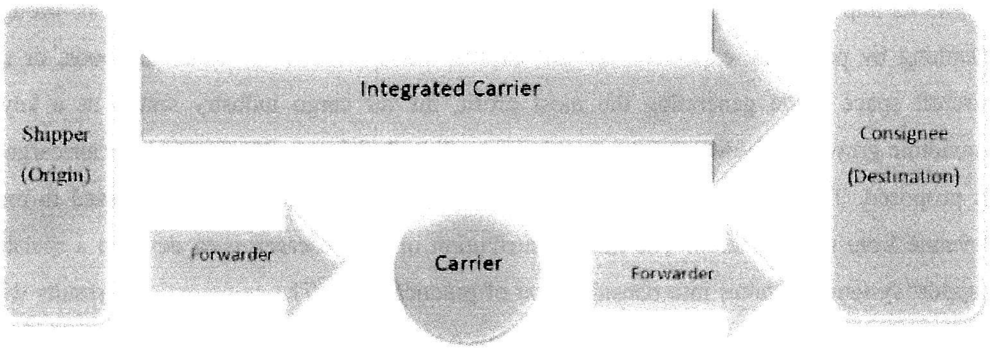


Fig. 1. Air freight value chain

Airlines will choose when to open for cargo space reservation. Normally, the price for early booking is cheaper than late booking. In addition, airlines could not just sell all cargo spaces at once because they will have to concern about available space for passenger luggage and also, most of the time, early reservations could be changed at the departure date, and the airlines will have to pay for the cancellation according to their refund policy. Airlines normally set their fares with different rates based on the weight of cargo which is challenging in terms of forwarders to develop mathematical model for consolidating cargos as a means to minimize shipping cost. Air cargo fare is set based on two factors; which are fixed price and surcharge. Fixed price is the cost concerning base activities, such as operating cost and transportation cost. Surcharge is the cost from external factors that are uncontrollable, versatile, and changed dynamically such as oil price.

To set an appropriate price and sell the right booking space at the right time are very challenging tasks in air cargo management. In this research, the objective is to create a complete decision support system for airline cargo reservation with an optimizer aiming to maximize the profit in doing air freight transportation activities while giving valid results which can be applied to real air freight transportation business [1-5].

2. Literature Review

Most of the researches relevant to cargo scheduling involve developing methodologies to enhance the efficiency of the business. Yan et al. [6] proposed an integer multi-commodity network flow problem for a short-term flight scheduling model. The research considers international air express carriers with a single hub operation. The model can be used to determine optimal routes and flight schedule and can be scaled up to 23,372 variables and 13,496 constraints. Li et al. [7] considered a large scale air freight consolidation problem and developed a neighborhood search algorithm based on a simulated annealing method. The proposed algorithm provide good quality solutions. Wong et al. [8] considered an air shipment scheduling using a mixed integer programming model. Large instances of data were solved by a tabu search based algorithm.

Huang and Chi [9] developed a decision support system based on a recursive heuristic algorithm. The focus was to assist air forwarders consolidate cargo shipment. Gupta [10] studied the relationship between a carrier and a forwarder. The objective was to investigate if a particular contract type can achieve the maximum system's efficiency, that is, the forwarder could use the best effort level in selling service and the carrier could optimally allot available capacity. Hellermann et al. [11] focused on studying the drawbacks of long-term capacity agreement between air cargo carriers and forwarders.

In the area of air cargo revenue management, Armaruchkul et al. [12] developed a model for a cargo booking problem in order to maximize the revenue. In the model, uncertainty of volume and weight was not known in advance. They problem was modeled using a Markov decision process and relied on a heuristic method to generate the solution for the problem. A two dimensional overbooking model was introduced by Luo [13]. The model considers both weight and volume of cargo. The optimal overbooking limit was determined in order to minimize the summation of capacity spoilage and cargo offloading costs. Levin [14] used a dynamic programming approach to solve a booking control problem for an airline that operates parallel flights between an origin-destination pair.

Totamane[15] considered a demand prediction model for air cargo in order to maximize cargo capacity utilization. Ha and Nananukul [16] considered an air cargo scheduling problem that takes into account three-dimensional orientation of cargo. Constraints from orientation of cargos, allotment contracts and commitment from forwarder and customers were considered.

3. Air cargo decision support system

The proposed decision support system consists of three main components, user interface (UI), server and database. Fig. 2 shows the components of the decision support system. The user interface (UI) provides functions to load data (customer orders or flight schedules) from either excel sheet or database. The UI also has functions to display orders, available flights and schedule results. Example of UI is shown in Fig. 3. In addition, the UI also provides functions to display route schedules by using GIS based on Microsoft MapPoint and to allow users to overwrite route schedules if necessary.The database contains flight schedule data and order data collected from customers. Also, the database stores schedule results generated by the optimization module.

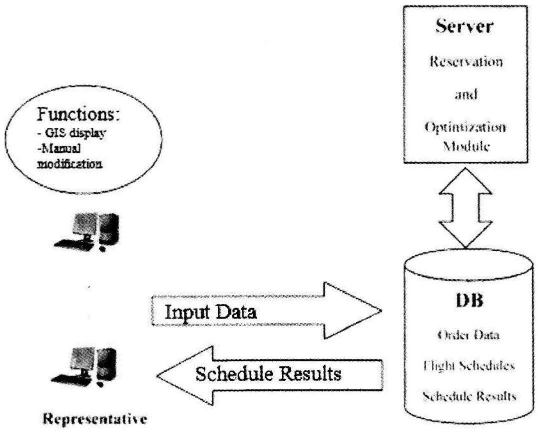


Fig. 2. Components of airline cargo decision support system

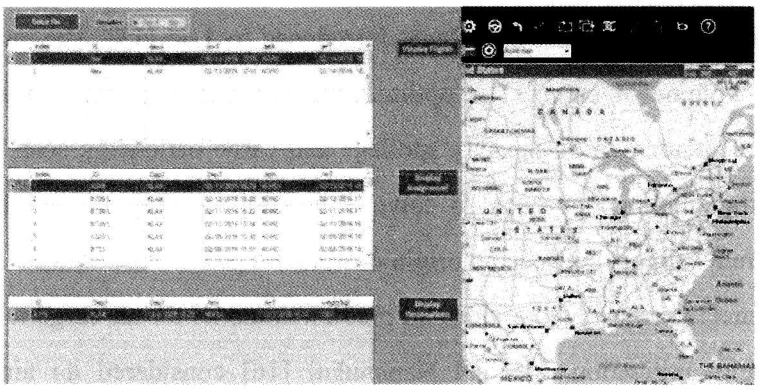


Fig. 3. User interface

At the server, reservation module and optimization module are implemented. The main function of the reservation module is to accept orders from customers. To be able to respond to customers' request in a few seconds, the reservation module consists of efficient flight screening function. Flight screening function checks for the feasibility of flight schedule for each order. Flight screening function checks the customer order through three conditions, and the order will be accepted for shipping if it passes all conditions. The three conditions are as follows:

1. The departure airport of the flight must be the same with the departure airport of the customer order, and both of their arrival airports must match, as well.
2. The received time of customer order must be prior to the departure time of flight, and the required arrival time of the order must be subsequent to the arrival time of the flight.
3. The shipment's weight and volume must satisfy with the available capacity of the flight. The capacity is varying with the airplane model of flights.

A flow chart represents the flow of Flight screening sequences is structured as in Fig. 4.

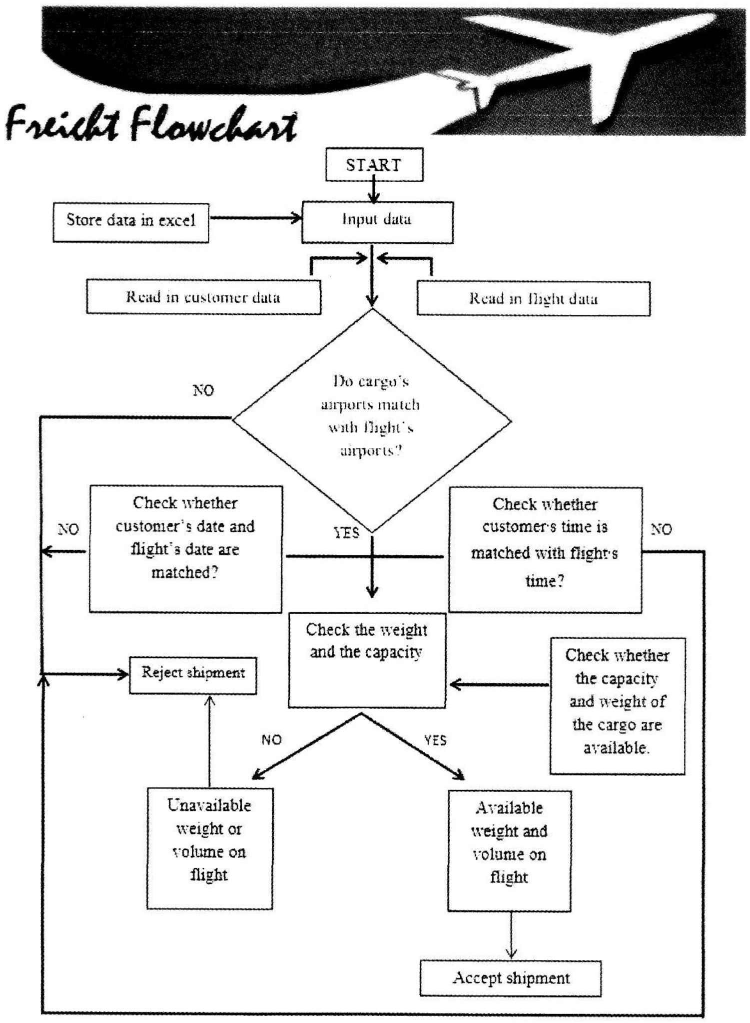
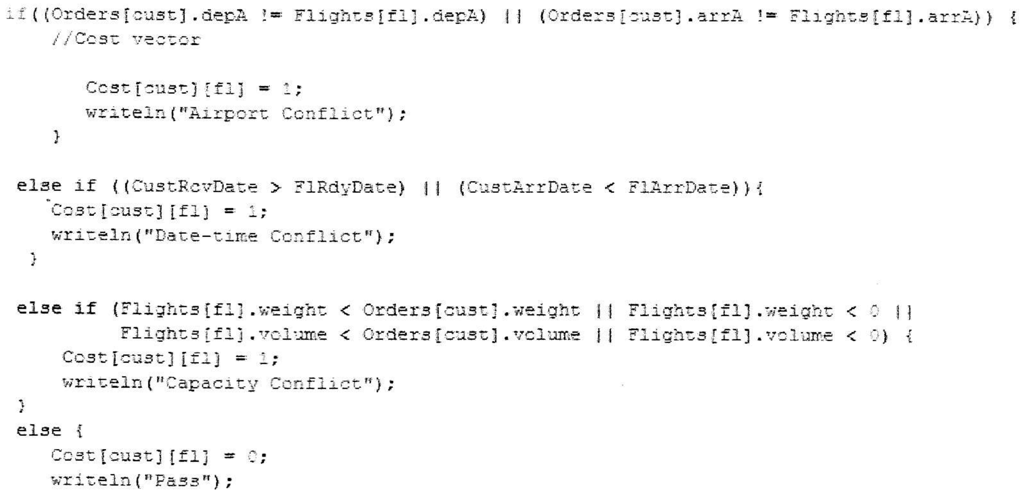


Fig. 4. Flight screening flow chart

Flight screening model is implemented by using IBM ILOG CPLEX OPL script. The model will be implemented as a script and will be executed when each customer places order into the system to check for feasibility. Script is a set of codes that pre-defines some values or conditions for an entity which will enter the script in order to meet constraints and satisfy the objective function. By doing this, the model will not perform any time-consuming function, rather it would check for criteria according to the conditions, and this is a relatively fast process. Example of IBM ILOG CPLEX OPL script is shown in Fig. 5.



```
if((Orders[cust].depA != Flights[fl].depA) || (Orders[cust].arrA != Flights[fl].arrA)) {
    //Cost vector

        Cost[cust][fl] = 1;
        writeln("Airport Conflict");
    }

 else if ((CustRcvDate > FlRdyDate) || (CustArrDate < FlArrDate)){
    Cost[cust][fl] = 1;
    writeln("Date-time Conflict");
  }

 else if (Flights[fl].weight < Orders[cust].weight || Flights[fl].weight < 0 ||
          Flights[fl].volume < Orders[cust].volume || Flights[fl].volume < 0) {
     Cost[cust][fl] = 1;
     writeln("Capacity Conflict");
 }
 else {
    Cost[cust][fl] = 0;
    writeln("Pass");
```

Fig. 5. Example of IBM ILOG CPLEX OPL script

The optimization module is used to generate order schedules and will be executed on a daily basis. The optimization model optimizes the assignments between cargo orders and available flights with the objective of maximizing the profit while considering uncertainty from flight arrival times. There are two types of costs which associate with freight transportation; fixed cost and variable cost. Fixed cost is a cost at a baseline that is paid once an airplane is booked. Variable cost, which follows a piecewise function in this case, is directly subjected to the amount of weight of the cargo to be transported, see [16].

Profit is computed from the difference between revenue and cost. Revenue is the price that is set by the forwarders, which is paid by customers when they place booking orders. Optimization model will assign each order entity to flight according to the objective function while satisfying the defined constraints. There are two decision variables which are defined as binary. Decision variable $y[CustInds][Inds][s]$ indicates if an order is assigned to a flight in a scenario. When the value of $y[CustInds][Inds][s]$ is equal to 1, it means the *CustInds* (customer indexes) cargo is successfully assigned to *flight*[*Inds*] in scenario *s*, otherwise the value is 0. Another decision variable is the decision variable z[*Inds*] which indicates whether a flight is selected for shipment. The value of z[*Inds*] is equal to 1 if the *Inds* flight is selected, otherwise it is equal to 0.

The mathematical model describing the concept of optimization used in this work is as follows:

Parameters:

a_i	revenue gained from shipping order i
b_j	fixed cost of reserving a flight j
p_i	variable cost for shipping order i based on piecewise function
$depAO_i$	departure airport of order i
$depA_j$	departure airport of flight j
$arrAO_i$	arrival airport of order i
$arrA_j$	arrival airport of flight j
$rcvTO_i$	receiving time of order i
$rdyT_j$	time that flight j requires order to be ready for shipment
$arrTO_i$	time that order i must arrive at the consignee
$arrT_{j,s}$	arrival time of flight j from scenario s
$weight_i$	weight of order i
$wCap_j$	available weight capacity of flight j
$volume_i$	volume of order i
$vCap_j$	available volume capacity of flight j
P_s	probability of scenario s
Pen_i	penalty for violating arrival time of order i

Decision variables:

$y_{ijs} = 1$; if cargo i is assigned to flight j in scenario s, otherwise 0

$z_j = 1$; if flight j is selected for shipment, otherwise 0

Objective function:

Maximize

$$\begin{aligned} &\sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{s=1}^{|S|} a_i \times y_{ijs} - \sum_{j=1}^{m} b_j \times z_j - \\ &\sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{s=1}^{|S|} p_i \times y_{ijs} - \sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{s=1}^{|S|} pen_i \times (arrT_{js} - arrTO_i) \times y_{ijs} \end{aligned}$$

Constraints:

$$depAO_i \times y_{ijs} = depA_j \times y_{ijs} \qquad \forall i \in n, \forall j \in m, \forall s \in S \tag{1}$$

$$arrAO_i \times y_{ijs} = arrA_j \times y_{ijs} \qquad \forall i \in n, \forall j \in m, \forall s \in S \tag{2}$$

$$rcvTO_i \times y_{ijs} \leq rdyT_j \times y_{ijs} \qquad \forall i \in n, \forall j \in m, \forall s \in S \tag{3}$$

$$arrTO_i \times y_{ijs} \geq \sum_s P_s \times arrT_{js} \times y_{ijs} \quad \forall i \in n, \forall j \in m, \forall s \in S \tag{4}$$

$$\sum_i weight_i \times y_{ijs} \leq wCap_j \qquad \forall j \in m, \forall s \in S \tag{5}$$

$$\sum_i volume_i \times y_{ijs} \leq volume_j \qquad \forall j \in m, \forall s \in S \tag{6}$$

$$y_{ijs} \leq z_j \qquad \forall i \in n, \forall j \in m, \forall s \in S \tag{7}$$

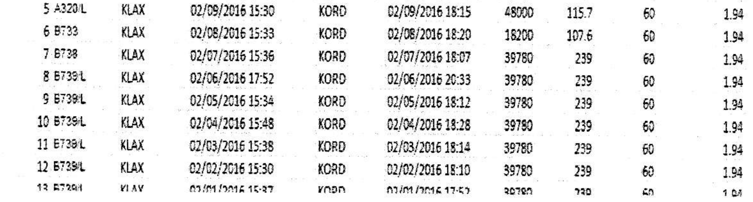
$$\sum_{j=1}^{m} y_{ijs} = 1 \qquad \forall i \in n, \forall s \in S \tag{8}$$

$$\sum_s P_s = 1 \qquad \forall s \in S \tag{9}$$

The mathematical model was developed using IBM ILOG CPLEX. There are two types of constraints defined in the model. Constraint *ctDecisionVar* is defined to represent a relationship between the two decision variables. To simplify, a cargo order cannot be shipped via an unselected flight. Constraint *ctCapacity* is defined to limit the capacity, in terms of weight and volume, of cargo orders to be less than the flight's available capacity. Moreover, the flight's available weight and volume cannot be negative.

4. System Performance

To verify that the decision support system proposed can be practically implemented, the system was tested with data sampled from flight schedules of nine airports in the U.S. in February 2016. The format of flight data consists of ID, origin (departure airport), capacity (available weight and volume), and cost (shipping rate). Example of flight data is shown in Fig. 6.



Index	ID	DepA	DepT	ArrA	ArrT	weight(kg)	volume(m3	minimum	USD per KG
1	A319	KLAX	02/13/2016 15:29	KORD	02/13/2016 18:18	48000	115.7	60	1.94
2	B739/L	KLAX	02/12/2016 15:20	KORD	02/12/2016 17:53	39780	239	60	1.94
3	B739/L	KLAX	02/11/2016 15:22	KORD	02/11/2016 17:54	39780	239	60	1.94
4	B739/L	KLAX	02/10/2016 15:34	KORD	02/10/2016 18:15	39780	239	60	1.94
5	A320/L	KLAX	02/09/2016 15:30	KORD	02/09/2016 18:15	48000	115.7	60	1.94
6	B733	KLAX	02/08/2016 15:33	KORD	02/08/2016 18:20	18200	107.6	60	1.94
7	B738	KLAX	02/07/2016 15:36	KORD	02/07/2016 18:07	39780	239	60	1.94
8	B739/L	KLAX	02/06/2016 17:52	KORD	02/06/2016 20:33	39780	239	60	1.94
9	B739/L	KLAX	02/05/2016 15:34	KORD	02/05/2016 18:12	39780	239	60	1.94
10	B739/L	KLAX	02/04/2016 15:48	KORD	02/04/2016 18:28	39780	239	60	1.94
11	B739/L	KLAX	02/03/2016 15:38	KORD	02/03/2016 18:14	39780	239	60	1.94
12	B739/L	KLAX	02/02/2016 15:30	KORD	02/02/2016 18:10	39780	239	60	1.94
13	B739/L	KLAX	02/01/2016 15:37	KORD	02/01/2016 17:52	39780	239	60	1.94

Fig.6. Flight data

Customer data contain information about customer's orders which includes origin airport, time to shipping, destination, and the capacity requirement. Flight data ranging from 100 to 100 flights and number of orders from 25 to 1000 were used in the test. The results are summarized in Table 1.

Table.1. Computational results of reservation and optimization modules

#Flights	#Orders	Flight screening (mins)	Optimization (mins)
100	25	0.033	0.105
100	50	0.036	0.126
100	100	0.044	0.221
150	100	0.048	0.427
150	150	0.057	1.230
1000	150	0.202	65.617
1000	1000	1.150	695.95

From Table 1., the run times of the reservation module were less than 30 seconds for data with number of orders up to 150, and number of flights from 100 to 1000. An extreme case with 1000 flights and 1000 orders, the run time was slightly more than 1 minute, this is acceptable for receiving and verifying orders from customers that could place orders via phone. The run times of the optimization module increase significantly when the size of test data increases. An instance with 1000 flights and 1000 orders took about 66 minutes on average which is acceptable since the optimization module will be executed once a day.

5. Conclusion

A decision support system for air cargo scheduling was proposed in this research. The system contains user interface that can be used to process and accept orders from customers by using the reservation module. Then, the optimization module is used to optimize flight assignment. Both modules can be practically implemented based on the provided computational results. The reservation module has short run time and is suitable for checking feasibility of orders. The optimization module is used to generate the optimal flight assignment and usually executed once a day.

In addition, the research can be further improved in several ways. Currently, all flight data are categorized as direct flight, which is not the only type seen in practical cargo transportation, especially when performing air freight transportation in global scale. Indirect flights, such as connecting flights or multiple-leg flights, should be considered. Different pricing strategies can also be taken into consideration in future research.

6. Acknowledgments

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