

AIRPORTS AND THEIR INFRASTRUCTURE

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MULTICRITERION MODEL OF AN AIR CARGO TERMINAL TECHNOLOGICAL AND PLANNING DECISION OPTIMIZATION

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Abstract. *Developed multicriterion economic and mathematical model to solve the technological and planning decision optimization problem for Air Cargo Terminal is presented in the article. The algorithm of the multicriterion Air Cargo Terminal parametrization problem solution has been formulated.*

Keywords: Air Cargo Terminal, economic and mathematical model, optimality criteria, optimization, technical and technological parameters.

1. Introduction

Aviation is one of the most important branches of the national economy, the effective functioning of which is an integral condition for stabilization, structural changes, development and carrying out foreign economic activity, satisfying population and social production transportations needs and protection of national interests of Ukraine.

Naturally, it is hard to overestimate air transport place in logistics and cargo delivery due to its obvious advantages: speed; wide geography; high reliability and safety of cargo deliveries; permanent control over cargo transportation.

2. Problem statement

All productive indices of aviation transport in the field of cargo transportations have stable tendency to growth year after year both in Ukraine and in the whole world. This fact illustrates the necessity of updating existing and constructing new Air Cargo Terminals for creating land servicing system of air cargo transportations, cargo processing and their further delivery to a final receiver.

At the same time, taking into account the present day technical level, technologies, economics and reliability, the importance of capital investments effectiveness is growing, as unreasonable technological and planning decisions can lead to considerable losses both in the course of constructing new installations and reconstructing those in operation.

Besides, along with the tendency of technological processes development, dealing with cargo processing in Air Cargo Terminals, there exists not only more complicated organization principle, increasing investments into construction works,

but also the necessity to decrease the probability of delays and failures in work.

These specific circumstances determine the necessity of creating economic and mathematical models of complicated technological processes going on in Air Cargo Terminals in order to check their proposed technological and planning decisions and thus obtain optimal ones at designing and operation stages, due to changing initial parameters of the system.

3. The analysis of the latest publications and researches

Theoretical and methodological bases of the research consist in the logistic and systematic approach to the investigation of processes, occurred during production organization in transport systems. Research-and-development activities of foreign and Ukrainian researchers on market economy problems, logistics, chain supply management, namely works of W. Cook (1998), W.H. Cunningham (1998), W.R. Pulleyblank (1998), A. Schrijver (1998), O.V. Goncharuk (1991), O.A. Lashchenykh (2006), O.F. Kuzkin (2006), E.S. Ventsel (1998), A.A. Smekhov (1998), M. Yannakakis (1997), have been used in the research. However, all these investigations do not take into account the systematic character of air goods traffic management, peculiarities of handling and storage different types of goods in an airport. The models created earlier don't include huge amount of criteria, reflecting quality of loading-unloading fronts and warehouses work in an airport.

Lack of system research, done by domestic and foreign scientists in the field of Air Cargo Terminal technological and planning decision optimization,

proves the necessity of generalization of theoretical and practical experience in this field and creation multicriterion model of an Air Cargo Terminal technological and planning decision optimization.

4. Multicriterion economic and mathematical model

Multicriterion economic and mathematical model, which gives the possibility to describe, with sufficient accuracy, ground cargo processing and select optimal variant of Air Cargo Terminal technological and planning decision with minimal costs is used and expressed mathematically in finding minimum of function of several variables.

Taking into account the necessity to create a model, which characterizes peculiarities of different types of cargo processing and storage as well as a great number of criteria, reflecting the quality of Air Cargo Terminals work in the conditions of market economy, the optimization problem is solved in two stages.

At the first stage, are considered parameters, which are characteristic for different cargos as well as criteria, performing functions of standards. At the second stage, the multitude of optimized parameters is expanded and new criteria are entered into the model, characterizing the process of functioning Air Cargo Terminals for specific cargos.

Thus, the task is to determine such values of Air Cargo Terminals technical and technological parameters $Z_H, T_H, t_{sav}, H_H, B_{warh}$, which provide the best criteria combination.

Here, Z_H is a number of loading-unloading machines; T_H is time of loading-unloading front and warehouse work during 24 hours; t_{sav} is the term of cargo being kept in warehouse; H_H is a number of tiers for storage; B_{warh} is warehouse width, etc.

The principle of Air Cargo Terminals location and parameterization foresees successive solution of the following tasks:

1. Characteristic of existing dimensions, cargo flows, and other parameters of external environment.
2. Making decision about Air Cargo Terminal technological and planning outline.
3. Financial analysis of each variant of Air Cargo Terminal designing decision.
4. Determination of current costs:

$$E_{CT} = \sum_{i=1}^t \sum_{r=1}^v E_{xy} + T_{xy},$$

where E_{xy} – current costs for Air Cargo Terminal at x variant of its location and y -one of its type;

$x=1, i \dots, t$ and $y=1, r \dots v$ – a number of Air Cargo Terminal location variants and cargo complexes types correspondently;

T_{xy} – annual transport costs at Air Cargo Terminal x variant of location and y – one type of cargo complex.

5. Creation of the multicriterion economic and mathematical model of Air Cargo Terminal, which includes optimized parameters $x, y \in \bar{a}$.

6. Determining the multitude of permissible values of parameters \bar{a} , including x, y .

7. Calculation of the optimal values of the parameter \bar{a} .

The principles of Air Cargo Terminals economic and mathematical modeling can be formulated in the following way:

1. Formation of the multitude of optimality criteria \bar{F} , which are the most important during decision making for modeled Air Cargo Terminals: terminal capacity; staying time of transport means; fuel and energy consumption; labor productivity; capital investments yield; prime cost; current costs; operational reliability; other criteria.

2. Determination of the optimality criteria \bar{F} statuses: criteria belongings; criteria constraints.

3. Determination of the multitude of optimized parameters \bar{a} , term of cargo storing, number of loading-unloading machines, number of storing tiers, warehouse width etc.

4. Determination of the multitude of permissible values \bar{a}_{per} .

5. Synthesis of the aim functions $\bar{F}(\bar{a}, \bar{b})$ and criteria constraints $\bar{\Phi}(\bar{a}, \bar{b})$.

6. Realization of the method of multicriteria optimality.

7. Outputting optimal values of parameters \bar{a}_{opt} .

At the first stage, the economic and mathematical model contains vector of optimality criteria and looks as follows:

$$F = \{F_1, F_2, \dots, F_8\},$$

where F_1 – transport means staying time at the zone of loading-unloading operations;

F_2 – prime cost of cargo processing in the zone of loading-unloading operations;

F_3 – capacity of terminal front, which considers quantity and type (productivity) of loading-unloading machines;

F_4 – capacity of terminal front, which considers volume of cargo storage area;

F_5 – consumption of electric energy, connected with loading-unloading machines operation as well as illumination of cargo storage area and cargo fronts;

F_6 – fuel consumption;

F_7 – number of workers, who provide loading-unloading works;

F_8 – capital investments yield.

Let's consider the structure of criterion F_1 , taking as an example vehicle staying time in the link of cargo operations. This period of time consists of waiting for beginning cargo operations, time to be provided with transport delivery and time proper for loading-unloading operations. Knowing the character of incoming cargo flow and servicing time distribution law, the criterion F_1 will have the following view:

$$F_1 = \frac{k_1 \left[\frac{k_2}{(Z_H k_3 - k_4) X_H} + k_5 \right]}{Z_H \left(1 - \frac{k_6}{Z_H} \right)} + k_7 X_H + \frac{k_8}{Z_H (k_3 - k_4)},$$

where

$$k_1 = Q_d k_d;$$

$$k_2 = Q_d k_d (v_{LR}^2 + v_R^2);$$

$$k_3 = q;$$

$$k_4 = \frac{Q_d}{T_a};$$

$$k_5 = H_H q_a (v_{LR}^2 + v_R^2);$$

$$k_6 = \frac{Q_d k_d}{q T_H};$$

$$k_7 = \left(t_1 + \frac{2L_{cf}}{V_m} \right);$$

$$k_8 = \frac{Q_d}{X_H},$$

where T_a – time of autoconveyor work during 24 hours;

t_1 – time for delivery, which doesn't depend on the length of cargo front, but depends upon the plan

of Air Cargo Terminal road development as well as storage area and cargo front location, hours;

L_{cf} – length of cargo front, m;

V_m – average maneuvering speed near the cargo front, km/hour;

X_H – number of trucks deliveries to the cargo front.

Prime cost of cargo processing F_2 depends upon costs, connected with performance of initial and final operations. In general view:

$$F_2 = \frac{E}{Q_{an}^{pr}},$$

where E – annual operational costs, UAH;

Q_{an}^{pr} – annual volume of cargo processing, t.

The value E includes costs on wages C_{wg} , power and lighting energy C_e , fuel C_f . Operational costs for Air Cargo Terminal, which provides loading-unloading operations and cargo storage, depend on such rule-proclaiming parameters as $Z_H, T_H, t_{sav}, H_H, B_{warh}$ etc.

It is rational to represent criteria F_3, F_4 in the following manner:

$$F_3 = \frac{T_H Q_d}{\left\{ \left[\frac{k_1}{X_H (Z k_3 - k_4)} \right] + k_7 \right\} X_H}, \frac{t}{day},$$

$$F_4 = \frac{F_{warh} k_{CT} H_H k_{res}^F}{f t_{savh} (1 - a_n)}, \frac{t}{day},$$

where F_{warh} – the warehouse area, m²;

k_{CT} – a coefficient of the warehouse area utilization;

k_{res}^F – a reserve standard of the warehouse area;

f – an area, occupied by one unit of cargo;

a_n – an overloading factor.

The criterion, expressing electric energy consumption F_5 can be presented in the following way:

$$F_5 = C_{LRM}(Q_d, Z_H) + C_{ligh}(Q_d, t_{savh}, H_H, T_H),$$

where C_{LRM} – costs of power electric energy of loading-unloading machines;

C_{ligh} – costs of lighting electric energy.

The criterion F_6 , expressing fuel consumption, can be presented as follows:

$$F_6 = \frac{365 k_1 (2 - a_n) k_9}{k_3},$$

$$k_9 = N_{en} \eta_{en} [k_i + (k_n - k_i) \eta_{en}],$$

where N_{en} – total power of loading-unloading machine engine, kVt;

η_{en} – an engine utilization coefficient according to its power;

k_n, k_i – specific fuel consumption per 1 kVt of nominal power per 1 year at normal loading and idle operation, kg/kVt/hour;

The criterion F_7 , expressing number of workers, handling loading-unloading machine, can be found according to the formula:

$$F_7 = Z_H \left[r \frac{T}{t_{sh}} + H_{rep} \right],$$

where r – number of workers of a certain profession, handling a loading-unloading machine one shift;

t_{sh} – duration of a working shift, hours;

H_{rep} – normative number of workers, employed in repairing (maintenance).

The criterion, which expresses yield of capital investments F_8 can be presented by the following ratio:

$$F_8 = \frac{Q_{an}^{pr}}{A_{bas}}$$

or

$$F_8 = \frac{P}{A_{bas}},$$

where A_{bas} – annual costs of basic assets, UAH;

P – an enterprise profit, UAH.

The value A_{bas} in Air Cargo Terminal, which provides cargo processing and storage, depends on rule-proclaiming parameters $Z_H, T_H, t_{sav}, H_H, B_{warh}$ i.e.

$$A_{bas} = f(Z_H, T_H, t_{sav}, H_H, B_{warh}).$$

At the second stage, the economic and mathematical model of parameters optimization contains optimality criteria vector, which looks as:

$$\bar{F}_{CT} = \{F_{CT1}, F_{CT2}, F_{CT3}\},$$

where F_{CT1} – current costs on Air Cargo Terminal creation and functioning, thousands of UAH;

F_{CT2} – a coefficient of loading-unloading machines utilization to time during 24 hours;

F_{CT3} – consumption of metals and materials for racks as well as carrying and lifting equipment, t.

Total current costs are determined according to the formula:

$$F_{CT1} = \sum_{i=1}^{18} C_i,$$

where C_i – i -th component of current costs, $i=1, \dots, 18$;

C_1 – current costs of loading-unloading machines taking into account normative coefficient of capital investments E_n ;

C_2 – current costs, connected with structures, communications, driveways operation;

C_3 – current costs, connected with construction of open areas;

C_4 – current costs for racks;

C_5 – current costs for carrying and lifting machines, working inside a terminal;

C_6 – costs, connected with trucks standing idle during loading-unloading operation;

C_7 – costs, connected with aircraft standing idle during loading-unloading operation;

C_8, C_9 – costs, connected with waiting for cargo handling operations by aircraft and trucks correspondently;

C_{10} – costs for delivery and removing aircraft;

C_{11} – costs of wages of workers, employed to service loading-unloading machines;

C_{12} – costs for power electric energy for loading-unloading machines;

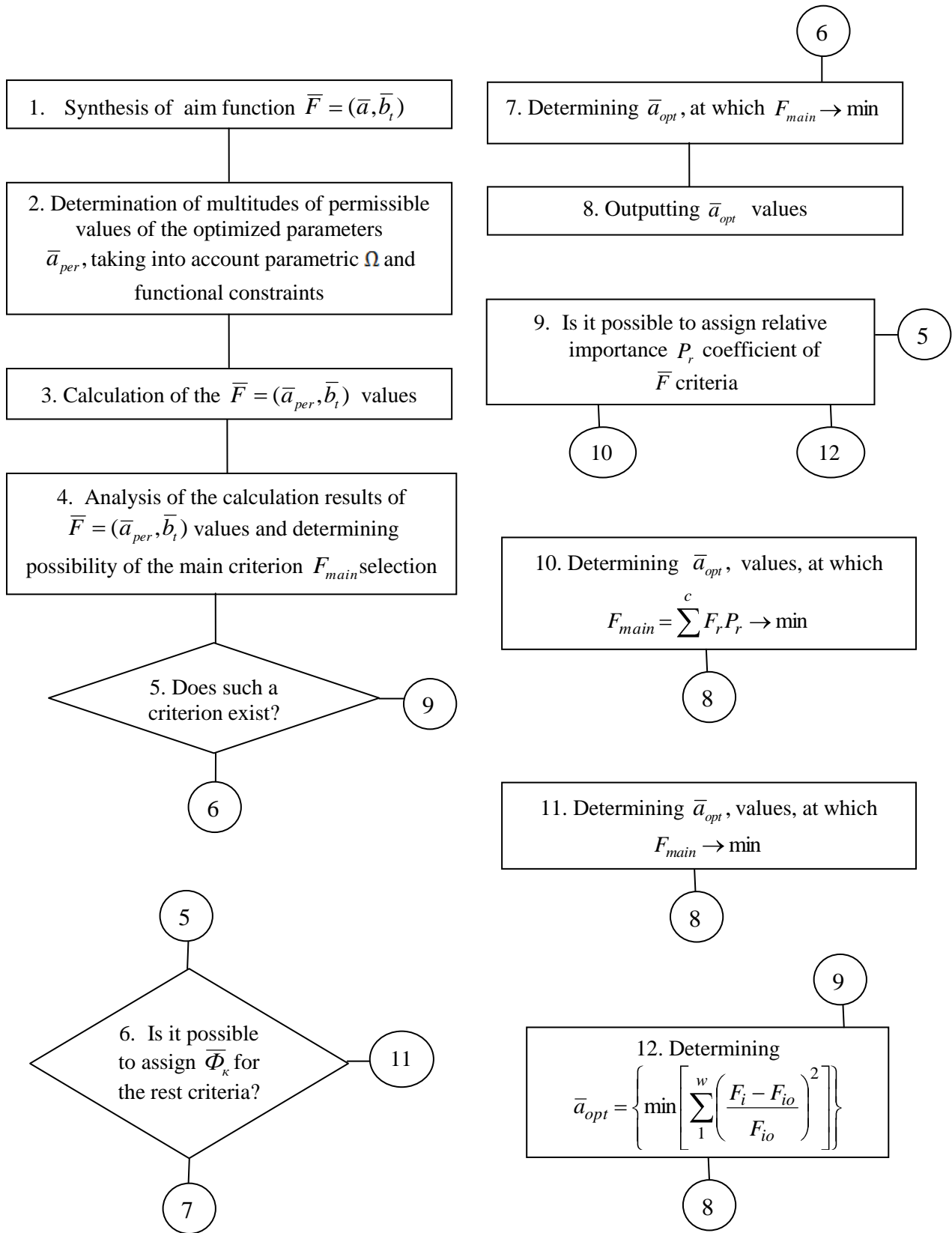
C_{13} – costs for cargo fronts and storage areas lighting;

C_{14} – costs for warehouse pallets, used for cargo processing at cargo front and storage area;

C_{15} – current costs for storage buildings;

C_{16} – current costs for charging station in case of electric loader usage;

C_{17} – costs, connected with mileage, travelled by trucks about Air Cargo Terminal;



Algorithm of solving the multicriterion problem of Air Cargo Terminal parameterization

C_{18} – costs for heating premises in case of heated warehouses.

They are recruited according to the established wage rates depending upon kind of works.

The criterion F_{CT2} , which expresses loading-unloading machines utilization with regard to time during 24 hours, is determined according to the formula:

$$F_{CT2} = \frac{Q_d(2 - \alpha_n)K_d K_d^a}{ZqT}.$$

The criterion F_{CT3} , which expresses consumption of deficit metals and materials for racks and carrying and lifting equipment is determined according to the formula:

$$F_{CT3} = Q_d \frac{1}{n_c} K_{res} t_{savh} (1 - \alpha_n) m_c + Z m_{LRM},$$

where m_c – an amount of metal, spent for one rack cell, t;

m_{LRM} – an amount of metal (material), spent on a unit of carrying and lifting equipment, t.

In a general case, multitude A_n of permissible values of the optimized parameters vector represents a closed region or a sum total of closed regions in m -dimensional of parameters space, which consists of A points with Cartesian coordinates $A = (a_1, \dots, a_m)$, specified by the following constraints:

- parametric: $a_j^* < a_j < a_j^{**}, j=1, \dots, m;$
- functional: $G_g^* < f_g(\bar{a}, \bar{b}) < G_g^{**}, g=1, \dots, m;$
- criteria: $\Phi(\bar{a}, \bar{b}) < \Phi_v^{**}, v=1, \dots, k,$

where a^*, a^{**}, G^*, G^{**} – values, expressing application field of Air Cargo Terminal optimizing parameters and resources, assigned for its development;

Φ_v^{**} – criterion constraints, determined during the process of problem solving.

5. Algorithm of the multicriterion problem solving

The algorithm of the multicriterion problem of Air Cargo Terminal parameterization includes successive decision of the tasks, presented in the Figure.

6. Conclusions

1. The multicriterion economic and mathematical model of Air Cargo Terminal has been developed, which includes optimality criteria,

characterizing Air Cargo Terminal functioning quality, technical equipment and operation technology and considers the volume of investments, assigned for its technical infrastructure development.

2. Methodology of optimal Air Cargo Terminals technical and technological parameters determination has been improved, which gives the possibility to determine simultaneously a variant of terminal complex arrangement taking into account its type, number of loading-unloading machines, working hours during 24 hours, the term of cargo storage in a warehouse.

3. Two-level algorithm has been formulated for Air Cargo Terminals optimization, which includes interactive man-machine calculation procedure of Air Cargo Terminal technological parameters according to the multicriterion model.

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В.Ю. Іваннікова. Багатокритеріальна модель оптимізації технологічного-планувального рішення вантажного комплексу аеропорту

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Наведено принципи економіко-математичного моделювання складних технологічних процесів, які протікають у вантажних комплексах аеропортів, щоб, змінюючи вхідні параметри системи, перевіряти технологічно-планувальні рішення, які висувуються, та отримувати оптимальні на етапах проектування та експлуатації для ефективного використання капітальних вкладень під час будівництва аеропортів. Розроблено багатокритеріальну економіко-математичну модель для розв'язання задачі оптимізації технологічно-планувального рішення всього вантажного комплексу аеропорту, яка включає критерії оптимальності, що характеризують якість функціонування, технічне обладнання і технологію роботи комплексу, та враховує розмір інвестицій, які виділяються на розвиток його технічної інфраструктури. Сформульовано дворівневий алгоритм рішення багатокритеріальної задачі параметризації вантажного комплексу аеропорту.

Ключові слова: вантажний комплекс аеропорту, економіко-математична модель, критерії оптимальності, оптимізація, техніко-технологічні параметри.

В.Ю. Иванникова. Многокритериальная модель оптимизации технологического-планировочного решения грузового комплекса аэропорта

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Приведены принципы экономико-математического моделирования сложных технологических процессов в грузовых комплексах аэропортов, позволяющие, изменяя входящие параметры системы, проверять технологическо-планировочные решения и получать оптимальные на этапах проектирования и эксплуатации для эффективного использования капитальных вложений при строительстве аэропортов. Разработана многокритериальная экономико-математическая модель для решения задачи оптимизации технологического-планировочного решения всего грузового комплекса аэропорта, которая включает критерии оптимальности, характеризующие качество функционирования, техническое оборудование и технологию работы комплекса, учитывает размер инвестиций, выделяемых на развитие его технической инфраструктуры. Сформулирован двухуровневый алгоритм решения многокритериальной задачи параметризации грузового комплекса аэропорта.

Ключевые слова: грузовой комплекс аэропорта, критерии оптимальности, оптимизация, технико-технологические параметры, экономико-математическая модель.

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