Application of Computer Load Optimization Model in an Aircraft Load Planning Process

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INTRODUCTION

Ground handling of aircraft is one of the key elements of ensuring the safety and regularity of air transportation. Ground handling covers all types of services that provide aircraft on the ground (aerodrome/platform). The flight ground handling process is an important part of milestone events for airport collaborative decision-making. (Li et al., 2022). One of the main challenges in air cargo transportation is how to assign cargo in an aircraft without exceeding safety constraints and including profit aspects. Changes in the aircraft ground handling process should focus on the positions of ground handling equipment before the arrival of the aircraft, the deployment of staff, routes of ground handling equipment, and others. (Szabo et al., 2021)

Therefore, challenging work planning must be done on every flight. Loading an aircraft is an extremely complex process in the face of many variable aspects that determine the planning of each flight separately.

Thus, the need to increase the efficiency of air transportation and at the same time maintain flight safety by fulfilling the requirements for the alignment and balancing of aircraft determines the need of developing a planning model for optimizing the loading of cargo ramp aircraft in a multi-leg route.

A virtual computer load planning model enables personnel who are responsible for flight planning to make faster decisions and predict the additional load on other sections of the route.

The successful application of the model in the operating activities of the airline contributes to improving the efficiency and safety of ground handling services. This contributes to the intensification of the use of the aircraft fleet by increasing the speed of commercial cargo handling.

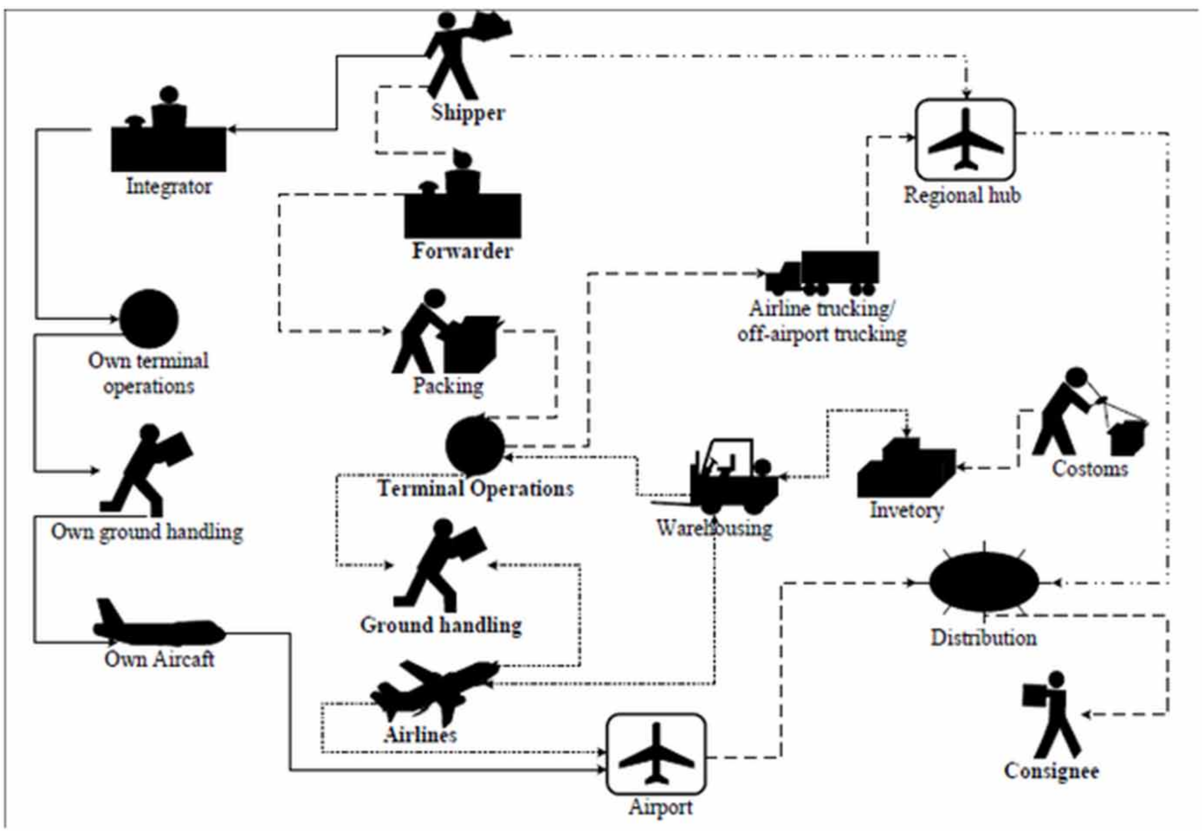
In the future, the computer model can serve as the basis for a rule-based expert system to prevent the reloading of containers on intermediate sections of the route.

DOI: 10.4018/978-1-6684-7366-5.ch012

Peculiarities of the Loading Process

Air cargo transport provides a range of services from point to point and also midpoints to move cargo with a help of a *shipper*, a *forwarder*, a *truck transport* (road feeder service), an *airline* (or carrier), and a *consignee*. The shippers' main goal is to send products/items to any place in the world with the lowest price and with a required service level. The forwarder plays a role of a link between the shipper and the career. The road feeder provides ground transportation service before and after the air flight. The airline provides a chain of services such as receiving, storage, transfer, loading and unloading cargo, assignment, and managing the compartment's capacity. The consignee gets the shipment. Figure 1 shows the process chain of the air cargo operations.

Figure 1. Air cargo operations technological chain (Sahun, 2020)



Sabine Limbourg (Limbourg, Schyns, Laporte, 2011), defines a ULD as 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 for rapid loading and unloading. The aircraft loading process of them can differ and depends on the ULD's content and quantity. Inside the boxes are stacked and united in such a way as to avoid the instability and fragility of the cargo items. Weight constraints inside the ULD allow loading it in an appropriate way (Mongeau & Bes, 2003; Souffriau, Demeester, Berghe, & De Causmaecker, 2008). Inside the aircraft, the ULDs are placed in designated loading positions and locked into position by latches on the floor. As the aircraft fuselage has a near-circular cross-section, there exist ULD types with different shapes to efficiently use the aircraft's interior space. Figure 2 shows a few frequently used ULD types (Brandt, 2017).

However, most of the aircraft need certain ULD types for special loading and assignment. There are also general ULDs, such as aluminum pallets and containers of different formats, and special-purpose ULDs for shipping cars, horses, or frozen goods. For transporting bigger cargo, the advantage is given to pallets because they can be packed in containers more easily and their contours can be moved freely. It is also popular to overhang items with the aim of a full load of the lower deck in width. But in this case, each pallet should be covered with a net which needs an additional handling effort. On the other hand, such containers possess certain boundaries and walls, so they can stay untied. Thus, they can be loaded only in a position that matches their contours. They are often used for small cargo or baggage.

The air cargo loading process is a complex process, which includes four individual handling processes: splitting process, removing of cargo, moving, and cargo assignment. These processes have commodity priority and grouping rules (Feng, Tian, Zhang & Kelley, 2010).

Removing of cargo: In case the total weight of the group of items exceeds the payload weight or the total volume exceeds the bin limits, items need to be removed from the loading list.

Cargo's assignment: Loading the items to the bin or container (ULD) of the aircraft.

Moving: While assigning a far destination group of cargo into one bin, it should be moved out through the near destination group of cargo to avoid blocking.

Splitting process: There are two ways for it. The first one is, to remove cargo some groups of it should be split to transport as much as possible, the second one is, when a big group of items is assigned into précised multiple bins, it should be split into several sub-groups.

BACKGROUND

It is necessary to consider approaches to optimizing loading both through the prism of mathematical methods and from the methods of scientific heuristics.

Mix Integer Linear Programming

Mix integer linear programming approach was developed while packing the cargo into Unit Load Devices (ULDs). The unused space is minimized by respecting some basic and specific constraints. Since all the containers are equal, it is equivalent to minimizing their number. As it solves the 3-dimensional Bin Packing Problem-BPP has some general requirements, which are non-overlapping of the boxes and other special requirements: distribution of the weight, rotations, stability, fragility, etc. The author of the mathematical model considers the 90 - rotation. Consequently, the space occupied by the box is described more than the box itself. It was proposed several suitable configurations. Paquay et al., 2011 propose mathematical programming to solve the aircraft loading problem (Paquay, 2011). The objective of this method is to minimize fuel consumption and satisfy stability and safety requirements. The author's approach helped to solve the loading problem within 10 minutes with the usage of integer linear programming.

The mathematical formulation includes structural constraints (volume and weight capacities) and total maximal weight per load.

The Rule-Based Optimization

The rule-based optimization approach correlates with expert systems (Feng, 2010). The author developed a load planning model including visualized rule editor, rule engine, and an extensible business object interface. Rule Editor is a visualized environment for rule creation. Each rules flow should begin with a Begin Node, then a mixture of conditions, actions, and messages, and end with an End Node or Flow. Rule Engine parses the rule file and executes based on the business object context to change the commodity and bin's status. The author considers different constraints for removing and assigning processes.

Different patterns include predetermined ordering and dynamic ordering. The predetermined ordering is achieved by employing some sort of criteria, such as box volume, number of boxes, base area, or a certain dimension of a box. Dynamic sorting is based on the usable space that remains after the next assignment, the volume of remaining boxes of the same type, and free-floor space (Zhaoa, Xiaozhou, Bennella, Bektas & Dowsland, 2016).

Heuristics

Various approaches are based on heuristics. Larsen & Middelsen (Larsen & Middelsen, G.,1980) and Amiouny (Amiouny, Bartholdi, Vande & Zhang, 1992) propose heuristic methods to define a feasible load plan for the aircraft. Larsen & Middelsen implemented an interactive, computer-based procedure for solving a loading problem of containers into the aircraft's compartment. They use benchmarks of ground stability, load limits, cargo position, balance, and compartment capacity limitations.

The other heuristic approach (Amiouny, 1992) was presented as a one-dimensional loading problem with balancing limitations around the aircraft's midpoint. The requirements were the following:

1) every container must be loaded.
2) containers must be arranged in a one-dimensional hold.

The problem defines the cargo that must be loaded in a finite sequence with the help of the branch and bound methods and opinions of loadmasters.

The wall building can serve as an example of a heuristic method (George and Robinson, 1980). The method develops a two-section heuristic based on a real industrial example of 800 boxes with no more than 20 types. Given the following space, initially the whole container, they choose the first box of each wall so that each wall has a size not too deep or too small, using the following ranking criteria. First, select the field whose smallest dimension is the largest of all candidates. If there is a link in the first criterion, select the box type with the largest amount. If the connection still exists, select the box type with the largest size. After at least one of the boxes of a certain type is packed, this type of box opens. Open box types have the advantage of having the highest number type have the highest rating. If the length of the non-filled container is too short, usually below a certain quantity, the packaging of the remaining containers no longer follows the rules of wall construction (Zhaoa, 2016).

Gueret (Gueret, Jussien, L'homme, Pavageau & Prins, 2003) is engaged in military operations such as sending troops to the cargo bay of the aircraft. This method of forming a load model consists of two steps:

1) generating a great number of feasible and attractive loadings.

2) selecting a subset from those loadings to cover all the items to be shipped with the final objective of minimizing the number of sorties (Gueret et al., 2003). But this pattern relates to the 2-dimensional bin packing problem.

Another group of researchers (Thomas, Campbell, Hines & Racer, 1998) also developed a heuristic method with branch-and-bound for loading containers into pre-defined positions to save feasibility constraints – determine a feasible packing with minimizing the nonproductive time.

Heuristic methods need to involve highly qualified and experienced ground staff to try arranging an appropriate loading (satisfy all constraints) by manual experimental methods and error process without maximizing.

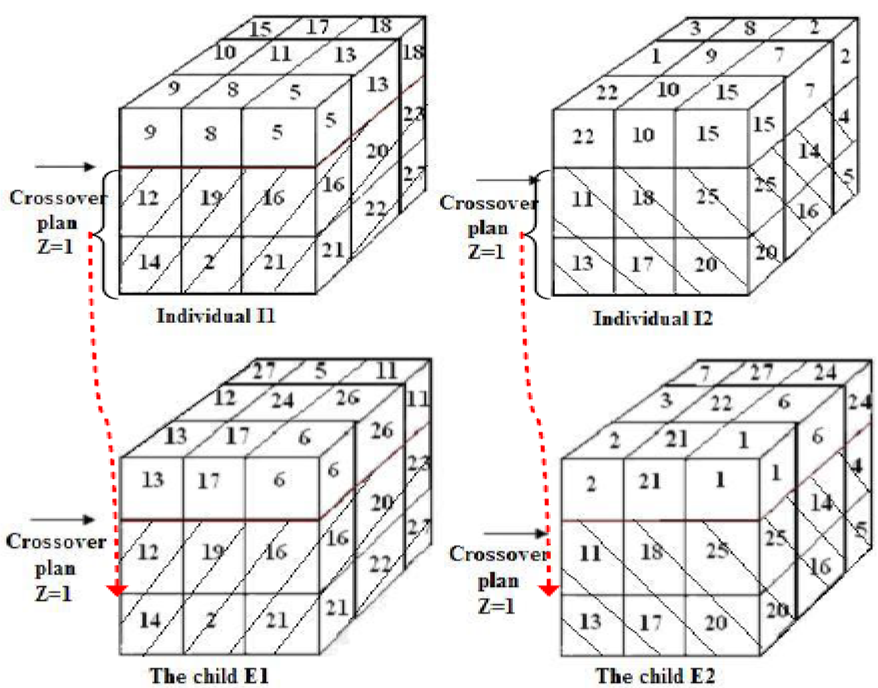
Genetic Algorithm

The mathematical appearance of a genetic algorithm is similar to nonlinear programming, except that any value can be a discrete variable.

This boot method was implemented in a genetic algorithm that processes the optimization function data with several target values, such as usage volume, total maximum load weight, and least load center weight to maintain balance (Bortfeldt, & Gehring, 2001).

A hybrid genetic algorithm was proposed by H. Gehring and A. Bortfeldt, which contains a basic heuristic loading method and genetic algorithm. The cube position heuristic allows the stacking of boxes based on boxes or containers selected as the base of the tower. A. Bortfeldt improved this algorithm in 2007 and replaced the towers with boxes with a layer (Bortfeldt, Mack, 2007). Assignment now includes several vertical layers containing a certain number of boxes (Figure 1).

Figure 2. Illustration of genetic algorithm



Tabu Search Approach

The tabu search approach is an example of dynamic ordering. This involves distributing palletized cargo to certain pallet positions within existing aircraft. The goal is to minimize deviations from the preferred loading requirements for aircraft while maximizing the time limits for pallets. The time limit determines the available "window" of acceptable days during which each pallet must reach its destination. These decisions enable decision-makers to determine the course of action from which they may choose their preferred option. Time constraints in the dynamic task of air travel allow aircraft to make multiple flights. The overall objective is to minimize not only the number of flights required to move all pallets, but also the number of aircraft required, and, at the same time, to minimize permissible violations in the loading of aircraft and temporary violations in the pallets' assignment (August, Roesener & Barnes, 2016).

Aircraft Load Optimization Problem Assumptions

The higher load factor needs more cargo shipments and more earnings. Reduced transfer time makes faster connections and thus higher salaries for the ground service staff. According to IATA information, the average weight load factor in the market varies between 40 to 50 percent (IATA Cargo Strategy, 2018). So, in the real world, load maximization is not the main challenge for air companies. But the minimization of handling time and rationalization of aircraft operations are much more difficult tasks to solve.

Cargo shipments need additional handling efforts. Firstly, cargo should be transported with the help of a *belt loader assembly* or forklift inside the terminal. Furthermore, it should be packed in ULDs, fixed with nets, and sent further up to its route. The packing procedure is also a challenge in cases when the shipment contains heterogeneous items.

While researching such load optimization problems, some aspects should be taken into consideration. These aspects are the containers' time of delivery to customers and the re-handling procedure. A re-handling means moving an item or cargo bay to open access to another bay, or to change the stowage. Such a procedure is considered as a result of ineffective load planning through the overall route of the flight. Permutation can be a synonym for it and means the rearrangement of cargo items or the whole containers towards the cargo compartment. It can be considered as a multi-dimensional (note that items cannot be stacked up in a bay) bin packing problem with heterogeneous containers. It is an NP-hard problem (Wilson, Roach & Ware, 2001).

According to Uwe H. Suhl and Leena M. Suho (Suhl, Uwe H. & Suhl, Leena M., 1999), in solving airline-fleet scheduling problems with mixed-integer programming, they have proposed the following heuristic algorithms:

First-in-first-out (FIFO): the aircraft which arrived first, will leave first

Last-in-first-out (LIFO): the aircraft which arrived last, will leave first

Best-first (BF): choose that flight from available flights which can be flown by aircraft with the shortest standing time

The heuristics they used may be used in a load planning algorithm:

First-in-first-out (FIFO): the loaded container which arrived first, will leave first

Last-in-first-out (LIFO): the loaded container which arrived last, will leave first

The Best-first (BF) method cannot be used in this research clearly as it ignores the factors of the center of gravity and load balancing.

For comparison, the author brings an example of the model of Fok and Chun (2004), whose aim is to minimize the cargo loading residual (under-load). A linear program model, similar to the authors was used.

And the work of Hussein (2012), who also uses the LIFO algorithm to solve the task of reloading items, the author called the approach a block relocation problem with weights (BRPW). The problem is encountered in the maritime container shipping industry and other industries where inventory is stored in stacks.

All methods mentioned previously can't solve the loading problem within time constraints. Pure mathematical programming is very time-consuming and provides too much quantity of decision variables. Pure heuristics ignores the balance restrictions as it was mentioned. Therefore, the future step of the problem's solution is a combination of a few previous approaches and the development of a new model. This model will contain a formal part – a mathematical model and a part of decision-making – searching for feasible alternatives. The reason why the alternatives can be feasible but not optimal is because of the uncertain conditions of the model. We have a deal with dynamic ordering as it was mentioned above. So, the stochastic environment which is forming around the loading process forces the author to create a model which would have different variants to choose from due to the functions of a rule-based expert system and its "if/then logic function.

The analyzed literature shows that every approach is justified and proved with mathematical and computer-based models. However, the problem of aircraft loading must be studied further because of its constraints, which cannot be satisfied simultaneously with a single algorithm. The range of approaches solves partial tasks connected with separate constraints and does not provide the overall solution that can satisfy the constraints which are in contradiction with each other. The problem needs to be solved with the help of specific applied virtual systems that can reflect the loading process algorithm.

The problem of loading an aircraft should be further studied due to its specific limitations, which cannot be considered simultaneously in one algorithm. The whole set of approaches proposed up to this point solve partial problems that are associated with individual constraints and do not provide a common solution that would satisfy all the limitations, as well as often contradict each other.

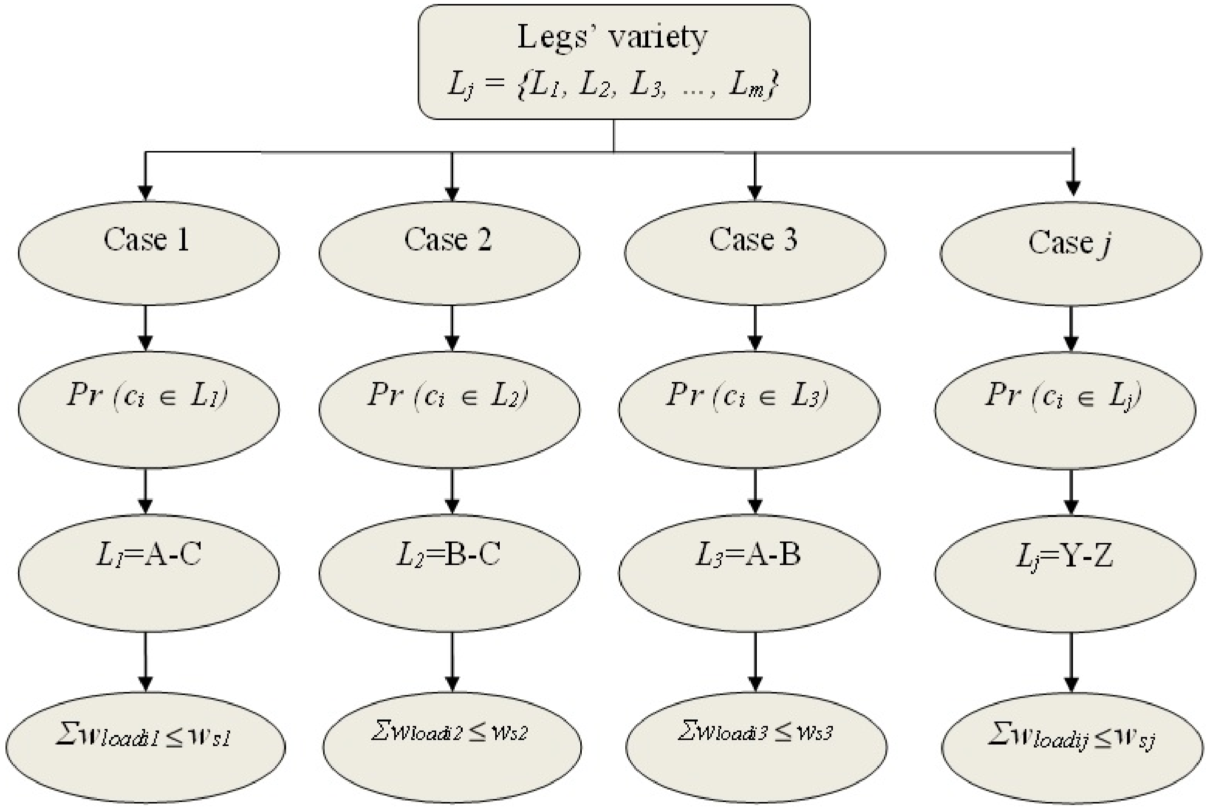
LOAD OPTIMIZATION MODEL IN AN AIRCRAFT LOAD PLANNING

Cargo Priority Selection

Cargo load optimization aims to determine the location of containers of rectangular shape in the aircraft cargo compartment, considering all constraints, having completed all loading operations before the end of the aircraft's parking time on the apron, maximizing the safety of loading operations and the overall operating profit of the airline from the handling procedures time reduction. The final time of the parking is the time of the end of all possible operations with the aircraft just before the beginning of its movement on the taxiways. The first and main constraint in the future model is the cargo's priority, so the algorithm is based on the priority criteria. The following cargo priority selection scheme is given below:

According to the priority selection rule containers are sorted respectively to priority criteria. For example, with three transportation points A-B-C (A is the starting point of departure; B is the intermediate point of arrival; C is the destination).

Figure 3. Scheme of the cargo priority selection rule (Sahun,2019)



Case 1.

There is a multiple-leg route that consists of the 3 points: A-B, B-C, and A-C. Each leg has its planned payload and a predefined unloading order according to its priority. The ramp cargo aircraft (this case is IL-76) is loaded with different types of ULD that follow the route from A–C (by-passing the point B)

Load Planning Algorithm

The following load planning algorithm given in Sahun and Sahun (2020) was designed for the ramp cargo aircraft, as there is no such problem for loading on a multi-leg route for aircraft that are equipped with apparel. Cargo aircraft IL-76T, AN-24, AN-26, and AN-22 were used for data with a final center of mass assignment. The graph IL-76T was chosen as a visual example in the 3D simulation in the Blender 3D program.

To optimize the loading process of the aircraft, handlers should make sure not only about the limits and procedures that should not interfere with the general restrictions of the aircraft but also make sure that the payload does not exceed the load limit for one IL-76 cargo bay. These restrictions are usually calculated based on the Flight Operations Manual (FOM) contained in appendix 3 IL-76 and have been added to the overall aircraft load planning algorithm.

Figure 4. Correlation of the final center of mass (CM) assignment graph and the aggregate sums of masses (IL –76)

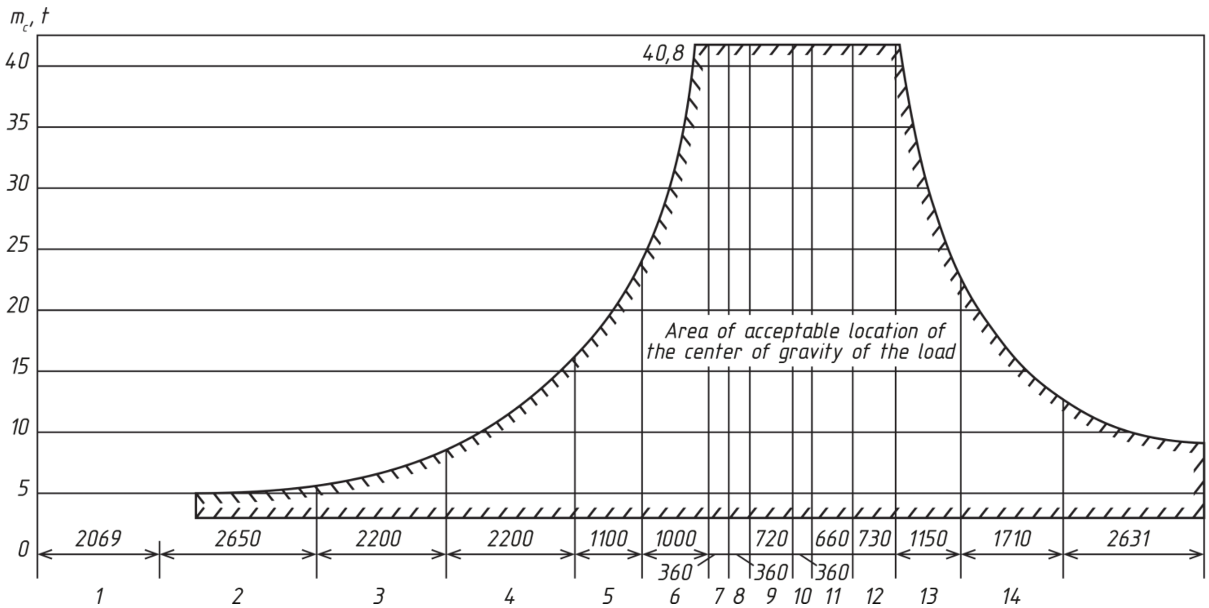


Table 1. Parameters of the load planning algorithm

Parameter's name	Parameter's Symbol
Number of legs	L_i (i=1,2,3)
Capacity	C
Number of containers	c_i
Number of sections	S_n
Maximum payload general	$W_{\max}$
Weight of the i container	w_i
Container dimensions	Dimensions, d_i
Weight of the loaded container,	$w_{iload}, w_{j_{load}}, w_{k_{load}}$
Cargo compartment's dimension	D
Maximum payload of the cargo section,	w_{s_n}.
Cargo section's dimensions	d_{s_n}

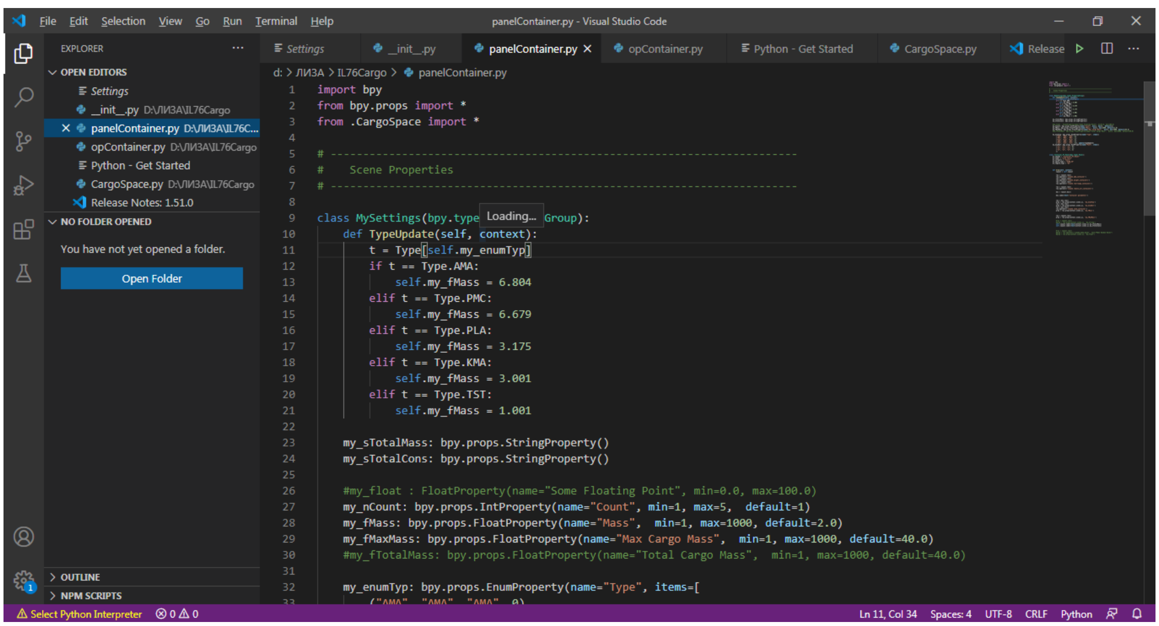
As an example of the cargo compartment, we can propose the cargo compartment of the IL-76 that is divided into 15 groups (sections) (figure 3). Each section corresponds to its area, which is determined by the length of the compartment and the final set of fuselage bulkheads.

In the work of Sahun & Sahun (2019) was assumed that a scientific attempt at load optimization is undertaken by a situational task that complies with the real-life aircraft operations process. The initial task parameters are listed below in Table 1.

Parameters were input into the MS Visual Studio Code in Python. Figure 5 indicates the example of the Python algorithm with container codes (AMA, FMS, KMA, and RLA) and their weight limits. If the actual figures do not match the weight limit entered initially in the algorithm, the container will not be loaded into the specific aircraft and the system will provide the next one for the conformity check.

The algorithm changes the mass distribution and the location of individual containers to different sections of one group of three possible sections. Available free space belonging to certain sections of the load compartment and corresponding to its weight limit continues to work the algorithm until the next suitable load fills the section (subject to weight and balance constraints).

Figure 5. Coded Python load planning algorithm, part: parameters 'input



Load Optimization Model's Implementation

The load planning model is implemented as follows:

1) The application database contains information about a certain number of containers to plan the load within the multi-leg route. This information is provided from documents prepared by the Flight Dispatch, Ground Dispatch, or several airline flight planners.
2) The program is updated with the standard types of containers used by the airline in advance. These are Type a (KMA) animal and general purpose ULDs PMC, PLA, and AMA.

3) The program uses the general aircraft constraints, (length, width, and height of compartment, maximum commercial load), the weight and balance restrictions specific section constraints, to select the container “Add container”. The container initially positions relative to its priority criterion (belonging to a particular route), as shown in Figure 6 using the command “by path”.

Figure 6. Model’s visualization: Containers assigned respectively to its final unloading procedure (Sahun, Bebitowa 2021)

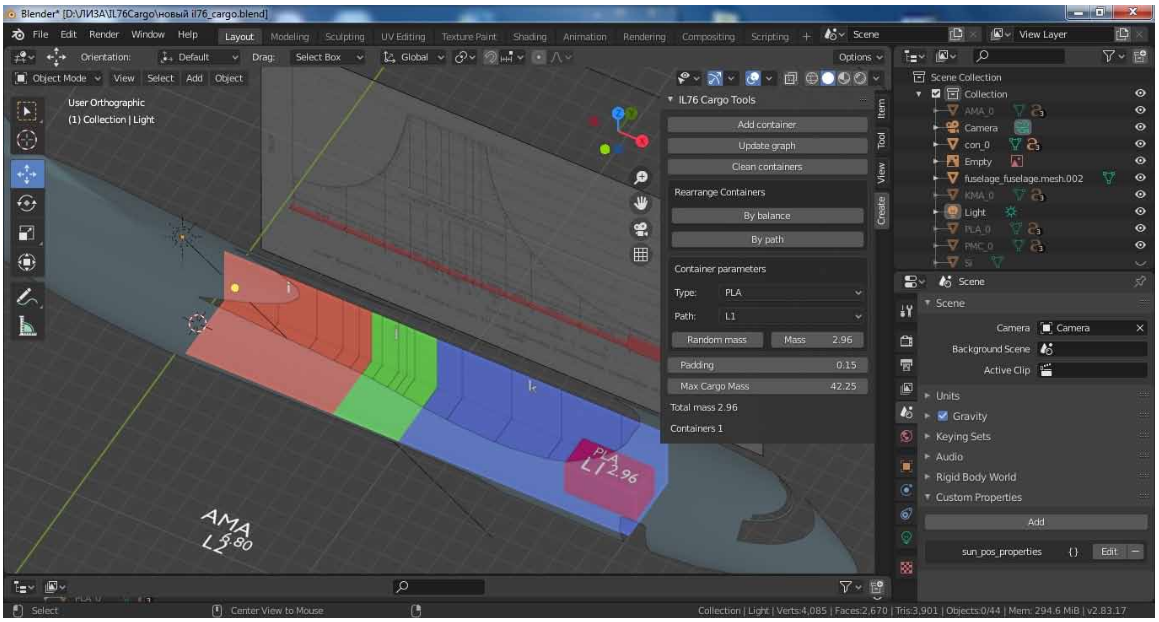
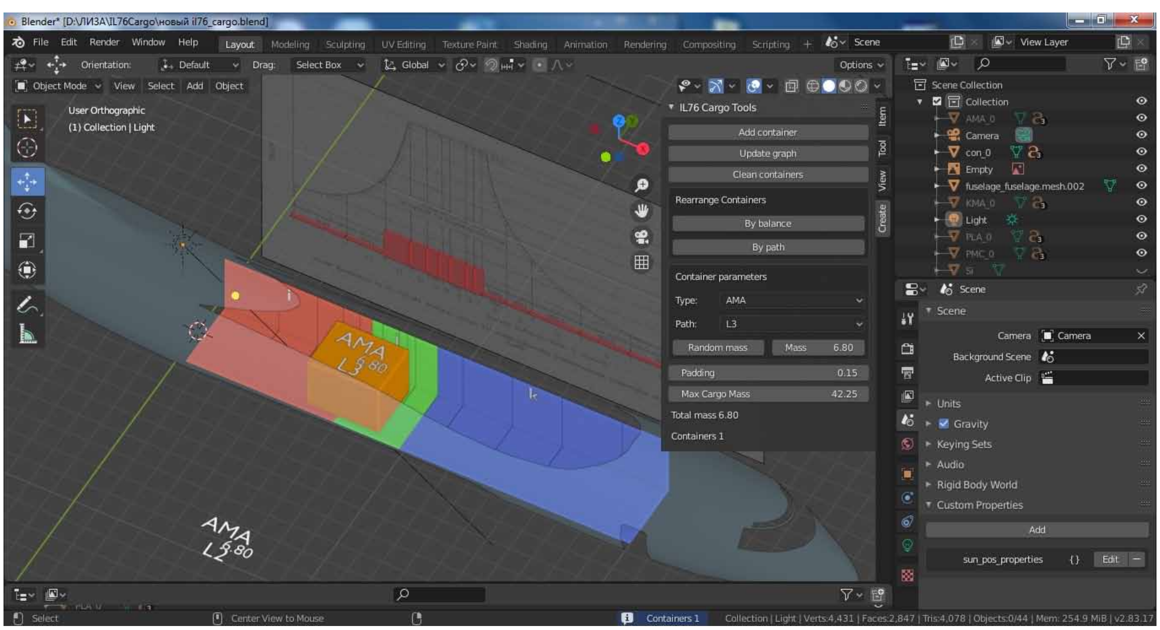


Figure 7. Model visualization: Container located according to Weight & Balance Chart requirements



The program contains data from the graph of the location of the resulting center of mass dependence of aircraft cargo (in this case, the IL-76 aircraft) on their total mass (Figure 4). Consequently, the distribution of the weight of containers occurs purely on schedule, so the weight and balance will not go

Figure 8. Model visualization: Loading several different containers according to the Weight & Balance requirements

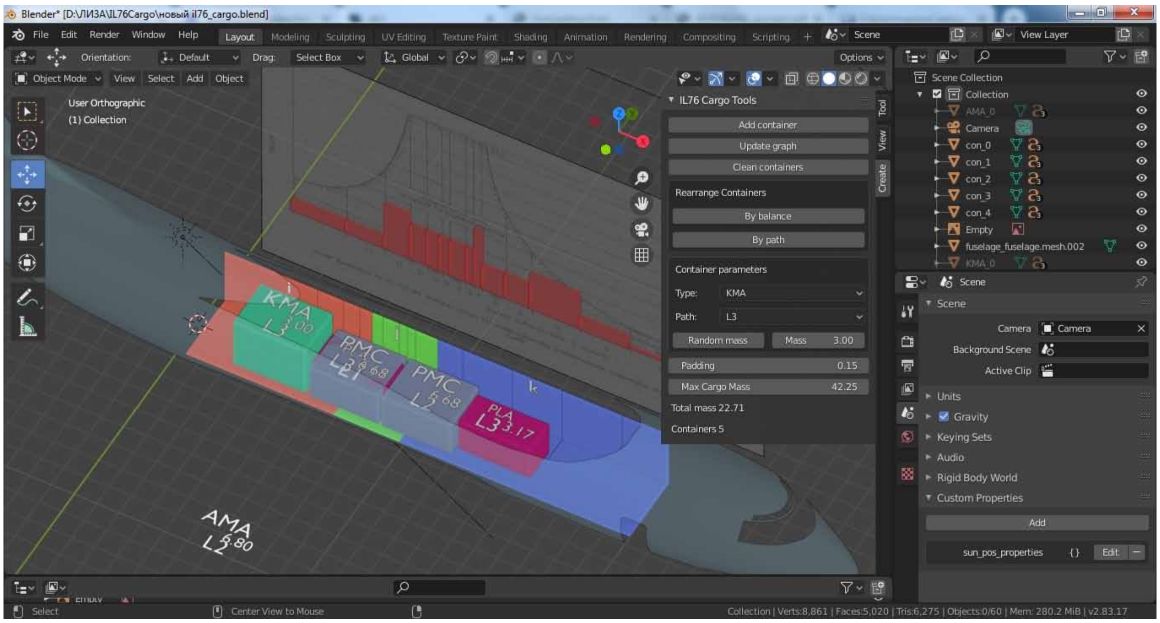
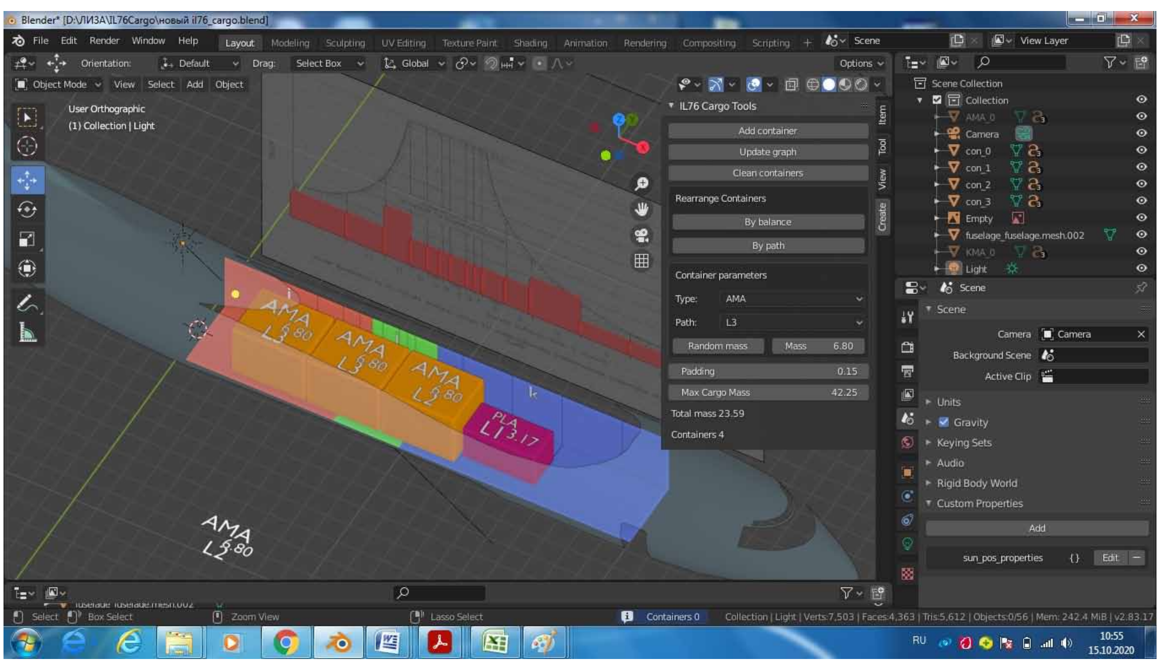


Figure 9. Model visualization: Arrangement of additional containers according to the Weight & Balance requirements

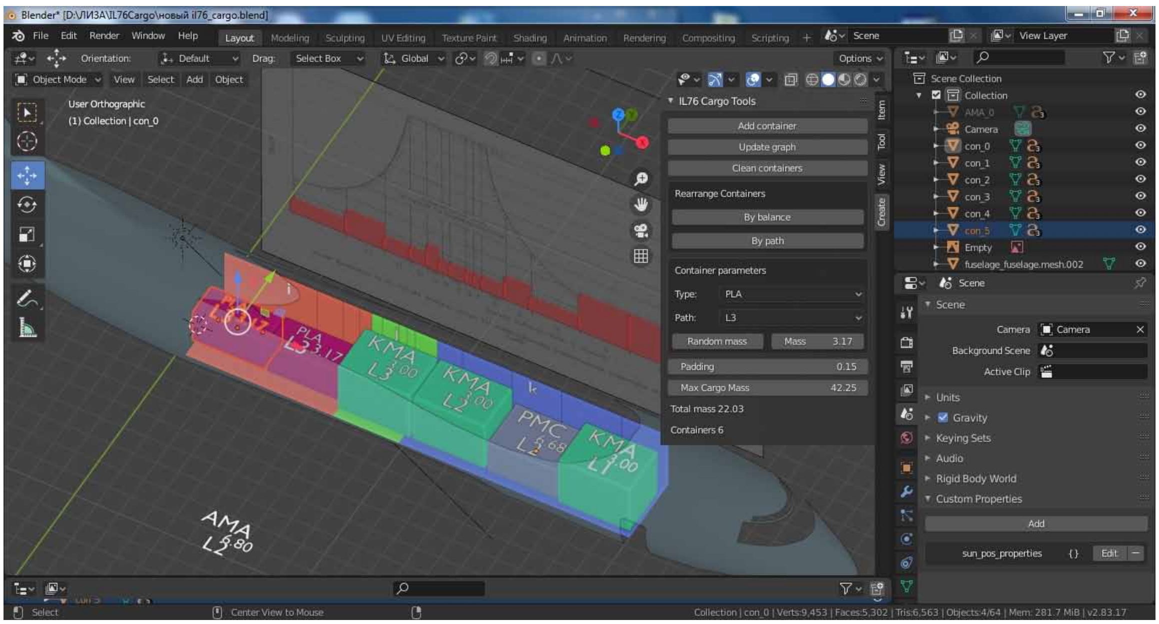


beyond the standard indicators. Thus, in figure 7 the container is already located not only according to the priority criterion but is also centered using the “by balance” command.

By consistently adding certain types of containers that match the given route priority, the view, and location of all containers loaded by the program change relative to the shipping area (figure 8, 9).

By adding and placing containers within two criteria at the same time, the weight of the container that is loaded last is within the normal range. However, in terms of its dimensions, it exceeds the overall dimensions of the cargo hold, as indicated in Figure 10. In this case, it should be excluded from the list, and we should select another container using the “Add container” command, which will also be suitable in size, without exceeding the size of the ramp.

Figure 10. Model visualization: The case when the container parameters do not correspond to the size of the cargo compartment



The program allows us to avoid a situation when certain criteria and restrictions cause sorting “manually” by all indicators, which is quite time-consuming in conditions of the urgency of servicing the aircraft at the airport.

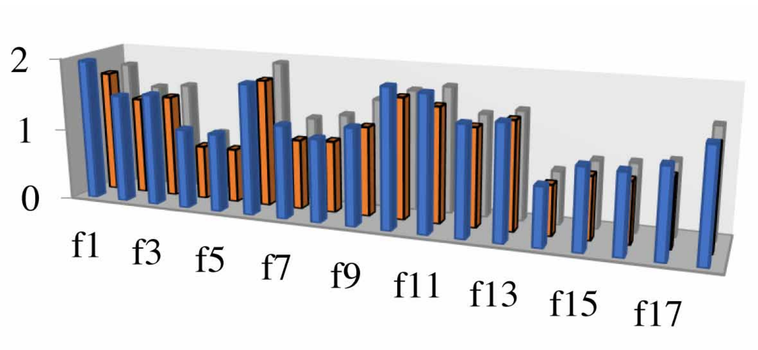
Experimental Examples of Optimization Model

The experiment was implemented in the work of Sahun et al., (2021) the LLC “Aircompany ZetAvia” in the following way: the set of round-trip straight and multi-leg flights was chosen. It counted the average loading time of each flight before the model implementation. Afterward, the load optimization model was integrated into the company’s load planning system and used by the load planning staff while taking their operational decisions as well. If we analyze the experimental data from Table 2, we see that most of the time parameters after the model implementation are less than before the experiment.

Table 2. Experimental results of aircraft load planning while operating the Zet Avia flights (Sahun, et al., 2021)

Nº	Route	General ULD's quantity	Loading, before the experiment, min.	Loading, after model implementation, min.
1	Al -Ain - Nukus - Almaty	7	105	102
2	Almaty - Nukus - Al -Ain	5	87	81,6
3	Al -Ain - Sharjah - Nukus	4	90	85,4
4	Sharjah - Al -Ain	4	50	45
5	Al -Ain - Sharjah	3	50	45
6	UTNN - Sharjah - Al -Ain	6	115	105,6
7	UTNN - Sharjah	4	70	58
8	Sharjah - Almaty	5	75	59,4
9	Al -Ain - Mykolaiv - Nukus	7	90	73,8
10	Almaty - Nukus - Sharjah	7	100	100
11	Sharjah - Nukus - Almaty	7	105	95
12	Al –Maktoum - Nukus - Almaty	5	85	81
13	Almaty - Nukus - Al –Maktoum	6	90	89
14	Ras-Al –Khaimah - Almaty	3	44	41
15	Almaty - Sharjah	4	55	51
16	Sharjah - Al -Ain	3	56	50
17	Nukus - Al -Ain	4	60	56
18.	Nukus - Mykolaiv - Al –Maktoum	7	90	83

Figure 11. Histogram of the experimental results during the set of round-trip flights



A histogram of the experimental results during the set of round-trip flights is presented in Figure 11.

The heuristic in the load optimization model includes the expert data based on professional experience and perceptions according to the finite problem statement. The group of 30 experts evaluated the model and the effect after program implementation.

There are three different columns on the histogram. The blue columns define the experimental loading time before the model implementation, the orange columns show the modeled loading time and the grey columns represent the experimental loading time after the model implementation. An example of a multiple-leg flight can be a flight on the route Sharjah – Nukus – Almaty. The duration of general loading operations after the model's implementation was reduced and became 10 minutes less than the modeled one. For the one-leg flight of Ras -Al -Khaimah – Almaty the duration of general loading operations became 3 minutes less than the modeled one. The parameters can vary due to the cargo specificity; however, if we base on the data in Table 3, the model demonstrates positive results after implementation.

The new practical results are directed to improve the effectiveness and safety of maintaining the handling procedures and intensify the air company aircraft fleets' utilization with a reduction of the handling procedures duration.

The practical value of the obtained results in Sahun et. al., (2021) is determined by a successful application of the load planning optimization computer model in air company operations. The developed optimization algorithm was presented on the example of the 3 IL -76 loading model. Experimental data from the range of LLC «Aircompany ZetAvia» flights demonstrated that the model implementation has enabled the reduction of the average loading/unloading time on the range of direct flights to 7% and the multi-leg flights to 12%.

The loading time reduction after the model implementation is caused by the conditions that were laid in the decision-making algorithm. These conditions make impossible the situational manual loading. Therefore, the Python algorithm returns the user to the prior action until the previous container from the same route leg will not be loaded. As it is to be loaded according to all compartment constraints, i.e., the finite sequence based on the flight data remains the same. The presented load planning algorithm contributes to avoiding the cases when the cargo is impossible to unload directly in the finite route leg without reloading the cargo that was attached before it.

With the help of the finite decisions, made by the algorithm variants the loadmaster or the ground dispatch staff can control the correlation between the container loading indicators and the general aircraft constraints. This enables one to sort of an appropriate variant without wasting time. Consequently, it will affect the load operations speed and the aircraft turnaround time.

The loading computer model now has restrictions due to the aircraft type. For algorithm operation, the career must operate the ramp cargo aircraft. In an aircraft equipped with apparel decisions will not be feasible. These types have free access to all cargo compartments and the problem of the loading speed can be solved just with the help of the handling staff without implementing the program optimization decisions.

Although the research weaknesses can include the exogenous factors that affect the cargo service time indicators such as human factors, weather conditions, etc. That case can mitigate the decision-making time during flight planning.

FUTURE RESEARCH DIRECTIONS

The computer load planning model enables the Dispatcher or the responsible Planner to form an expert system, which knowledge base that contains information about the cargo. The aim is to avoid the reloading procedures at a transportation midpoint.

The reasons to use expert systems in decision - making process of air cargo planning are the following:

- Air cargo transportation is more complicated than passenger transport because it involves more third parties, challenging processes, a combination of weight and dimension constraints, and various prioritized services.
- Air cargo transportations have higher uncertainty than passenger transportation due to its available capacity.
- Cargo capacity forecast is substantially more complicated than passenger aircraft capacity forecast. Passenger aircraft's capacity is constrained by several seats, while cargo capacity depends on the used ULD type.
- The load planning conditions are very uncertain and information details can change at the last minute.

However, before implementing this approach the author should define which kind of ES would apply to the following research. Rule-based ES that defined by Feng et al., (2010) will be the most applicable for the load planning case. Consequently, the main features and structure of a rule-based ES should be considered for filling it with the required data.

Such a prototype of an expert system (ES) would let the weight and balance sheet be arranged in such a way, as to prevent an impact of formed "empty" space points, left from the unloading procedures in a first midpoint on a further trim and would not go beyond the required boundaries. The input parameters will be presented as digital data, processed in real-time, from the sensor, which is reflected on a working screen and recorded to the ES database, and as reference data, that is placed on a server, with the possibility of their correction and rewriting. The output parameters are reflected as graphics and numbers on a working screen in real-time mode.

CONCLUSIONS

The following work presents the analysis of the order and specificities of the loading process. The research also provides a review, which clarifies the difference between current load optimization models. The research contains the analysis of an air cargo operations technological chain and also technological issues of various ULD types in natural proportions.

The objective of load planning optimization lies in the assignment of container groups to minimize the loading time, which means the number of handling operations (operations of cargo reloading/unloading) with the consequent cutting of the operating costs per flight.

The bottlenecks in the cargo planning technological chain exist at every step of the load planning procedure. In a particular case, the author considers bottlenecks in the assignment stage. So, the point is, to place the cargo in such a way, as to foresee its further motion according to its leg and also to avoid the reloading or unloading procedures. A large number of scientists were faced with a load optimization problem and solved it with different and contradictory methods to reduce fuel costs or optimize the aircraft's capacity. But the following work seeks to plan the containers' permutation to speed up the handling process while being under conditions of a flight, consisting of multiple legs.

The complex load planning optimization model was developed that enables automation of the load planning process, reduces the number of errors in flight planning, and considers the unplanned "last-minute cargo" without exceeding the weight & balance limits.

The three-dimensional load optimization model has all the necessary conditions and parameters to proceed as a rule-based expert system that can manage all flight data, with a designed database that is based on general aircraft parameters, cargo sections, and container parameters. The dimensions of a container and the position of loaded containers are described by the positive integer data type. These data can be stored in the tables of the database.

Cargo air companies can increase their profit with the presented model implementation. Last-minute cargo can be transported in larger volumes and load planning, handling, and operation costs can be substantially reduced.

Different load optimization methods and approaches were studied: Mix Integer Linear Programming, Rule Based Optimization, Tabu Search Approach, and Heuristic methods.

Some new assumptions were imposed still counting that the problem remains NP-hard. A few criterions were imposed into a new model. Now it includes criteria of loading time minimization which means reducing the number of cargo reloads.

Our objective remains to define a suitable and robust overall load plan, respective to all the constraints we determined above.

Practical results aimed at increasing the efficiency and safety of ground commercial service, as well as intensification of use of air-carrier's fleet. The model reduces the duration of long-term handling operations. Results were effectively applied to the computer model of load planning under the operating conditions of the tested air carrier.

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KEY TERMS AND DEFINITIONS

Bin Packing Problem: A problem that defines items of different volumes that have to be packed into a definite number of bins of finite volume in such a way that minimizes the number of bins used in the aircraft cargo compartment.

Center of Mass: A distribution of mass in space and a position that corresponds to an object or system of objects. It is the average position of all the parts of the objects, weighted according to their masses.

Container Loading Problem: A problem that defines the loading of a set of rectangular boxes into a rectangular bin of fixed dimensions to maximize the volume of the boxes.

Expert System: Artificial intelligence system that converts the knowledge of an expert in a specific subject into software code.

Knapsack Problem: Problem in combinatorial optimization which solves how the chosen set of items, with parameters of weight and a value, should be loaded in a way so that the total weight is less or equal to a set aircraft constraint and the total value is as large as possible.

Multi-Leg Flight: A flight that stops at one or more intermediary points of the route before reaching the final arrival point at the finite airport.

Unit Load Device: 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 for rapid loading and unloading.