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OVERVIEW OF AVIATION AIRPORT INFRASTRUCTURE IN THE SYSTEM OF ENSURING SECURITY PROCEDURES AT THE AIRPORT

Introduction and formulation of the problem

According to expert forecasts, the global aviation infrastructure market will grow from USD 24,87 billion in 2023 to USD 92,84 billion by 2030, with a compound annual growth rate (CAGR) of 17,9 % over the forecast period. Airport infrastructure modernization significantly enhances the efficiency of airport operations while ensuring all procedures necessary for travel are in place.

According to data analyzed from the ICAO [1] report on the assessment of risks to improve global aviation safety, Figure 1 presents the forecast of the aviation infrastructure market for the period from 2023 to 2030.

The specification of the resources utilized by the airport, along with the outcomes of its operations, represents a critical stage in evaluating airport efficiency, as illustrated in Fig. 1.



Fig. 1. Forecast of the aviation infrastructure market for 2023–2030

Together with telecommunications, air transport represents the sectors that epitomize globalization in an economic as well as in a sociopolitical sense worldwide

This suggests that formulating and implementing optimal air transport policies constitutes a critical component of effective strategies for economic development and poverty reduction.

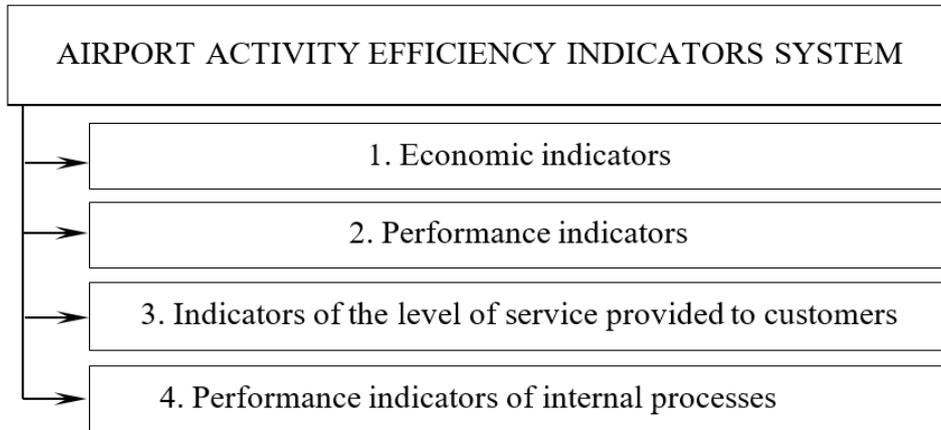


Fig. 2. System of airport performance indicators [2]

Analysis of recent research and publications

A number of scientific publications have been devoted to the issues of safety and the development of the air transportation market, in which the nature, structure, and global development trends of this market have been explored. In particular, study [3] examines the role of global strategic alliances in shaping the international air transportation market, which has made it possible to substantiate the strategic advantages of international cooperation for Ukrainian air transport enterprises during wartime and in the post-war period.

The authors of study [4] have the assessment of the each component awareness level of the «aircraft – automatic control system – crew – environment – special situation» system regarding possible risks and threats caused by their activities has been improved. It is proposed to consider the «illegal interference act «as a component in this system, namely: «aircraft – automatic control system – crew – environment – illegal interference act – special situation». The dynamics of IIA types for the years 2020–2022 were analyzed and it was found that today there are much fewer such events and this indicates proper regulation to prevent similar acts of illegal interference.

The issue of aviation security system analysis is addressed in studies [5] and [6], where the feasibility of integrating technical and organizational measures into a unified system based on a comprehensive approach is substantiated.

The issue of aviation security system analysis is examined in [5] and [6], where the feasibility of integrating technical and organizational measures into a unified system based on a comprehensive approach is substantiated. A comparative analysis of the share of different modes of transport in the overall

passenger traffic during the period of Ukraine's independence has been conducted, leading to conclusions on the prevailing trends in the development of air transport. (It should be emphasized that the findings presented pertain to the period before the onset of 2022).

In scientific publication [7], the performance of Central European airports is analyzed. It is worth noting that Ukraine demonstrated the highest growth rate in passenger traffic.

Given the above, it should be emphasized that safety and quality of service represent fundamental components in the implementation of air passenger transportation.

The purpose of this work an analysis of the «SAFETY-QUALITY» model to identify subjective negative impacts on air passengers aimed at enhancing airport service quality.

Presentation of the main material and substantiation of the obtained research results

Aviation services and aviation activities associated with the appropriate level of safety and service is achieved under the condition compliance with all technical safety standards in the provision of air transport services. Key indicators of aviation safety are compliance with standards for aircraft registration and maintenance, pilot training and advanced training, certification of aircraft operators, airport infrastructure standards, certification of air traffic controllers, air navigation equipment.

The aviation airport infrastructure market must ensure efficient and safe air transportation. Globally, both the volume of air passenger traffic at airports and the number of aircraft are increasing every year. This, in turn, affects the congestion levels at airport terminals.

The corresponding segment of aviation enterprises, namely airports worldwide, requires modernization. It is forecasted that the modernization of aviation airport infrastructure will be a key driver of global market growth over the next decade.

Specifically, the implementation of advanced technologies, including artificial intelligence, in aviation airport infrastructure will lead to increased passenger and cargo transportation volumes, positively impacting global market turnover. It is important to note that air transport plays a crucial role in economic relations, influencing both microeconomic and macroeconomic indicators.

The present day is characterized by clear conditions of global competition, and a modern, well-developed aviation enterprise infrastructure, particularly airports, has become one of the factors that can enhance a nation's economic growth and provide opportunities for gaining competitive advantages in the global market.

One of the most prominent trends in the evolution of global aviation infrastructure is the systematic expansion of airport capacity to address the continuous growth in passenger and cargo traffic. Leading hub airports in strategic aviation markets - such as the United States, China, and the Middle East – are undertaking large-scale development projects aimed at enhancing terminal infrastructure, increasing runway throughput, and expanding aircraft apron areas.

Another critical dimension of aviation infrastructure development is the incorporation of sustainable practices and environmentally responsible technologies. Airports and airlines are increasingly investing in energy-efficient construction, the deployment of renewable energy systems, and the adoption of low-impact operational procedures. These initiatives are designed to reduce carbon emissions, conserve natural resources, and contribute to broader climate change mitigation efforts. Examples include the installation of solar photovoltaic panels, LED lighting systems, and high-efficiency HVAC (heating, ventilation, and air conditioning) technologies aimed at lowering overall energy consumption and minimizing greenhouse gas output.

Strategic investments in the modernization and expansion of airport infrastructure enable countries to address the increasing demands of the aviation transportation sector while simultaneously enhancing their competitiveness in the global market.

Amid the rise of global security threats, particularly terrorism, airports are increasingly tasked with ensuring the safety of millions of passengers annually. While conventional security measures – such as metal detectors and baggage scanners – remain effective, they are often perceived as insufficient in meeting contemporary expectations for

both safety and efficiency. In response, airports are progressively adopting advanced technologies, including biometric identification systems and artificial intelligence, to enhance screening procedures and streamline the passenger security experience.

Furthermore, the integration of the Internet of Things (IoT) into airport infrastructure is reshaping multiple facets of airport operations, including passenger services, security protocols, and overall operational efficiency. With the continual advancement of sensor technologies and data analytics, IoT applications are expected to expand significantly. Airports that embrace this digital transformation will be better equipped to adapt to the dynamic and evolving demands of the global aviation industry.

The main goal of the measures being implemented to improve airport infrastructure is to assess the operations of a specific aviation enterprise – the airport.

The organizational and infrastructural discrepancies between different airports are so significant that attempting to make comparisons is difficult and carries certain risks. Accordingly, the managers of individual airport services need to be aware that specific areas of responsibility are being evaluated. This helps eliminate potential objections regarding who should take control and corrective actions if the assessment system indicates the necessity for such measures.

Maintaining a clear and seamless operation of the airport with high passenger volumes is quite challenging, especially if there is a likelihood of limited resources and technological capabilities.

It is important to note that effective planning and maximum utilization of existing resources are fundamental to the quality and profitability of airport operations. Key infrastructure resources of airports include aircraft parking spaces, gates, check-in counters, baggage claim carousels, and chutes

The implementation of a resource management system is crucial for the effective use of airport resources and for ensuring smooth airport operations. Key benefits of a resource management system include:

- Optimization of resource utilization;
- Reduction of operational costs;
- Increase in airport revenues;
- Enhancement of airport capacity;
- Improvement in punctuality, reliability, and passenger satisfaction;
- Identification of potential bottlenecks;
- Creation of new profit opportunities based on timing. [8]

Ground handling at the airport, resource planning, and optimal utilization of labor and equipment are some strategies for cost reduction, especially for airlines and ground handling teams. Limitations in airport capacity and on-ground resources play a crucial role in delays of scheduled flights, leading to dissatisfied customers and increased costs for airlines. [9]

It is important to note that the airport's capacity largely depends on the physical capabilities of the service personnel involved at this stage of operations.

The refore, it is essential to improve the management of resources and to distribute the available power to all essential processes in an optimal manner. To investigate possible solutions without influencing daily operations of the airport, mathematical models or simulations may be used. [10]

The next decade is expected to be characterized by effective approaches to managing airport operations, making it essential to analyze all aspects. The aviation transportation industry belongs to the service segment with intense competition; therefore, the analysis and study of airport management are beneficial both for users of air transportation and for the aviation enterprises themselves in order to enhance their competitiveness.

The most important characteristics that maximize the efficiency of an airport are the number of passenger movements and the number of low-cost aircraft movements. This shows that, other things being equal, an airport with more low-cost movements is more efficient than an airport with fewer low-cost movements and more movements with traditional carriers. [11]

The air transport sector market has moved towards more competitive contexts, characterized by high competition between multiple carriers, with a constant growth in transport demand which has consequently brought about the need for better infrastructures supporting the system. [12]

According to the classic definition, airport infrastructure is the use of available resources to maximize the volume of services provided. It (airport infrastructure) is more standard, but has its own peculiarities.

Airport terminals are important hubs of the global transportation network, managing internal and external flights as well as connecting flights and their corresponding passenger flows. The continuous growth and development of the aviation industry, as well as geopolitical crises and extreme weather conditions, make airport terminals necessary in order to provide passengers with a safe, efficient and successful travel experience [13]. To cope with the complex environment of airport terminals, various crowd management strategies have been developed to streamline processes and provide passenger-friendly design [14].

Since the specification of the resources used and the results of airport operations are heterogeneous, researchers choose the most optimal approach in terms of the study. The theoretical framework for evaluating efficiency includes a wide range of

methods, each with its own strengths and weaknesses. Scientific approaches to assessing airport performance include both calculations based on simple linear indicators and the use of complex models with production boundaries. The simplest approach to evaluating airport efficiency is calculating the relationship between the performance indicators of the selected airport and the resources used. Considering that no two airports are the same (even if they are similar in terms of categories, design, and service processes), finding criteria for efficiency is a challenging task. Therefore, it is reasonable to measure airport efficiency using parameters such as PROCESS/TIME.

Safety and security in the aviation sector of passenger transport are top priorities for all elements and resources involved at the airport.

When a passenger undertakes air travel, they go through a series of routine actions, including security screening procedures, which may take some additional time.

Therefore, the patterns of changes in the parameters of the process of forming the level of aviation security during service at the airport are the basis of the presentation of some elements of the author's scientific research.

The constructed mathematical model «SAFETY-QUALITY» reflects the dynamics of the flow of passengers through airport procedures and allows calculating the dynamic allocation of airport resources to perform inspection procedures both during normal operation of the airport and when operating under threat conditions.

Passenger flows are time-varying. As a rule, changes are considered with a discrete step. Note that in the materials of IATA [15], steps of 10, 15, 20 minutes are used in the formulas for calculating the required amount of equipment, areas, and specialists. The main flow at the airport is, as a rule, the flow of passengers. This flow is constantly changing both during the day and during the week, month, year. It depends on the schedule, number of flights, types of aircraft used, season, demand for air transportation. The specified flows are connected by equality [16]:

$$F(t) = F_r(t) + F_p(t) + F_d(t) + F(t)_{v1} + F(t)_{v2} + F(t)_{v3}. \quad (1)$$

The ratio between flows depends on the throughput of the procedures.

Passage of all procedures by passengers of one flight can be shown on a common scheme (Fig. 4) [16].

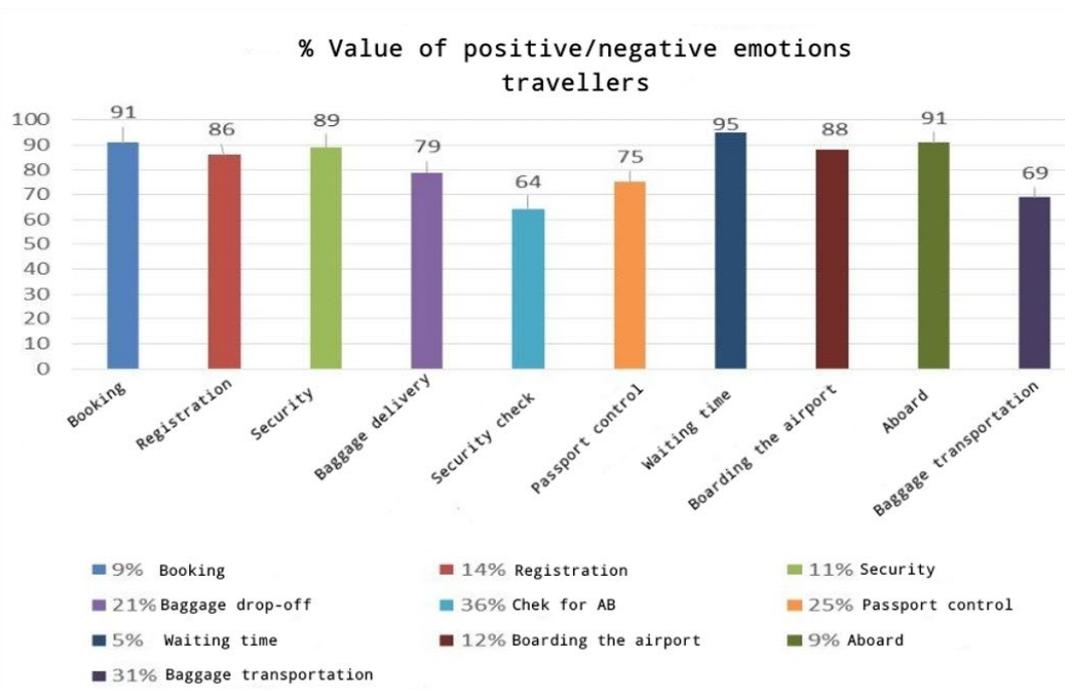


Fig. 3. Meaning of positive/negative emotions of travelers [2]

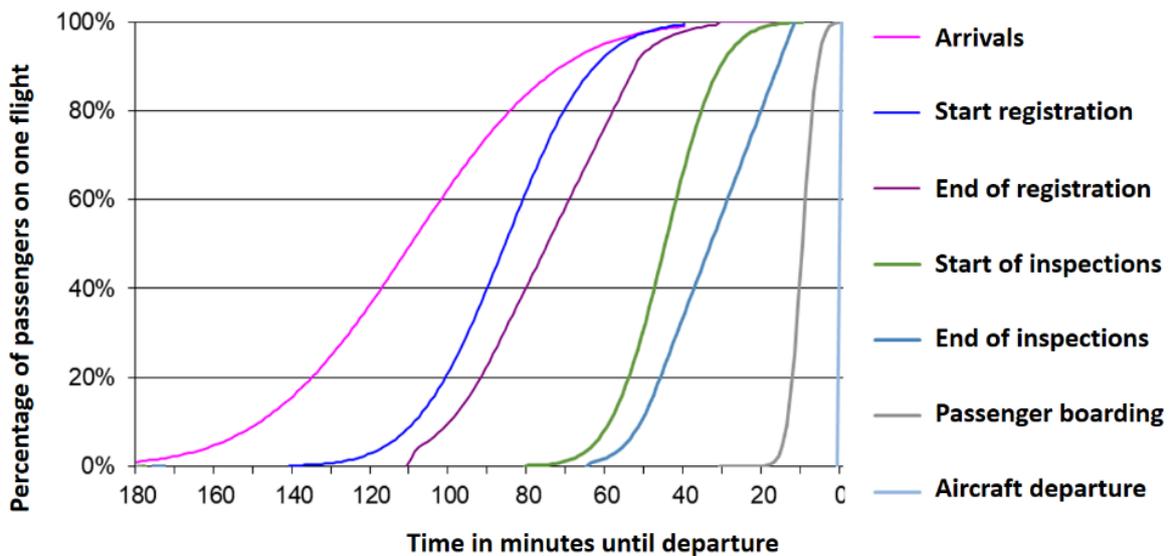


Fig. 4. Schedules of finding passengers of one flight at the airport before departure. Source: built by the author, model calculations

The curves representing passengers going through the procedures are listed from left to right. As mentioned above, the horizontal cross-section shows how the time is distributed at the airport for passengers of a specific percentage [16].

The curves representing passengers going through the procedures are listed from left to right. As mentioned above, the horizontal cross-section shows how the time is distributed at the airport for passengers of a specific percentage $F(t)_{v1}, F_r(t), F(t)_{v2}, F_p(t), F(t)_{v3}, F_d(t)$.

A mathematical model can be used to consider different questions and obtain different estimates [16].

First of all, we will consider the issue of passenger service quality and, as mentioned above, one of the quality criteria is the speed of passing checks. This question can be formulated as follows: what are the conditions of the threats $\zeta \in Z_T$ on a time period T under the expected scenarios of its implementation $\sigma \in \Theta_T$ choose protection scenarios $\delta \in D_\sigma$ and how to distribute the existing resources of aviation events and which additional resources to attract, so that the

average time of passengers passing checks and waiting in queues is minimal within the limits of possible time.

To answer the question, you need to calculate the average time $\Delta\tau_{\delta}^0$ passing checks by passengers and waiting in queues. It is calculated as the total time spent by all passengers divided by the number of all passengers, namely [16]:

$$\Delta\tau_{\delta}^0 = \frac{\sum_{j \in J} \sum_{c \in C} \sum_{j\delta t \in T} H_{jt}^c \Delta t \sum_{j \in J} \sum_{c \in C} N_j \Delta\tau_j^c}{\sum_{j \in J} N_j}. \quad (2)$$

An assessment of the impact of security measures on the time intervals during which a passenger passes mandatory procedures at the airport, which depend on the behavior of passengers and on the capacity of airport processes, which in turn depend on the selected security measures and the allocated available and additional airport resources, is developed.

Conclusions and prospects for further research

The main priority of the airport's operation is to ensure flight safety.

The authors of the article consider the «SAFETY-QUALITY» model. The basis for the analysis is the efficiency of the airport's operation under normal conditions and in conditions of potential danger. Accordingly, this requires comprehensive planning of all technological stages of the airport's operation.

Calculations using the «SAFETY-QUALITY» model show that an increase in the duration of passenger security checks can lead to several subjectively negative consequences for passengers.

If it becomes necessary to introduce additional security measures that will be in effect for a long time and will apply to all flights, then, accordingly, there is an effect of accumulating a deficit of resources of all airport services and increasing the delay of all subsequent flights. The authors analyzed the assessment of the impact of security measures on the time intervals during which a passenger undergoes mandatory procedures at the airport. It is worth noting that all proposed additional airport resources directly depend on the time intervals and airport throughput.

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ОГЛЯД АВІАЦІЙНОЇ ІНФРАСТРУКТУРИ АЕРОПОРТУ В СИСТЕМІ ЗАБЕЗПЕЧЕННЯ ПРОЦЕДУР БЕЗПЕКИ В АЕРОПОРТУ

В роботі розглянуто модель «БЕЗПЕКА-ЯКІСТЬ» з точки зору ефективності роботи аеропорту. Оцінка ефективності роботи аеропорту базується на розрахунках на основі простих лінійних показників і на використанні більш складних моделей з конкретними параметрами, які мають чіткі обмеження.

В результаті аналізу та досліджень побудовано математичну модель «БЕЗПЕКА-ЯКІСТЬ», яка відображає повну динаміку пасажиропотоку через призму всіх технологічних процедур аеропорту та дозволяє розраховувати динамічний розподіл наявних ресурсів аеропорту для виконання всіх передбачених процедур інспекції як під час нормальної роботи аеропорту, так і під час роботи в умовах небезпеки.

Наукові підходи до оцінки ефективності аеропорту включають як розрахунки на основі простих лінійних показників, так і використання складних моделей з встановленими чіткими виробничими обмеженнями.

Проаналізовано оцінку впливу заходів безпеки на часові інтервали, протягом яких пасажир проходить необхідні процедури в аеропорту, які прямо залежать від дій пасажирів та від пропускнуої здатності аеропорту

Інфраструктура аеропорту є фундаментальним компонентом авіаційного сектору, пропонуючи основні засоби та послуги, необхідні для забезпечення ефективної, безперебійної роботи та задовільної якості авіапасажирських перевезень. Підтримка авіаційних операцій вимагає комплексного планування, проектування, будівництва та обслуговування широкого спектру фізичних активів, що доповнюється інтеграцією передових технологій та систем. У цих рамках питання безпеки залишаються першочерговими для всіх технологічних елементів та операційних ресурсів в середовищі аеропорту.

Аналіз моделі «БЕЗПЕКА-ЯКІСТЬ» показує, що збільшення часу, виділеного на процедури безпеки пасажирів, може призвести до кількох суб'єктивно сприйнятих негативних наслідків для пасажирів. Відповідно, впровадження додаткових заходів безпеки, які зазвичай вимагають певного часу та застосовуються до всіх рейсів, призводить до накопичення дефіциту ресурсів та збільшення затримок наступних рейсів.

Ключові слова: авіаційна безпека, авіаційний сервіс, аеропорт, системи аеропорту, безпека, авіаційна інфраструктура.

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The study examines the «SECURITY–QUALITY» model in the context of airport operational efficiency. The assessment of airport performance is based both on calculations using simple linear indicators and on the application of more sophisticated models with specific parameters and clearly defined constraints.

As a result of the analysis and research, a mathematical model of «SECURITY–QUALITY» has been developed. This model reflects the full dynamics of passenger flows through the lens of all technological procedures of the airport and enables the calculation of the dynamic allocation of available resources for performing all prescribed inspection procedures, both under normal operational conditions and in emergency situations.

Scientific approaches to evaluating airport efficiency include both calculations based on simple linear indicators and the use of complex models with clearly established operational constraints.

The study further analyzes the impact of security measures on the time intervals required for passengers to complete necessary airport procedures, which directly depend on passenger behavior and the throughput capacity of the airport.

Airport infrastructure is a fundamental component of the aviation sector, providing essential facilities and services required to ensure efficient and seamless operations as well as satisfactory quality of air passenger transportation.

Supporting aviation operations necessitates comprehensive planning, design, construction, and maintenance of a wide range of physical assets, complemented by the integration of advanced technologies and systems. Within this framework, security considerations remain a priority for all technological elements and operational resources within the airport environment.

Analysis of the «SECURITY–QUALITY» model demonstrates that increasing the time allocated to passenger security procedures may lead to several subjectively perceived negative consequences for travelers. Accordingly, the implementation of additional security measures - which generally require additional time and apply to all flights - results in resource deficits and increased delays in subsequent flight operations.

Keywords: aviation security, aviation service, airport, system of airport, safety, aviation infrastructure.

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