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PRIORITY LOADING ALGORITHM AS THE PART OF AIRCRAFT LOAD OPTIMIZATION MODEL

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Abstract

Purpose: *development of a new load optimization algorithm in order to solve the aircraft load optimization problem with further implementation it to the innovated load optimization model.* ***Methods****: heuristics, formalized approach, computer modeling.* ***Results****: the innovated load optimization algorithm was designed, which implies the containers groups' assignment with minimization of loading time.* ***Discussion****: Most of studied scientific works contain various descriptions of bin packing problem's solutions, knapsack optimization models and also outline a term of "aircraft cargo loading" as a problem of container selection, packing and cargo loading into the aircraft compartment. These models are concentrated on separate features, whereas the real load optimization problem is inextricably linked with aircraft handling and operations. This innovated load optimization model consists in decomposing the loading problem and also implementation of a new priority load planning algorithm. The following algorithm refers the predefined Unit Load Devices' assignment in the aircraft cargo compartment in priority order to unload them according to data's documentation without exceeding weight and balance constraints and with loading time reduction and consequently cutting handling and operation costs.*

Keywords: bin packing problem, aircraft load optimization, aircraft load planning algorithm, aircraft loading time, ULD (Unit Load Devices), priority loading criteria.

1. Introduction

Optimizing the cargo loading operations is an essential part of a constant development for the air companies. The stakeholders that are involved in the process have multiple objectives. Sales department seeks for maximizing profit and simultaneously minimizing costs while ground handling department aims to reduce the handling effort. Aircraft operations work with fuel consumption's optimization and Unit Load Device (ULD) utilization.

ULDs are used to consolidate cargo items before loading into the aircraft cargo compartment by different devices such as hydraulic lift (fork lift) [1]. On the next loading stage they are being moved manually to their final position with a roller floor's utilization, before finally being fixed by nets to the finite position to avoid mis-loading [8].

Mis-loading consequences:

- aircraft compartment's damage during the flight;
- runway excursion while operating take-off or landing;
- loss of control of the flight. [8]

Loading of air cargo is always in a full compliance with the generally used regulations and limitations, the loading procedures and also with the instructions given by stuff that is responsible for the loading process for a particular flight. Such loading instructions must satisfy the requirements for cargo distribution and trim in the aircraft compartment's documentation.

As air cargo transportation is a sort of a very challenging business which depends on a turnaround time and fights for a load time reduction, the career simultaneously should follow the aircraft safety constraints without spending too much operation costs on it. The article contains a description of an algorithm, which clarifies the priority assignment process of containers (ULD) matching the multiple constraints with further unloading of cargo in a finite order.

2. Review of publications

The topic of cargo load optimization was mentioned in a large amount of scientific works.

The earliest time, the load optimization problem was presented as a cutting and packing problem and also referred to simulated annealing [6,7].

This problem was described as a Bin packing Problem by A. Trivella and D. Pisinger [12]. Nowadays authors implement heuristic rules which examine the impact of the number of different types of items on the loading efficiency [2].

A. Bortfeldt & H. Gehring implemented an integrated greedy heuristic which means the usage of specific genetic operators towards generated stowage plans which are reflected in a complex data structures, related to this problem [4].

Also load optimization problem is represented as multi container loading problem, with solving integer linear models [13].

Various works are linked with heuristic solution are based on the load bearing strength in order to avoid the fragility of cargo [3]. A large amount of researches contains mathematical modeling with optimum solutions for 3D container loading problem – mixed integer linear programming [5].

3. The aim of the research

The aim of this work is the development of a specific load optimization algorithm, which simplifies the load planning with formalizing it to Python program language with further implementation into the new optimization model.

Research tasks:

- parameters' description;
- sorting rule's description;
- load optimization algorithm's description;
- writing a pseudo-code with formalizing it to Python program language.
- development of three-dimensional load optimization model with priority criteria.

4. Parameters description

As the requirements and the objectives are formalized in previous stages of a research [10], the main objective will be the *aircraft loading time*, which has to be reduced and implies handling operations' time. The loading was divided into three transportation legs which are the part of one route. The following load optimization approach is improved by combination of a formalized part and heuristic approach. Heuristics was based on data, collected after interviewing the load planning staff. The parameters are divided into three groups and are presented in the Table.

Table

Parameters of the load optimization model

General parameters	Aircraft parameters	Container parameters	Cargo sections parameters
The number of legs, L_i	Capacity, C	Number of containers, c_i	Number of sections, S_n
	Maximum payload, W_{max}	Weight of the i container, w_i	Maximum payload, w_{s_n}.
	Cargo compart-ment's dimension, D.	Dimensions, d_i	Dimensions, d_{s_n}
		Weight of the loaded container, $w_{i_{load}}, w_{j_{load}}, w_{k_{load}}$	

General constraints:

1. *Compatibility*. An aircraft can only carry items that are compatible with it [7].
2. *Typology of containers*. The containers are homogeneous.
3. *Position*. Each item may be packed at any location inside a bin orthogonally, that is, the edges of the item are parallel to those of the bin. There is no overlapping inside the container.
4. *Rotation*. Container can be rotated only to 90 degrees.
5. *Storage*. Cargo is stored at the storage and will be moved to the platform/ramp;
6. *Unloading Sequence*. A container can be unloaded if the floor above it is also unloaded.
7. *Integer values and variables*. Containers dimensions and the coordinate values of the items in the bin are positive integers.

Specific constraints:

1. Load bearing strength. Maximum pressure that can be applied on the top of a container.
2. Weight limit. Items packed in each container cannot exceed a given maximum weight.
3. Weight distribution. The weight is distributed within the container according to finite criteria (priority of delivery).[11]

5. Sorting rule

The containers are sorted by the priority criteria. There are three cases of sorting rule:

Case 1. The cargo is loaded on the departure point and will be unloaded at the final point of destination, L1.

Case 2. The cargo is loaded at the midpoint and will be unloaded at the final point of destination, L2.

Case 3. The cargo is loaded on the departure point and unloaded at the midpoint, L3 (Fig. 1).

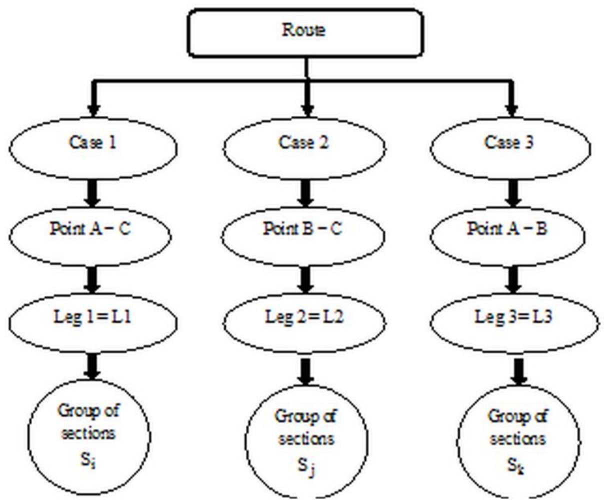

Fig. 1. Sorting rule's description

6. Load optimization algorithm

The problem reflected at this research is described as follows: the aim is to define the assignment of rectangular shaped bins in the aircraft cargo bay respecting safety and other specific constraints. Load operations should be finished before the closing time of the aircraft in order to increase the total profit from the processed freight.

Step 1. There are 15 sections (S_n) in IL-76 T cargo compartment. Sections are divided into three group sections. Each group S_i, S_j, S_k has a finite number of sections. $S_i = 4; S_j = 6; S_k = 4$. Each section has its own dimensions $d_{S_n}(x_{S_n}, y_{S_n}, z_{S_n})$. z_{S_n} is a priori $\le Z$, as the dimensions of c_i cannot be more than D (1):

$$z_{S_n} \le Z; \ \forall z. \qquad (1)$$

Step 2. Each section has a finite maximum weight w_{S_n}, which cannot exceed the maximum overall aircraft payload, W_{max} (2):

$$w_{S_n} \le W_{max}; \forall w_{S_n}. \qquad (2)$$

Step 3. Container is going to be loaded according to the sorting rule if the weight of it w_i does not exceed the maximum weight of the aircraft cargo section w_{S_n} (3):

$$c_i \in S_n \leftarrow w_i \le w_{S_n}; \ \forall w_i. \qquad (3)$$

Step 3 repeats until all containers, that fit the selected section are loaded.

Step 4. Repeat step 1, step 2 and step 3 related to other compartment sections.

The flowchart of the following algorithm is shown in the Fig. 2.

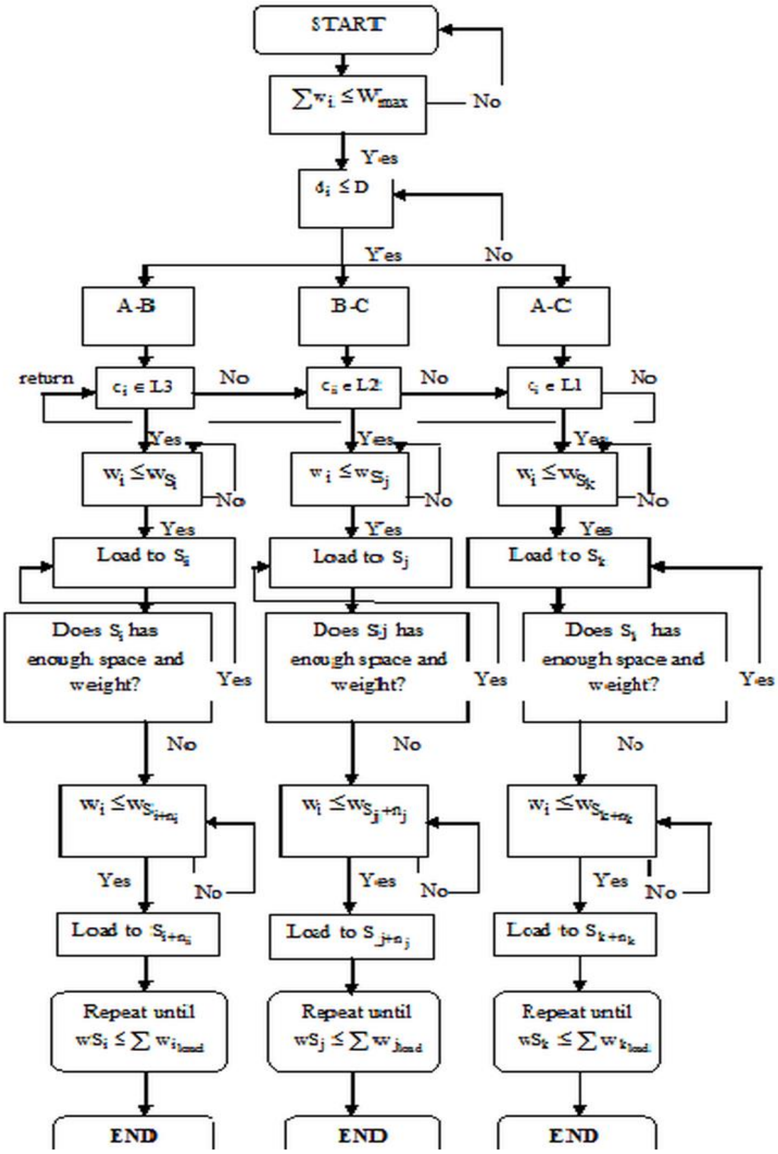

Fig. 2. The flowchart of load optimization algorithm

7. Pseudo coding of a new load optimization algorithm

For modeling of the algorithm that is being respectable to all general constraints of the aircraft should be done following the constraints towards the separate aircraft cargo section. We calculate it from the data based on flight manual of the IL-76 Annex 3 [9].

Algorithm 1

- // FOR ALL c_i
  (let i=1, k≤ 50000 (kg), i ++ integer)
- // READ c_l
- // READ $d_{x_i y_i z_i}$
  (let x>1, y>1, z>1; $x \le D_x$, $y \le D_y$, $z \le D_z$; x,y,z ++)
- // IF $d_{x_i y_i z_i} \le D_{xyz}$, THEN
- // READ L_i
  (let i= 1,2,3; i ++)
  - // ELSE
  - // READ c_{i+n}, (n=1)
- // IF $c_i \in L_i$, THEN
- // READ Algorithm 1a
  - // ELSE
  - // READ L_{i+n}, (n=1)
- // END

The algorithm 1 presents general order of load planning at the time of containers' distribution according to their route (leg) origin.

The next stage provides three algorithms on the stage of containers' sorting after their route characteristics. Algorithm 1a represents order for containers of a group section S_k, algorithm 1b represents order for containers of a group section S_j, algorithm 1c represents order for containers of a group section S_l respectively.

Algorithm 1a

- // FOR (list of "c_i") $\in$ L1

(let k=1≤50000(kg), ++, integer, i>0)

- // READ w_k
- (let k= 1,2,3,…n, i>0, integer, i++)
- // IF $w_i \le w_{S_k}$, THEN
  (let i $\{S_k\}$=11,12,13,14)
  - // LOAD $\rightarrow S_k$
- // ELSE $\rightarrow$
- // READ w_{k+1}
  - LOAD $\rightarrow S_k$
- // REPEAT UNTIL $w_{S_k} \ge w_{k_{load}}$
- // END IF
  - $w_{k_{load}} - w_k$ <0>1

Algorithm 1b

- // FOR (list of "c_i") $\in$ L2

(let j=1≤50000(kg), ++, integer, i>0)

- // READ w_j
- (let j= 1,2,3,…n, i>0, integer, i++)
- // IF $w_i \le w_{S_j}$, THEN
  (let i $\{S_j\}$=11,12,13,14)
  - // LOAD $\rightarrow S_j$
- // ELSE $\rightarrow$
- // READ w_{j+1}
  - LOAD $\rightarrow S_j$
- // REPEAT UNTIL $w_{S_j} \ge w_{j_{load}}$
- // END IF
  - $w_{j_{load}} - w_j$ <0>1

Algorithm 1c

- // FOR (list of "c_i") $\in L3$

(let i=1≤50000(kg), ++, integer, i>0)

- // READ w_i
- (let k= 1,2,3,…n, i>0, integer, i++)
- // IF $w_i \le w_{S_i}$, THEN
  (let[i] { S_i }=11,12,13,14)
  - // LOAD $\rightarrow S_i$
- // ELSE $\rightarrow$
- // READ w_{i+1}
  - LOAD $\rightarrow S_i$
- // REPEAT UNTIL $w_{S_i} \ge w_{i_{load}}$
- // END IF
  - $w_{i_{load}} - w_{S_i}$ <0>1

Pseudo-code was translated to Python script in Visual Studio Code environment with integration to Blender Modeling Program Version 2.83. Beta (Fig. 3,4)

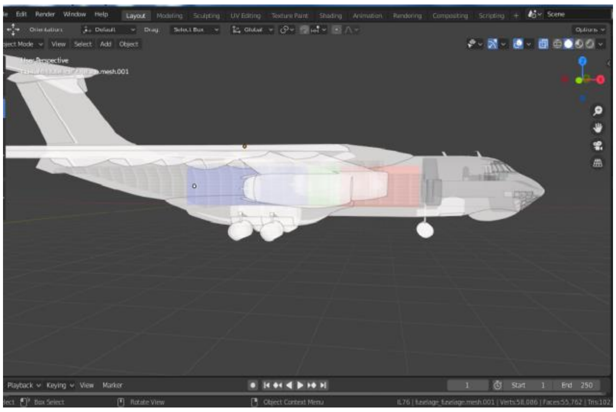

Fig. 3. Blender's 3D model of IL-76

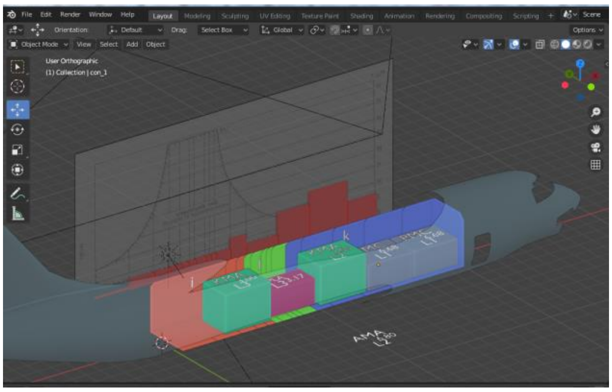

Fig. 4. Load optimization model

8. Conclusions and future research directions

The load planning optimization means an effective assignment of container groups with reducing of loading time, which means the number of cargo reloading/unloading in order to reduce all the costs per a one flight.

Air companies search the instruments for the best payload utilization including fuel consumption's optimization and rising of profitability. The last efforts of load optimization solutions are often limited by the aircraft's safety constraints, and often considered separately from them. The presented algorithm provides a solution how to manage the cargo loading process considering all safety constraints and route characteristics.

Cargo air freighters can improve their operations with implementation of the presented prototype and approach. Last-minute cargo may be transported in larger volumes and handling costs can be significantly minimized.

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Є.С. Сагун

Пріоритетний алгоритм завантаження як частина оптимізаційної моделі завантаження повітряних кораблів

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Мета: розробка нового алгоритму оптимізації завантаження з метою вирішення проблеми оптимального завантаження повітряних кораблів із подальшим впровадженням алгоритму у новітню модель оптимізації. **Методи**: евристика, формалізація, комп'ютерне моделювання. **Результати**: був розроблений новий алгоритм оптимізації, який передбачає розташування груп контейнерів, мінімізуючи час завантаження. **Обговорення**: Більшість вивчених наукових праць містять різноманітні характеристики вирішення проблеми пакування, оптимізаційні моделі рюкзака, а також виділяють термін «завантаження повітряних кораблів» як проблему вибору контейнерів, пакування та завантаження у вантажний відсік повітряного корабля. Такі моделі сконцентровані на окремих аспектах, в той час як, у реальному часі, проблема оптимізації тісно пов'язана із здійсненням хендлінгових операцій. Вищезазначена новітня модель оптимізації завантаження передбачає декомпозицію проблеми завантаження та впровадження нового пріоритетного алгоритму його планування. Даний алгоритм відноситься до механізму попереднього розташування засобів пакетування у вантажному відсіку повітряного корабля заздалегідь, у пріоритетному порядку, з метою вивантаження згідно документів, із виключенням перевищень допустимих значень із центрування та завантаження та із зменшенням часу завантаження та послідовним скороченням хендлінгових та операційних витрат.

Ключові слова: проблема пакування, оптимізація завантаження повітряних кораблів, алгоритм планування завантаження повітряних кораблів, час завантаження, ULD (засоби пакетування), критерій пріоритетності завантаження.

Е.С. Сагун

Приоритетный алгоритм загрузки как часть оптимизационной модели загрузки воздушных кораблей

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Цель: Разработка нового алгоритма оптимизации загрузки с целью решения проблемы оптимальной загрузки воздушных кораблей с дальнейшим внедрением алгоритма в обновленню модель оптимизации. **Методы:** эвристика, формализация, компьютерное моделирование. **Результаты**: Разработан новый алгоритм оптимизации, который предусматривает расположение групп контейнеров минимизируя время загрузки. **Обсуждение**: Большинство изученных научных трудов содержат различные характеристики решения проблемы упаковки, оптимизационные модели рюкзака, а также выделяют термин «загрузка воздушных кораблей» как проблему выбора контейнеров, упаковки и загрузки в грузовой отсек воздушного корабля. Данные модели сконцентрированы на отдельных аспектах, в то время как, в реальном времени, проблема оптимизации тесно связана с осуществлением хендлинговия операций. Вышеупомянутая обновлення модель оптимизации загрузки предусматривает декомпозицию проблемы загрузки и внедрение нового приоритетного алгоритма её планирования. Даный алгоритм относится к механизму предварительного размещения средств пакетирования в грузовом отсеке воздушного корабля в приоритетном порядке, с целью выгрузки согласно документов и не превышая допустимые значения по центровке и загрузке, а так же с уменьшением времени загрузки и последовательным сокращением хендлинговых и операционных затрат.

Ключевые слова: проблема упаковки, оптимизация загрузки воздушных кораблей, алгоритм планирования загрузки воздушных кораблей, время загрузки, ULD (средства пакетирования), критерій приоритетности зазрузки.

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