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Air Cargo Loading Management System for Logistics Forwarders

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***Abstract*:** *The research addresses a problem of an international air cargo forwarder who has to manage allotment contracts in terms of ULDs with several airlines for their single –leg. The forwarder needs to pack cartons of shipments, which have different sizes and released dates, into ULDs. A three dimension packing model is formulated and tested with different data sets. The model considers overlapping problem, practical position of cartons, cargo priority, weight limitation and other commitment stated by the forwarder. An improvement to original model, by relaxing complicated constrains, is proposed to address unsolved cases from original model. The results from relaxed model are presented with comparison and explanation. Obtained results from the paper suggest new directions for further research in this field.*

Keywords: *3D packing, air cargo loading management, allotment contract, heuristic algorithm.*

1. Introduction

Air cargo industry has been playing an increasingly important role in transporting high value products with short lead-time. More than 60% of domestic and 90% of international air cargo capacity is sold to forwarders [1]. Forwarders buy cargo space on a contracted basis or on a request-reply basis [2, 3]. In the former, allotment contracts allows forwarders to reserve amount of capacity for a predetermined period (six months or a year) on a specific flight or specific time such as weekends or weekdays [2]. The contracts hedge airlines from capacity utilization risk in absent of sales agreements [4]. Although allotment contracts provide favourable freight rate to forwarders, it is important for forwarder and airlines to avoid wasting space from allotment in order to maximize the efficiency of the operation.

In this paper, an example of a typical international freight forwarder is used to illustrate the air cargo loading management. Assume that a freight forwarder has shipments that need airfreighting from Hanoi (HAN), Vietnam to Charles de Gaulle (CDG), France. The forwarder makes their bookings in terms of Unit Load Devices (ULDs). A ULD is an assembly of components consisting of a container or of a pallet covered with a net, whose purpose is to provide standardized size units for individual pieces of baggage or cargo, and to allow for rapid loading and unloading [5]. ULDs have some special shapes and measurements which are subject to the operation conditions of the individual airline company. The first major decision is to load multiple sized shipments with different released dates into ULDs. The paper distinguishes well from previous studies for developing an air cargo 3D packing model which is subject to overlapping constraints, practical position of cartons, cargo priority, weight limitation and other commitments stated by the forwarder. An idea to improve the model is suggested so that optimal solutions can be obtained, with large input data, in a short time.

2. Literature Review

Packing problem is traced back to one-dimensional bin packing or partitioning problem, in which a set of n associated sizes must be divided into the minimum number of subsets so that the sum of sizes in each subset does not exceed a given capacity [6]. Later on, many researchers addressed two-dimensions packing problem with exact approaches and heuristics approaches. The problem is to allocate a set of n heterogeneous rectangular items, defined by width and height, to a minimum number of identical rectangular bins, with the edges of items paralleling to those of the bins but without overlapping [7]. Examples of exact approaches for two dimensional packing problem can be found in studies [8]; [9]; [10] and [11]. Efficient heuristics approaches were presented in [12].

Recently, three dimensional packing problems have drawn more attention of researchers. Among huge amount of research on packing problems, to the best of our knowledge, there is a little research with mathematical models which can be solved by standard software package. The first three dimensional packing model was to load boxes of different sizes into a pallet without overlapping [13]. In 1995, Chen and his colleagues proposed a mixed integer linear programming model to solve 3D container loading problem. The problem is raised to pack a set of non-uniform cartons into unequal-sized containers (Multi-Container Loading Problem-MCLP) with carton orientation and overlapping constraints [14]. Although the mathematical model guarantees to lead to optimal total unused space of container(s), a large number of constraints and variables make the model computationally unfeasible for real-life complex problems. [15] also introduced a mixed integer model for Knapsack Loading Problem (KLP), in which the objective is to pack maximum number of multiple sized boxes into only one type of container. Another optimal model for MCLP was proposed in [16]. They built the model as an extension of research work on Process Plant Layout (PPL) in [17] and [18] and Facility Layout (FL) problems in [19]. In [20] a mixed integer linear programming model (MIP) for KLP considered constraints of multi-dropping and the vertical stability of the cargo. The authors solved the problems of packing boxes with different customers (destinations) into containers. In order to avoid additional handling, boxes to the same customer should be placed close to each other and delivery order should be taken into account. More recently the paper of [21] discussed a linear model to pack a set of strongly heterogeneous boxes into ULDs with various shapes for air cargo loading. Many practical constraints in air cargo industry are mathematically formulated in their paper. More definition and review of constraints used so far in container loading problem especially in air cargo industry can be found in [22]

3. Model

In this section, an air cargo packing model is introduced and tested with data of electronic products. It should be assumed that the forwarder uses this data to make booking with contracted airlines. Dimension of an ULD in this study is fixed by the forwarded as 317.5 cm (L) x 223.5 cm (W) x 162.6 cm (H). The ULD type is LD-9 and has IATA code APA and fits to lower hold of aircraft. In this research work, a packing model is enhanced by adding constraints incurred from the allotment contracts and commitments between forwarder and their customers. The proposed model takes concern of loading priority by adjustment of the coefficients in the objective function. Maximum total weight of cartons in each ULD is considered. Additionally, a commitment by the forwarder to their customers is that cartons must be airfreighted within 2 days after being released. Precondition to satisfy the previous requirement is that each pallet can carry at most 2 cartons released more than 2 days apart from each other.

Parameters:

O: Set of ULDs available in a week. N: Set of cartons available in a week. M: An arbitrarily large number. p_i, q_i, r_i : Length, width, and height of carton i. we_i : weight of carton i. v_i : Released date of carton i. pr_i : Co-efficient representing priority level of carton i. L, W, H: Length, width, height of ULD.

Variables:

n_j : A binary variable which is equal to 1 if the pallets j is used; otherwise, it is equal to 0. S_{ij} : Binary variable which is equal to 1 if carton number i is placed in pallet j. m_j : Weight of ULD j after packing. x_i, y_i, z_i : Continuous variables (for location) indicating the coordinates of the front-left bottom (FLB) corner of carton i placed on the pallet. l_{xi}, l_{yi}, l_{zi} : Binary variables which are equal to 1 if the length of carton i packed is parallel to the X, Y or Z, otherwise they are equal to 0. w_{xi}, w_{yi}, w_{zi} : Binary variables which are equal to 1 if the width of carton i packed is parallel to the X, Y or Z, otherwise they are equal to 0. h_{xi}, h_{yi}, h_{zi} : Binary variables which are equal to 1 if the height of carton i packed is parallel to the X, Y or Z, otherwise they are equal to 0. $a_{ik}, b_{ik}, c_{ik}, d_{ik}, e_{ik}, f_{ik}$: Binary variables which are equal to 1 if box i is on the left, right, in front, behind, bellow, upper side of carton k, respectively, otherwise, they are equal to 0. $TotalVol_j$: Total volume of ULD j after packing. $UsedVol_j$: Used volume of ULD j after packing

Objective function: Minimize $\sum_{j=1}^{O} L.W.H.n_j - \sum_{i=1}^{N} p_i.q_i.r_i.pr_i$ (1)

The first part of objective function is the total volume of ULDs used. The second part, which is the adjusted total volume of cartons inside ULDs, takes cargo priority into account. The objective function is to minimize number of ULDs used and unused space of ULDs.

Constraints:

$$\sum_{j=1}^{O} \mathrm{S_{ij}} = 1 \quad \forall i \in N \tag{2}$$

$$\sum_{i}^{N} we_i.S_{ij} \leq 4500 \quad \forall j \in O \tag{3}$$

$$|v_k - v_i| \leq 2 + M.(1 - S_{ij}) + M.(1 - S_{kj}) \quad \forall \mathrm{j} \in \mathrm{O}, \text{and i, k} \in \mathrm{N} : \mathrm{k} > \mathrm{i} \tag{4}$$

$$m_j = \sum_{i}^{N} we_i.S_{ij} \quad \forall i \in N \tag{5}$$

$$\sum_{i}^{N} S_{ij} \leq M.n_j \quad \forall j \in O \tag{6}$$

$$TotalVol_j = L.W.H.n_j \quad \forall j \in O \tag{7}$$

$$UsedVol_j = \sum_{i}^{N} vol_i.S_{ij} \quad \forall j \in O \tag{8}$$

Constraint (2) ensures that each carton will be placed in exactly one ULD. Constraint (3) sets upper bounds for weight of containers which is subject to allotment contracts. Constraint (4) ensures that in every pallet, there are no 2 cartons released in more than 2 days later than each other. Constraint (5) ensures that the weight of any ULD is equal to sum of weight of carton packed inside it. Constraint (6) describes if any carton is assigned to an ULD, the ULD is considered used. Constraints (7) and (8) describe how to calculate total volume and used volume of ULD after packing.

Non- overlapping constraints:

$\forall i, k \in N / k > i$:

$$x_i + p_i.l_{xi} + q_i.w_{xi} + r_i.h_{xi} \leq x_k + (1 - a_{ik}).M \tag{9}$$

$$x_k + p_k.l_{xk} + q_k.l_{xk} + r_k.h_{xk} \leq x_i + (1 - b_{ik}).M \tag{10}$$

$$y_i + p_i.l_{yi} + q_i.w_{yi} + r_i.h_{yi} \leq y_k + (1 - c_{ik}).M \tag{11}$$

$$y_k + p_k.l_{yk} + q_k.w_{yk} + r_k.h_{yk} \leq y_i + (1 - d_{ik}).M \tag{12}$$

$$z_i + p_i.l_{zi} + q_i.w_{zi} + r_i.h_{zi} \leq z_k + (1 - e_{ik}).M \tag{13}$$

$$z_k + p_k.l_{zk} + q_k.w_{zk} + r_k.h_{zk} \leq z_k + (1 - f_{ik}).M \tag{14}$$

Constraints (9)-(14) describe that the cartons can rotate orthogonally in the container and there is no overlapping for two cartons. $\forall i, k \in N$:

$$z_k \leq e_{ik}.H \tag{15}$$

$$z_i \leq f_{ik}.H \tag{16}$$

Constraints (15) and (16) force the coordinate of the front-left bottom (FLB) corner of carton along z equal to 0 when there is no another carton bellow it.

$$a_{ik} + b_{ik} + c_{ik} + d_{ik} + e_{ik} + f_{ik} \geq S_{ij} + S_{kj} - 1 \quad \forall i, k \in N : k > i \tag{17}$$

$\forall j \in O,\ i \in N:$

$$x_i + p_i.l_{xi} + q_i.w_{xi} + r_i.h_{xi} \leq L + (1 - S_{ij}).M \tag{18}$$

$$y_i + p_i.l_{yi} + q_i.w_{yi} + r_i.h_{yi} \leq W + (1 - S_{ij}).M \tag{19}$$

$$z_i + p_i.l_{zi} + q_i.w_{zi} + r_i.h_{zi} \leq H + (1 - S_{ij}).M \tag{20}$$

The next constraint (17) guarantees relative position of each pair of cartons, which also checks for overlapping. Constraint (18) - (20) ensures that cartons do not exceed their container's size.

Since the length (or the width, or height) of cargos must parallel to one of axes X or Y or Z:

$$l_{xi} + l_{yi} + l_{zi} = 1 \tag{21}$$

$$w_{xi} + w_{yi} + w_{zi} = 1 \tag{22}$$

$$h_{xi} + h_{yi} + h_{zi} = 1 \tag{23}$$

Also, length or width or height (one of three dimension of the carton) must parallel to X (or Y, or Z):

$$l_{xi} + w_{xi} + h_{xi} = 1 \tag{24}$$

$$l_{yi} + w_{yi} + h_{yi} = 1 \tag{25}$$

$$l_{zi} + w_{zi} + h_{zi} = 1 \tag{26}$$

4. Computational Results

This section aims to test the limit of using CPLEX to solve assignment problem, several instances of packing cargoes into ULDs with different numbers of cargoes and ULDs are presented. Computer used for testing has CPU 3.30 Hz, 8.00GB RAM, and 64-bit operating system and, is equipped with IBM ILOG CPLEX Optimization Studio version 12.3. Data sets for testing are subsets of a full data file provided by the forwarder with 315 cargoes to be packed in week 4 of the year 2014 (20/Jan/2014 to 26/Jan/2014). The table below shows a data set used for a testing. The first column is numbers of Delivery Order (D/O) which specifies the shipments to be airfreighted. Those shipments are packed into cartons by the forwarder's customer. Those cartons have specifications about weight (kg), height (cm), width (cm), length (cm) and model as shown in the table. All the shipments are transported from Hanoi international airport, Vietnam to Charles de Gaulle (CDG), France. SOP stands for standard operation procedure. In this study, SOP states for the specified week in which shipment must be shipped. The Data dealing with cargoes during 20/Jan/2014 to 26/Jan/2014, for planning in week 04 of the year (2014); therefore, shipments with SOP W04 must be taken into priority over W05 and W06 to be shipped within the week (Week04). In order to form the model with Cplex, SOPs are weighted according to the priority levels (for W04, W05, and W06, the weights equal 3, 2, and 1 respectively). Forecast column informs date of cargo readiness. For this illustration, two ULDs are given to pack those fifteen cartons of shipments.

TABLE I: Data set for testing CPlex model

No.	DO	Weight	Height	Width	Length	Volume	Model	Port	SOP	Forecast	Priority
1	7683321	297	63	85	122	653310	A-T110NDWAXLD	CDG	W04	20-Jan	3
2	7683323	297	64	83	121	642752	A-T110NDWAXLD	CDG	W04	20-Jan	3
3	7683326	297	64	84	121	650496	A-T110NDWAXLD	CDG	W04	20-Jan	3
4	7837405	298	63	85	122	653310	A-T110NDWAXLD	CDG	W04	21-Jan	3
5	7837406	296	65	84	122	666120	A-T110NDWAXLD	CDG	W04	21-Jan	3
6	7831955	370	106	83	121	1064558	A-N9005ZKEBZU	CDG	W05	21-Jan	2
7	7835466	350	97	85	123	1014135	A-N9005ZKEBZU	CDG	W05	21-Jan	2
8	7943010	356	120	81	99	962280	D-I9195ZKAXLD	CDG	W04	22-Jan	3
9	7954858	350	115	84	100	966000	D-I9300OKDXLD	CDG	W04	22-Jan	3
10	7954885	65	52	60	80	249600	D-N8000ZWAXLD	CDG	W05	22-Jan	2
11	8139534	163	60	68	110	448800	D-I9300OKDXLD	CDG	W04	23-Jan	3
12	8139570	430	117	84	120	1179360	D-I9506ZWAFOS	CDG	W05	23-Jan	2
13	7960357	77	55	61	96	322080	A-V7000ZKAXLD	CDG	W04	24-Jan	3
14	8140795	322	108	108	123	1434672	D-S5360UWAXLD	CDG	W05	24-Jan	2
15	8140875	328	100	110	114	1254000	A-N9005WDEXLD	CDG	W04	24-Jan	3

This test took around twelve seconds (00:00:11:84) with an optimal solution (-80360608). This model has 1705 constraints and 1809 variables. The results are summarized in the following tables and figures:

TABLE II: Cargoes assignment result

No	DO	ULD 1	ULD 2	No	DO	ULD 1	ULD 2
1	7683321	0	1	8	7943010	1	0
2	7683323	0	1	9	7954858	1	0
3	7683326	0	1	10	7954885	1	0
4	7837405	0	1	11	8139534	1	0
5	7837406	0	1	12	8139570	1	0
6	7831955	0	1	13	7960357	1	0
7	7835466	0	1	14	8140795	1	0
				15	8140875	1	0

TABLE III: Result of coordinates of the front-left bottom (FLB) corner of carton

No	D/O	**x**	**y**	**z**	No	DO	**x**	**y**	**z**
1	7683321	0	83	0	8	7943010	84	0	0
2	7683323	0	0	0	9	7954858	0	123	0
3	7683326	196	0	0	10	7954885	84	171	0
4	7837405	171	84	0	11	8139534	84	99	0
5	7837406	131	0	0	12	8139570	0	0	0
6	7831955	234	84	0	13	7960357	154	99	0
7	7835466	63	84	0	14	8140795	209	0	0
					15	8140875	217	108	0

Table III gives positions of cartons inside the ULDs. Bellow Figure 3 describes ULD 2 which holds 7 cartons after packing.

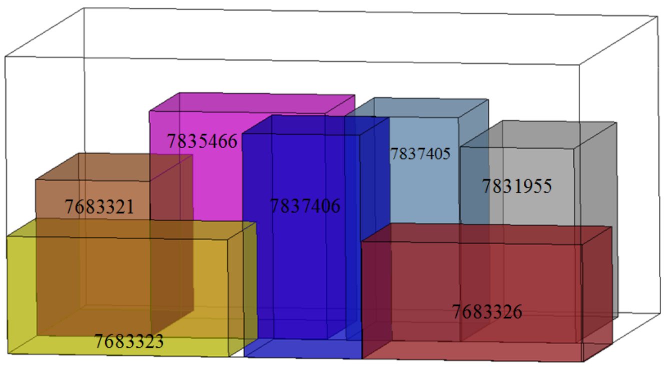

Fig. 1: ULD 2 after packing

Since different configuration requires different amount of time for running, different data sets were generated randomly via excel to test the time and gap of model. Searching time is set at 7200 seconds (2 hours). Below table shows computational results after solving other data sets with Cplex.

As can be seen from the Table IV, a change in configuration results in a significant change in running time, which causes the problem unable to solve (out of memory) by the testing computer, within reasonable time. An improvement for this original model needs to be done. The paper suggests relaxing the group of 3-dimmension constraints which are constraints from (9)-(26). Parameters relating to positions of cartons should be removed, and the following parameters and constraint are added.

Added parameters: $vol_i = p_i.q_i.r_i$: Volume of carton i. Fd : Usage percentage of ULD

Added constraints: $UsedVol_j \leq Fd.TotalVol_j \quad \forall j \in O$ (27)

Constraint (27) specifies the percentage of ULDs' volume which can be used. In this research, in order to set this parameter, the full data set is tested with the Fd equal to 85% then the results from the three fullest ULDs, one by one, are tested with 3D constraints. The process is continued with 5% adjustment every time and stop when the 3D constraints report feasibility. From the experiment, the Fd set to 75% which guarantees the feasibility of 3D constraints for all ULDs.

TABLE IV: Cplex test results with different data sets

Data Set#	#carton used	# Constraint	# Variable	Time	Objective	Gap
2ULDs x 15 cartons		1705	1089			
1	2			00:00:19:79	-82155744	0.00%
2	2			00:00:21:90	-87154608	0.00%
3	2			00:00:21:44	-94878564	0.00%
4	2			00:00:21:41	-76254528	0.00%
5	2			00:00:21:49	-82804420	0.00%
3ULDsx 20 cartons		3415	1873			
1	3			02:00:00:00	-359304858	9.56%
2	3			00:28:09:11	-335165112	0.00%
3	3			02:00:00:00	-241707870	14.21%
4	3			02:00:00:00	-374282307	9.18%
5	-			00:59:21:75	Out of memory	
5ULDs x 40 cartons		16585	7021			
1	-			02:00:00:00	Time limit exceeded	
2	-			00:06:10:52	Out of memory	
3	-			00:09:04:80	Out of memory	
4	-			00:04:23:90	Out of memory	
5	-			02:00:00:00	Time Limit Exceeded	

TABLE V: Cplex test results with different data sets from relaxed model

Data Set#	#ULDs used	# Constraints	# Variables	Time	Optimal Result	Difference to Original Model
2ULDs x 15 cartons		237	39			
1	2			00:00:03:41	-82155744	0.00%
2	2			00:00:02:97	-87154608	0.00%
3	2			00:00:02:85	-94878564	0.00%
4	2			00:00:02:87	-76254528	0.00%
5	2			00:00:02:82	-82804420	0.00%
3ULDsx 20 cartons		608	73			
1	3			00:00:03:37	-359304858	0.00%
2	3			00:00:03:26	-334341504	24.57%
3	3			00:00:03:45	-241975764	11.08%
4	3			00:00:04:87	-374282307	0.00%
5	3			00:00:04:28	-394770933	
5ULDs x 40 cartons		3970	221			
1	5			00:00:04:97	-2138130025	
2	4			00:00:08:50	-2110041035	
3	5			00:00:08:47	-2441584750	
4	5			00:00:08:45	-2078435300	
5	4			00:00:03:36	-1916113085	

As can be seen from the Table V, relaxed model gives the solutions for the same data sets with the original model in a short time. For some data sets, the results are very close to the one from the original model (Difference to original model = 0%). For other data sets, differences in results of two models are caused by decreasing the maximum percentage by 5% each time. The relaxed model also generates solution to unsolved cases of the original model in a short time.

5. Result Summary

This paper deals with packing model for air cargo loading. Cartons for packing in the model have different sizes and released dates. The first model considers overlapping problem, practical position of cartons, cargo priority, weight limitation and time constraints. Testing results from Cplex shows the variation of runtime required for different configurations. For some configurations, no optimal solution is obtained within the CPU memory of the computer, in reasonable time. An idea to relax some constraints is proposed and tested with the same data sets. Optimal solutions from relaxed model are achieved fast however there exist gaps in optimal results between the two models which are caused by decreasing the maximum percentage by 5% each time. However, the obtained results would help to test the more suitable techniques and new procedures combining heuristics and exact algorithms in order to adjust usage percentage among ULDs.

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