AN UNCONVENTIONAL APPROACH TO THE EVALUATION OF TECHNICAL INFORMATION SYSTEMS

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The article deals with the analysis of the design of technical information flows and the assessment of the reliability of Airport Information Systems (AIS). It presents mathematical approaches to modelling time differences, failure probabilities and the efficiency of airport processes. The approach is based on identifying connections between individual subsystems and assessing their impact on overall reliability. The presented method enables the maximum probability of AIS operating without failure to be estimated. At the same time, it determines the optimal distribution of financial investments in modernising these systems. The results suggest that reducing the failure rate requires targeted investment in electronic, security, and signalling systems, which form the core of each airport's critical infrastructure. The findings of this study could directly impact the significance of strategic decision-making in airport development and highlight the need to implement artificial intelligence in future optimisation processes.

KEYWORDS

Airport Information Systems (AIS), Process control Information Transfer Optimization, Reliability, Probability of airport systems

1 INTRODUCTION

The basic procedure that enables the reliable and safe operation of complex airport systems (CAS), as well as addressing their operational management, is situational management. The process of managing safe airport operations is divided into two stages:

- The planned procedure of the management process (organisational planning and security activities).
- Operational management of complex airport systems (i.e., operator activity).

Situational management of airport processes and monitoring of CAS reliability are carried out separately in terms of both time and space [Bozek 2021, Sedlackova 2024]. This approach is based on a set of hypotheses concerning the dynamics of the airport system within the aviation environment, where the entire process remains non-linear until the desired outcome is achieved. The preparatory phase results in a methodology and valid algorithms for controlling the airport process. When monitoring CAS reliability, selected evaluation criteria that influence the control process are applied, i.e., the choice of possible and assumed alternatives. These alternatives result from a series of continuous airport decision-making processes representing an adjusted strategy according to actual operating conditions (e.g., the seasonal flight situation at the airport) during periods of increased airport management. Setting the final goal and selecting criteria to assess the reliability of complex airport systems remains the exclusive domain of human decision-making. One example is the operational and security systems used in airport control. Activities for which there are currently no formal algorithms, such as repetitive activities like airport checks, are referred to as non-formalized [Catlos 2018]. This level of control involves achieving successful interventions based on systematic observation and monitoring by information technology systems. Airport-specific activities (e.g., airport security) include actions resulting from the specifics of a given situation (e.g., passenger checks) and new relationships between subjects and security situations. For example, a security situation can be resolved in two fundamentally different ways [Repko 2018, Pandova 2020, Panda 2020 & 2022, Harnicarova 2019, Sukhodub 2018 & 2019, Nahornyi 2022].

- Intuition, i.e., an unconscious assessment, usually has no basis in established procedures. However, the security operator relies on their own experience, which can be applied to solve significant problems [Kuric 2021].
- Reactive evaluation: this results from a given security situation and creates new possibilities for solutions that can subsequently be used in a priori conditions.

2 OPERATIONAL MANAGEMENT AND COORDINATION OF ACTIVITIES IN COMPLEX AIRPORT SYSTEMS

In operational management of complex airport systems, assumptions and hypotheses of specified activities with possible imperfections are continuously solved in real time, adapting to actual conditions. The operational management of complex airport systems is also based on the theory of decision-making processes of airport operators [Kierzkowski 2021]. Their management interventions, which are carried out for the purpose of optimisation and mainly relate to the decision-making process (or minimising errors), are almost impossible to optimise until completion. We can ensure the planned stratification of operational information management in airport systems by developing sets of alternative activities that cover all possible situations that may arise during management. In cases where it is necessary to solve the so-called map distribution system of management, outlined by an information-adaptive vector, the interplay between perception (sensors and partial subsystems) enables us to solve the prediction of activity at the airport (Fig. 1). Whether it is every activity at the airport or the security situation itself that is presented by a negative value, we can reduce every possible map situation by the gradient $\nabla.\vec{v}$ when some elements in perception fail [Labun 2017]. This strategy is useful for creating a replacement procedure, which typically has lower reliability, quality and economic parameters, but which still allows us to overcome periods of unsuccessful situations. Meanwhile, v(t) is an adaptive intervention in perception; if its divergence $\nabla.\vec{v}$ takes on negative values.

$$R(t) = exp\left(\int_0^t \lambda(s)ds\right) \qquad (1)$$

The safety map loses its information capacity, the hazard λ increases, and the probability of trouble-free operation, $R(t)$, decreases (1). Failure of individual sensors directly affects D(t), so the direct mapping of the state λ deteriorates (increasing it). As $\lambda(s)$ increases due to negative $\nabla.\vec{v}$, it causes perception $R(t)$ to fail exponentially. An important means of taking effective action is therefore to monitor the development of the vector using a situational management methodology that focuses on providing optimal coverage of a large set of dangerous situations with a small number of control algorithms (see Fig. 1).

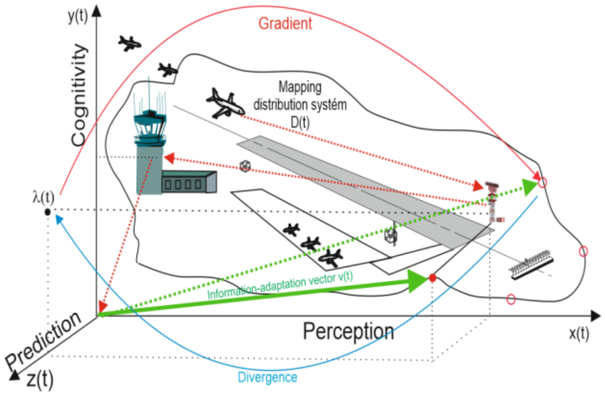

Figure 1. Triadic mapping distribution model

Such an approach to assessing the reliability of an airport system often includes the duration of the aggregate input activities and output quantities (indicators), as well as the aggregate control activities (CAS). The quality of an aviation system's performance can be evaluated as a tangible function determined by the sets $\{T, X, Y, \Omega\}$ under the condition that the control activity u in OIS changes the initial state (t_0, x_0) to the final state when the last point on the $x(t)$ axis is reached [Jakubisinova 2025]. To distribute the problem in the process of dynamic control of one exemplary system, Fig. 1 is translated into the states that form the basis for creating algorithms for evaluating airport systems (Fig. 2).

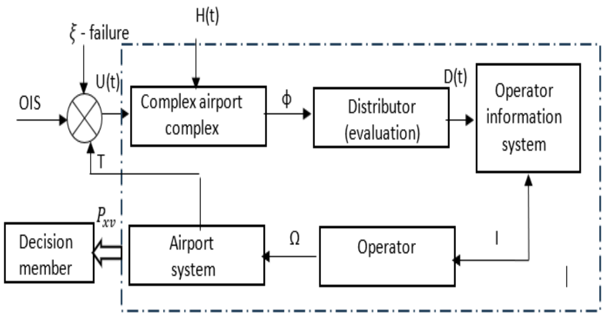

Figure 2. Dynamic control of an exemplary n-aircraft system in an airport complex

Legend: OIS – Operations Information Airport System - input reference quantity, Xi – failures, T – Technical system limitations for complex airport systems; $H(t)$ – environmental conditions; φ – output information about the system status; $D(H)$ - distributed evaluated data. Ω – output response from the airport system; Z – operator decisions; Bidirectional output I (information signal back to the operator).

$U(t) = OR\,(t) + Xi(t) + T(t)$ – The structure of the airport system from which the operator's feedback signal is derived is key for decision-making and the management of airport processes.

3 RESULTS

Evaluating the properties of random airport processes in CAS involves evaluating large sets of measurements taken on a given aviation system under the same conditions. The causes of random changes in individual measurement sets are independent of each other, resulting in different instantaneous values of the course. An example of different random processes can be found in the various fault states of airport systems. If we were to measure random variables, we would theoretically obtain an infinite record. Therefore, it is necessary to determine the final measurement time and repeat the measurements under the same conditions. Subsequently, it is possible to create a graphical presentation of the results obtained [Vargas-Cuentas 2015].

The statistical model used to forecast the reliability of the airport system accepts the results of physical measurements, which are given in the form of the vector $x = [x_1; \ldots; x_5;]$, and the values of the probabilities (P_{XV}) were determined by calculation (see Fig. 3). The forecast model was designed using the regression method. Information for creating the model was drawn from Kosice Airport's internal databases, which included:

1. Airport take-off and landing systems.
2. Airport logistics systems.
3. Passenger security control systems;
4. Airport control management systems.
5. Airport material, information and transport processes.

A calculation of row linear matrices was performed using the known x coordinates (perception), the calculated P_{XV} coordinates and the measured outputs (the rows of the matrix presented the probability distribution at the observed time) [Kurdel 2023]. The individual matrices are defined as follows:

x_1: reliability of airport systems.

x_2 – the a priori probability of the number of passengers.

x_3: Probability of reliability of control authorities.

x_4: probability of the product of the aircraft preparation τ –operators and random failures during aircraft preparation;

x_5: probability of random failures.

P_{XV} – already defined airport reliability probability, airport constant.

After adjustment, we obtain the probability of CAS errors in punctual airport operations (Fig. 3) [Labun 2017 & 2021].

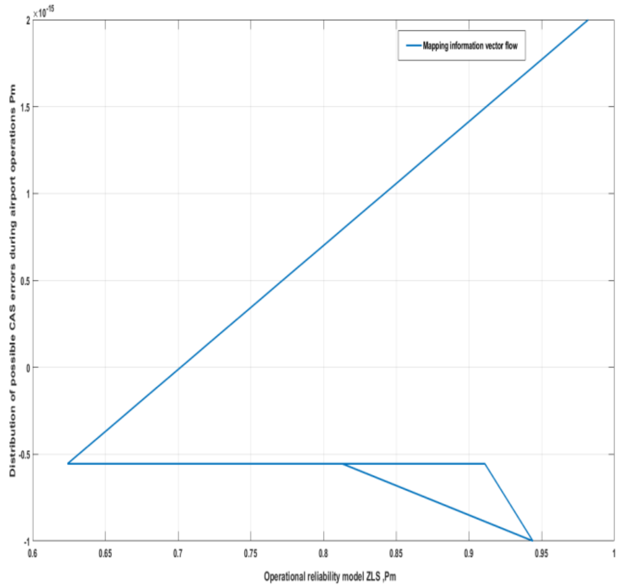

Figure 3. Probability of CAS errors in time-critical airport operations

The reliability of airport systems can be increased and ensured (through backup) by improving the quality of information obtained by the airport in real time. Given the volume of information intended for managing airport systems, it is possible to predict the reliability of individual subsystems. It is also clear that reliability is affected by random input failures. Reliability is also limited by airport conditions, the period over which the airport information system is used, and the technology supporting its long-term operation. Increasing the reliability of airport systems is crucial for ensuring effective airport operation and passenger protection. These systems and the technologies that support them are constantly exposed to random influences, such as power outages, technical failures and human error. It is therefore important that airport management and the legal authorities invest in modernising and maintaining information systems.

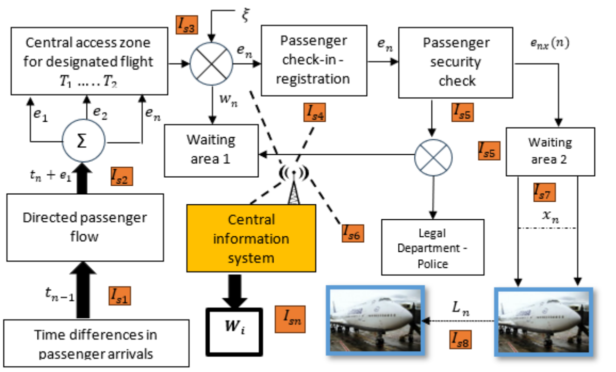

Figure 4. The recurrent exchange of information is used to monitor the efficiency of aircraft handling

To correctly evaluate and classify AIS, it is necessary to consider the number of mutual information links at the airport, as shown in Fig. 4. It is important to understand that the central information system generates information according to a specified weight for each AIS. This must be expressed mathematically; otherwise, it cannot be used to model complex systems. Therefore, in most of our expressions, we present the time unit t_n and the Euler expression $e_{\ n}$ to express the ongoing course of the AIS in the form of information or weight (i.e. a sequence of decision processes). To this end, we present a mathematical expression for total passenger processing time in the form of time distributions.

$$C_n = [t_n(1 - t_n] + (t_n + e_n) + T_n + e_{nx}(n) + (e_n x_n) \quad (2)$$

The reliability, cost and efficiency of an airport are expressed as the probability that an aircraft will depart on time:

$$R = P_0(C_n \le D) \quad (3)$$

Where:

R - this is the probability that the aircraft will depart on time.

P_0 - is the reliability of the monitored airport system;

C_n - this is the total time required for passenger and aircraft check-in.

D - is the maximum allowable time limit before terminating airport processes with deviations.

The airport in Kosice, which has medium technical awareness, has 25 airport information systems (AIS) connected in series. The failure probabilities $v_i$and the total cost C_{IS} of these systems are known. The prices of the i^{th} AIS components will enable the k_1 and k_2 coefficients to be calculated, with the aim of determining the maximum achievable probability of the AIS operating without failure and its optimal distribution among the airport system's elements (4).

$$P_S = \prod_{i=1}^{N} (1 - q_i) \quad (4)$$

The need for a model of price reciprocity and technological advances that increase the reliability of P_S systems can be illustrated by the requirement to modernise the complex electronic system that indicates and signals dangerous situations at airports.

By adjusting relation (4), it is possible to obtain the resulting probability of airport pricing options being concentrated with respect to the parameters of the aviation system. As these parameters degrade over time, it is possible to determine the likely repair or replacement costs (5) in advance with a certain degree of accuracy.

$$log_{10} C_S = log_{10} \left(k_{1i} \left(\frac{P_S}{vik_{1i}\, k_{2i}} \right)^{\frac{k_{2i}}{1+k_{2i}}} \right) \quad (5)$$

Cs - resulting quantity (probability concentration of the price of a sub-component of the system),

Ps - value from the previous expression;

v - parameter $v_{\ i}$estimation of AIS work;

log10Cs = [1.9430 2.2305 2.3933 1.8700 2.6746 2.3010 0.9620 0.5895 2.7492];

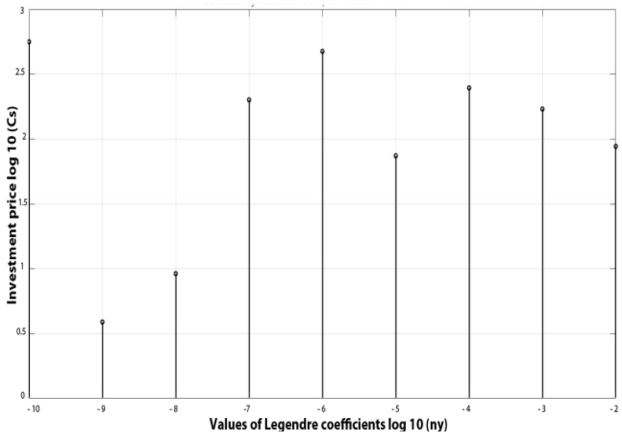

Figure 5. The Estimated cost of investment in AIS

The total price of the information system (C_{IS}) can be expressed in relation to the required reliability of the AIS as follows:

$$C_{IS} = \prod_{i=1}^{N} \left(k_{1i} \left(\frac{P_S}{v_i k_{1i} k_{2i}} \right)^{\frac{k_{2i}}{1+k_{2i}}} \right) \quad (6)$$

The output is a graphical representation of the probability of fault-free operation and associated costs for airport information systems (see Fig. 6).

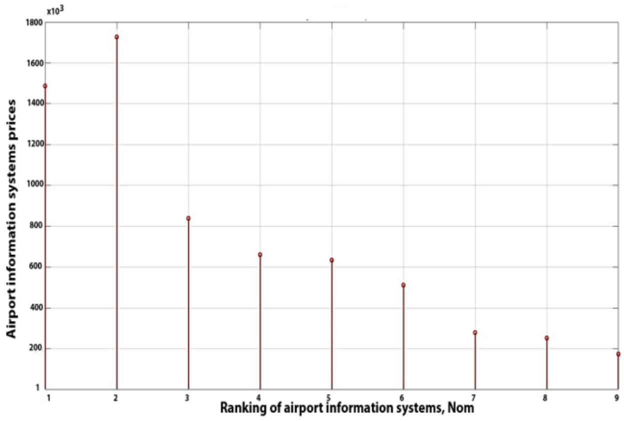

Figure 6. The Price distribution for reduced AIS failure rate

CONCLUSION

The method has its limitations, as it is still not possible to reliably obtain absolute values of information characteristics. Nevertheless, it enables designers and airport operators to develop relatively accurate solutions when adopting new technologies, such as AI. Currently, the presented method has no basis in aviation legislation and is not covered by standards for the introduction of AI in aviation. However, it forms part of operational analyses to support the overall management of airport operations, so safety remains the only criterion for its application [Panda 2014 & 2021]. Based on the analysis and modelling of airport information systems (AIS), several key findings were made that were essential for effectively managing and optimising Kosice Airport's operations.

The maximum achievable probability of the information system (AIS) at Kosice airport operating without failure was calculated based on the failure probabilities of individual components and their interconnected functions. The results showed that, to achieve the required level of reliability, the AIS will require modernisation and investment in new information technologies in the foreseeable future. Calculating and comparing the required and current AIS failure probabilities revealed a significant discrepancy, indicating a substantial need for improvement in the reliability of airport information systems.

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