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Decision Making on Cargo Container Loading with Intermediate Hub

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***Abstract*:** *The research presents a decision model for air freight forwarders that considers renting air containers and loading cargos with the objective to minimize cost. The cargos considered in this article are transported from regions to a hub first for unloading, sorting, and then delivered to destinations. The decision making is made at both regions and hub. The proposed model is formulated based on the cargo demand information provided by the forwarders' customers. The model is applicable for air freight forwarders to plan their bookings with airlines with either regular shipment or irregular demand of cargos during peak season. The proposed model takes into account constraints related to weight and volume limits of containers and also on constraints related to available containers. The computational results show that the proposed model can be used for practical air cargo planning. The obtained results from the paper also suggest new research directions in this field.*

Keywords: *air cargo loading, air cargo planning with intermediate hub, air cargo decision support system.*

1. Introduction

Air cargo industry is one of the most important components in global distribution network for worldwide transportation. Air transport is the best choice for delivering high value products or short life products since it provides reliable service with short lead-time. In air cargo distribution network, goods are moved from origins to destinations through several parties such as a shipper, a forwarder, a trucker, an airline, and a consignee [1]. The process of air shipment requires involvement from all parties, beginning from shipper point until reaching consignee at the destination point [2].

Within this process, air freight forwarders, who act as intermediary between shippers and airlines, make profit by buying cargo space from airlines and re-selling it to shippers. The cargo space can be bought under a contracted basis or a request-reply basis [3]. Although space can be reserved in advance before the shipment date, the freight forwarders need to be careful in planning a booking with airlines since renting or cancelling air containers urgently will cause them to pay higher price.

This paper addresses the decision of air freight forwarders on renting air containers from airlines for loading their cargos to minimize the total cost. Cargos are shipped from regions to destinations via a hub. The research considers real situation experienced by the forwarders based on the accuracy of cargo information received from the shippers. A decision support model is presented for the case when certain cargo demand is known.

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2. Literature Review

The research in air cargo scheduling area begins with the consolidation problem from air freight logistics forwarders. Suggestion of transforming consolidation problem into a set covering problem was found in studies by [4] and [5], using lagrangian relaxation and heuristic algorithm in which results were obtained within reasonable time. Another work on consolidation issue addresses the idea of dividing shipments into multiple jobs operated by many processing units. The problem was solved using branch-and-bound and heuristic method [6]. Later on, the studied in [6] was extended by adding constraints on shipment target cost, capacity limit, and delivery time [7].

The studies on cargo container loading problems were conducted by many research works. Containers are large boxes with standardized dimensions and used for holding goods to transport from one destination to another [8]. The early work on air cargo loading decision was found in the case study of air freight forwarder in Hong Kong [9]. They presented a mixed integer programming model to minimize total cost of renting containers without violation on constraints related to container volume and weight limits. Also, the work of [10] studied further by adding constraint on cargo quantity besides other constraints found in [9]. The problem of pallet selection and cargo loading was proposed in [11]. They introduced a two-phase intelligent decision support system for minimizing total operating cost. The application of large-scale neighborhood search heuristic approach for planning cargo loading in real time was introduced by [12]. In [13], a mixed integer programming and a piece-wise cost function were discussed for the problem of transporting goods from multiple origins to multiple destinations. The constraints were subjected to volume and weight limit, flight departure/arrival time, shipment ready date, capacity limit, and over-declaration constraint. The scheduling of cargos into the aircraft based on aircraft capacity to maximize profit and customer satisfaction was presented in [14]. Other works related to loading plan of cargos into the aircraft were found in [15] and [16].

3. Mathematical Model

In this section, a decision support model for container booking and cargo loading decision is described. The shipment is transported from regions to a hub for unloading and sorting before being delivered to destinations. Note that containers available for renting at the hub come from two sources: previously used containers from regions and new containers available for renting at the hub. The proposed model is applicable for regular shipment when certain cargo demands are known. The model distinguishes well from the previous study by taking concern on constraints related to container weight and volume limit, and constraints on quantity of booked containers which cannot exceed the available quantity of containers provided by airlines.

3.1 Parameters:

I: Set of container types, J: Set of cargo types, R: Set of regions, D: Set of destinations, K_i : Set of numbers of breaking-point for container type i, L_{ir} : Set of available quantity of container type i in region r, L_i^h : Set of available quantity of container type i at the hub, a_{ik} : Weight limit at break point k of container type i, p_{ik} : Unit charge rate in the weight range $[a_{i(k-1)}, a_{ik}]$ of container type i, f_{ir}^o : Fixed cost of renting container type i in region r, f_i^{ho} : Fixed cost of renting container type i at the hub, b_i : Unit repacking cost of container type i at the hub, θ : Discount rate on fixed cost when using previous container from region at the hub, q_{jrd} : Quantity of cargo type j in region r to be shipped to destination d, q_{jd}^h : Quantity of cargo type j to be shipped to destination d at the hub, v_j, w_j : Volume, weight of cargo type j, V_i, W_i : Volume, weight of container type i.

3.2 Variables:

X_{ilr} : Binary variable which is equal to 1 if the l^{th} container of type i is used in region r; otherwise, it is equal to 0. X_{ild}^h : Binary variable which is equal to 1 if the l^{th} container of type i is used for shipping to destination d at the hub; otherwise, it is equal to 0. X_{ilrd}^{hc} : Binary variable which is equal to 1 if the l^{th} previous used container of type i from region r is used for shipping to destination d at the hub; otherwise, it is equal to 0. Y_{iljrd} : Integer variable indicating the quantity of cargo type j loaded into the l^{th} container of type i in region r to destination d. Y^{h}_{iljd} : Integer variable referring to the quantity of cargo j loaded into the l^{th} container of type i to destination d at the hub. Y^{hc}_{iljrd} : Integer variable presenting the quantity of cargo j loaded into the l^{th} previous container of type i from region r to destination d at the hub. G_{ilkr} : Continuous variable indicating the cargo weight distributed in the weight range $[a_{i(k-1)}, a_{ik}]$ inside the l^{th} container of type i in region r. G^{h}_{ilkd} : Continuous variable presenting the cargo weight distributed in the weight range $[a_{i(k-1)}, a_{ik}]$ inside the l^{th} container of type i to destination d at the hub. G^{hc}_{ilkrd} : Continuous variable referring to the cargo weight distributed in the weight range $[a_{i(k-1)}, a_{ik}]$ inside the l^{th} previous container of type i from region r to destination d at the hub. $Z_{ilkr}, Z^{h}_{ilkd}, Z^{hc}_{ilkrd}$: Binary variables which are equal to 1 if $G_{ilkr}, G^{h}_{ilkd}, G^{hc}_{ilkrd}$ are within the weight range $[a_{i(k-1)}, a_{ik}]$, respectively; otherwise, they are equal to 0.

3.3 Objective function: Minimize $\left(\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}} f^{o}_{ir}.X_{ilr} + \sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}}\sum_{k=1}^{K_i} p_{ik}.G_{ilkr}\right) + \left(\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}} b_i.X_{ilr}\right) +$

$$\left(\sum_{d=1}^{D}\sum_{i=1}^{I}\sum_{l=1}^{L^{h}_{i}} f^{ho}_{i}.X^{h}_{ild} + \sum_{d=1}^{D}\sum_{i=1}^{I}\sum_{l=1}^{L^{h}_{i}}\sum_{k=1}^{K_i} p_{ik}.G^{h}_{ilkd}\right) + \left(\sum_{d=1}^{D}\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}} \theta.f^{o}_{ir}.X^{hc}_{ilrd} + \sum_{d=1}^{D}\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}}\sum_{k=1}^{K_i} p_{ik}.G^{hc}_{ilkrd}\right) \quad (1)$$

The first part of the objective function is the fixed and variable costs of renting containers in regions. The second part is the container repacking cost at the hub. The third part is the fixed and variable costs of renting new containers at the hub. The fourth part is the fixed and variable costs of using previously used containers from the regions at the hub. The objective function is to minimize the total cost.

3.4 Constraints:

$$\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}} Y_{iljrd} = q_{jrd} \quad \forall j \in J, r \in R, d \in D \quad (2)$$

$$\sum_{i=1}^{I}\sum_{l=1}^{L^{h}_{i}} Y^{h}_{iljd} + \sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{l=1}^{L_{ir}} Y^{hc}_{iljrd} = q^{h}_{jd} \quad \forall j \in J, d \in D \quad (3)$$

$$\sum_{r=1}^{R}\sum_{l=1}^{L_{ir}}\sum_{d=1}^{D} X^{hc}_{ilrd} \le \sum_{l=1}^{L_{ir}}\sum_{r=1}^{R} X_{ilr} \quad \forall i \in I \quad (4)$$

$$\sum_{d=1}^{D}\sum_{l=1}^{L_{ir}} X^{hc}_{ilrd} \le \sum_{l=1}^{L_{ir}} X_{ilr} \quad \forall i \in I, r \in R \quad (5)$$

$$\sum_{k=1}^{K_i} G_{ilkr} = \sum_{j=1}^{J}\sum_{d=1}^{D} w_j.Y_{iljrd} \quad \forall i \in I, r \in R, l \in L_{ir} \quad (6)$$

$$\sum_{k=1}^{K_i} G^{h}_{ilkd} = \sum_{j=1}^{J} w_j.Y^{h}_{iljd} \quad \forall i \in I, d \in D, l \in L^{h}_{i} \quad (7)$$

$$\sum_{k=1}^{K_i} G^{hc}_{ilkrd} = \sum_{j=1}^{J} w_j.Y^{hc}_{iljrd} \quad \forall i \in I, d \in D, r \in R, l \in L_{ir} \quad (8)$$

$$G_{ilkr} \le Z_{ilkr}.(a_{ik} - a_{i(k-1)}) \quad \forall i \in I, r \in R, l \in L_{ir}, k \in K_i \quad (9)$$

$$G_{il(k-1)r} \ge Z_{ilkr}.(a_{i(k-1)} - a_{i(k-2)}) \quad \forall i \in I, r \in R, l \in L_{ir}, k \in K_i \cap k \ge 2 \quad (10)$$

$$G^{h}_{ilkd} \le Z^{h}_{ilkd}.(a_{ik} - a_{i(k-1)}) \quad \forall i \in I, d \in D, l \in L^{h}_{i}, k \in K_i \quad (11)$$

$$G^{h}_{il(k-1)d} \ge Z^{h}_{ilkd}.(a_{i(k-1)} - a_{i(k-2)}) \quad \forall i \in I, d \in D, l \in L^{h}_{i}, k \in K_i \cap k \ge 2 \quad (12)$$

$$G^{hc}_{ilkrd} \le Z^{hc}_{ilkrd}.(a_{ik} - a_{i(k-1)}) \quad \forall i \in I, r \in R, l \in L_{ir}, d \in D, k \in K_i \quad (13)$$

$$G^{hc}_{il(k-1)rd} \ge Z^{hc}_{ilkrd}.(a_{i(k-1)} - a_{i(k-2)}) \quad \forall i \in I, r \in R, l \in L_{ir}, d \in D, k \in K_i \cap k \ge 2 \quad (14)$$

$$\sum_{j=1}^{J}\sum_{d=1}^{D} v_j.Y_{iljrd} \le V_i.X_{ilr} \quad \forall i \in I, r \in R, l \in L_{ir} \quad (15)$$

$$\sum_{j=1}^{J} v_j.Y^{h}_{iljd} \le V_i.X^{h}_{ild} \quad \forall i \in I, d \in D, l \in L^{h}_{i} \quad (16)$$

$$\sum_{j=1}^{J} v_j . Y_{iljrd}^{hc} \leq V_i . X_{ilrd}^{hc} \qquad \forall i \in I, r \in R, d \in D, l \in L_{ir} \tag{17}$$

$$\sum_{j=1}^{J} \sum_{d=1}^{D} w_j . Y_{iljrd} \leq W_i . X_{ilr} \qquad \forall i \in I, r \in R, l \in L_{ir} \tag{18}$$

$$\sum_{j=1}^{J} w_j . Y_{iljd}^{h} \leq W_i . X_{ild}^{h} \qquad \forall i \in I, d \in D, l \in L_i^h \tag{19}$$

$$\sum_{j=1}^{J} w_j . Y_{iljrd}^{hc} \leq W_i . X_{ilrd}^{hc} \qquad \forall i \in I, r \in R, d \in D, l \in L_{ir} \tag{20}$$

Constraints (2) and (3) represent cargo quantity constraints at regions and hub. Constraint (4) ensures that for each type of container, the total previously used containers at the hub cannot exceed the total containers used in all regions. Constraint (5) makes sure that for each container type, the quantity of previously used container in the hub cannot be greater than the previously used containers from each region. Constraints (6)-(8) guarantee that the total cargo weight distributed in all weight ranges of a container equals to the total weight of all cargoes loaded into the container. Constraints (9)-(14) ensure that the cargo weight in the weight range $[a_{i(k-1)}, a_{ik}]$ cannot be positive if the weight range $[a_{i(k-2)}, a_{i(k-1)}]$ is not fully used. That means $Z_{ilkr}, Z_{ilkd}^{h}, Z_{ilkrd}^{hc}$ are equal to 1 if $G_{ilkr}, G_{ilkd}^{h}, G_{ilkrd}^{hc}$ are in the weight range $[a_{i(k-1)}, a_{ik}]$ ($G_{ilkr}, G_{ilkd}^{h}, G_{ilkrd}^{hc}$ are less-than-or-equal-to the difference between a_{ik} and $a_{i(k-1)}$). Constraints (15)-(17) are container volume constraints. The container weight constraints are illustrated in constraints (18)-(20).

4. Computational Results

This section aims to test the performance of the model by using CPLEX with several test data sets. Computer used for testing has CPU 2.50GHz, RAM 8.00GB, and 64-bit operating system, and is equipped with IBM ILOG CPLEX Optimization Studio version 12.4. Data sets for testing are subsets of a full data from electronic products shipment with 315 cargos. However, it is assumed that cargos are classified into 3 types: large, medium and small, with weight 340; 308; and 213 kilograms and volume 1,278,116; 989,192; and 511,712 cubic centimetres, respectively. Also, it is assumed that airlines provide 5 different types of air containers for forwarders to rent at both regions and hub; each type has only one container available. The demands of cargos are picked up randomly from the full data set for testing. Table I shows an example of test data that represents required shipping quantity for each type of cargo.

TABLE I: Cargo quantities for each type of cargo

Regions	Destinations	Cargo quantity		
		Large	Medium	Small
R1	D1	1	6	3
	D2	2	3	5
R2	D1	6	2	2
	D2	3	2	5

For air containers, the information including fixed cost, repacking cost, penalty cost for returning/renting container on the shipping day, volume limit, weight limit, weight breaking-point and unit charge rate is provided as shown in table II. However, information regarding to prices is treated confidentially, so the data related to prices is generated randomly with excel in a given range presented in Table II. All the shipments are assumed to be transported from two regions (R1, R2) to a hub first. At the hub, cargos are unloaded and consolidated before shipping to two destinations (D1, D2). Note that containers at regions and hub are assumed to have the same characteristics. If the previous containers from regions are selected to be reused at the hub, the fixed cost is discount 5%, that is $\theta = 0.95$.

TABLE II: Air Container Information

Container type (i)		1	2	3	4	5
Fixed cost ($)		600-700	500-600	400-500	300-400	200-300
Repacking cost ($)		300-350	250-300	200-250	150-200	100-150
Unit penalty cost for returning container ($)		550-650	450-550	350-450	250-350	150-250
Unit penalty cost for urgent renting container ($)		800-900	700-800	600-700	500-600	400-500
Volume limit (cm^3)		15900000	10800000	7200000	6900000	5000000
Weight limit (kg)		5035	4624	3176	2450	1588
Weight break-point (kg)	a_{i1}	100	100	100	100	100
	a_{i2}	300	300	300	300	300
	a_{i3}	500	500	500	500	500
	a_{i4}	1000	1000	1000	1000	1000
	a_{i5}	3000	3000	3000	3000	3000
	a_{i6}	6000	6000	6000	6000	6000
Unit charge rate ($)	p_{i1}	0	0	0	0	0
	p_{i2}	3.5 - 5	3.5 - 5	3.5 - 5	3.5 - 5	3.5 - 5
	p_{i3}	0	0	0	0	0
	p_{i4}	2.5 - 3.4	2.5 - 3.4	2.5 - 3.4	2.5 - 3.4	2.5 - 3.4
	p_{i5}	0	0	0	0	0
	p_{i6}	1 - 2.4	1 - 2.4	1 - 2.4	1 - 2.4	1 - 2.4

Based on the sample test data, the model took around nine seconds (00:00:08:23) with an optimal solution cost (USD 24401.05). This model contains 593 constraints and 671 variables. The results of container booking and cargo loading plan at regions and hub are summarized in the Tables III and IV. Note that “L, M, S” are used to represent large, medium and small types of cargos to be shipped to destination 1. “l, m, s” represent large, medium and small types of cargos to be transported to destination 2.

TABLE III: Result of Container Rental and Cargo Loading Plan at Regions

Rented container type	Loading plan	
	R1	R2
1	6M, 1S, 2l, 1m	6L, 2l, 2m
4	1L, 2S, 2m, 5s	2M, 2S, 1l, 5s

TABLE IV: Result of Container Rental and Cargo Loading Plan at the Hub

Rented container type		Loading plan	
		D1	D2
1	From hub	6L, 1M, 3S	
	From R1	1L, 7M, 2S	
	From R2		5l, 2m, 3s
4	From R1		3m, 7s

To fully test the computational performance of the model, additional test data sets were generated. Table V provides computational results for additional data sets with number of containers from 10 to 30 containers and number of cargos from 40 to 280 cargos. In Table V, columns 1 and 2 show the description of the test data, number of containers and cargos. Columns 3 and 4 report number of constraints and variables. Column 5 gives the solution time from CPLEX. Note that the runtime is limited to 2 hours for this study. Columns 6 and 7 represent objective value and the gap from optimality. As can be seen from Table V, a change in configuration results in a significant change in runtimes. The model provides optimal solutions within time limit for some data sets. With more than 20 containers and 120 cargos, optimal solution does not exist within the time limit.

TABLE V: Test Results with Different Data Sets

Data Set#	#Cargos	#Constraints	#Variables	Time	Objective Cost	Gap
10 containers x 40 cargos		593	671			
(1R has 5 containers, 1D needs 10 cargos)						
1	40			00:00:06:53	21914.59	0.00%
2	40			00:00:06:82	22643.40	0.00%
3	40			00:00:05:50	23609.00	0.00%
4	40			00:00:07:18	21068.04	0.00%
5	40			00:00:06:51	23204.60	0.00%
10 containers x 60 cargos		593	671			
(1R has 5 containers, 1D needs 15 cargos)						
1	60			00:00:17:81	35581.82	0.00%
2	60			00:00:09:68	36627.50	0.00%
3	60			00:01:17:60	34636.35	0.00%
4	60			01:54:13:25	37005.69	0.00%
5	60			00:00:08:59	37353.08	0.00%
10 containers x 80 cargos		593	671			
(1R has 5 containers, 1D needs 20 cargos)						
1	80			00:00:18:86	48064.20	0.00%
2	80			00:40:38:65	47024.96	0.00%
3	80			00:11:06:00	48389.59	0.00%
4	80			00:17:40:56	47674.77	0.00%
5	80			00:18:20:45	45731.43	0.00%
20 containers x 120 cargos		1153	1341			
(1R has 10 containers, 1D needs 30 cargos)						
1	120			00:42:42:67	65980.03	0.00%
2	120			Time limit exceeded	73910.29	1.24%
3	120			Time limit exceeded	68018.49	1.32%
4	120			Time limit exceeded	70626.21	1.20%
5	120			Time limit exceeded	67104.28	0.61%
20 containers x 160 cargos		1153	1341			
(1R has 10 containers, 1D needs 40 cargos)						
1	160			Time limit exceeded	91003.86	0.14%
2	160			Time limit exceeded	86289.42	0.21%
3	160			Time limit exceeded	88499.62	0.51%
4	160			Time limit exceeded	90143.61	0.26%
5	160			Time limit exceeded	87796.37	0.16%
20 containers x 200 cargos		1153	1341			
(1R has 10 containers, 1D needs 50 cargos)						
1	200			Time limit exceeded	112171.32	0.21%
2	200			Time limit exceeded	114523.10	0.45%
3	200			Time limit exceeded	116171.84	0.47%
4	200			Time limit exceeded	111405.55	0.49%
5	200			Time limit exceeded	114112.32	0.35%
30 containers x 240 cargos		1713	2011			
(1R has 15 containers, 1D needs 60 cargos)						
1	240			Time limit exceeded	133984.48	0.70%
2	240			Time limit exceeded	131748.35	0.47%
3	240			Time limit exceeded	133452.41	0.53%
4	240			Time limit exceeded	130221.06	0.57%
5	240			Time limit exceeded	130374.94	0.17%
30 containers x 280 cargos		1713	2011			
(1R has 15 containers, 1D needs 70 cargos)						
1	280			Time limit exceeded	160624.21	0.53%
2	280			Time limit exceeded	157128.76	0.51%
3	280			Time limit exceeded	157743.81	0.49%
4	280			Time limit exceeded	152519.85	0.40%
5	280			Time limit exceeded	157732.44	0.37%

5. Result Summary

This paper deals with the forwarder' decisions on renting air containers for loading their cargos which are transported from regions to destinations via a hub. A decision making model is proposed to deal with the real situations normally faced by forwarders. The model can provide solutions for different configurations up to 20 containers and 120 cargos. However, no optimal solution is obtained for large size problems within the time limit. To deal with large size problems, heuristic methods would be suitable techniques used for further work.

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