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ASSESSMENT OF AIRSIDE AERODROME INFRASTRUCTURE BY SAW METHOD WITH WEIGHTS FROM SHANNON'S INTERVAL ENTROPY

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Abstract:

Multi-criteria decision support (MCDM) methods are widely used in many areas of science. This applies to economic, social and technical sciences. Implementing activities at the strategic, tactical or operational level requires appropriate tools to support decision-makers. The use of these tools requires the preparation of a decision model along with the formalization of the goal and the acquisition and preparation of data to make the decision accurate. Due to the wide application of MCDM in engineering practice, the article presents their application in air transport. It is an area that is constantly evolving, and all decisions at the strategic level have long-term effects and must be adequately justified. In the paper a compartmental extension of the classical SAW method with weights obtained using the compartmental Shannon entropy was proposed.

This paper presents issues concerning the choice of airport layout and describes the problems that occur in determining the cost and capacity of airports. This paper reviews the literature on airport capacity and operations and airside air transport processes and the application of various multi-criteria decision support methods to airport problems. The main part of the article contains an optimization mathematical model aimed at determining the parameters of the elements comprising the airport, on the basis of which a simulation model was developed and a modified method of multi-criteria evaluation of SAW taking into account the interval numbers was presented, in which the set of weights was estimated by the Shannon entropy method. In the application part for 3 variants of the airport arrangement, the parameters were determined in the form of interval numbers and then evaluated using the presented method. The presented numerical example shows that the proposed method is an excellent tool to assist in solving complex decision problems where the data are imprecise and represented by interval numbers.

Keywords: *entropy, aerodrome infrastructure, SAW*

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1. Introduction

1.1. Current situation of air transport

The growing demand for passenger and cargo transportation by air has resulted in an increase in the number of aircraft operations, especially at major passenger airports. In the passenger flight segment, there is a noticeable correlation between the number of passengers carried and the GDP level of the world's major economies. It is estimated that the growth rate of air transport is several percent higher than the economic growth rate. Between 2010 and 2019, there was a noticeable nearly 3-fold increase in the number of passengers (1.764 trillion in 2000 to 4.397 in 2019 (World Development Indicators Database). At the same time, the number of passengers in Poland doubled. Although not on such a scale, but also noticeable is the increase in the number of transported loads, in the world and in Poland the volume of work done by air transport has doubled World Development Indicators Database). The article does not include the data from 2020 as they are not reliable due to the SARS-Cov 2019 pandemic.

As air transportation expands and the number of flight operations increases, the de-sired structure / architecture of airports is changing. The appearance of current airports has evolved from modestly equipped field airstrips to intercontinental hub with dozens of flight operations per hour. With modern navigation equipment, procedures, knowledge and skills of aviation service personnel and modern aircraft designs, today's airports are increasingly independent of weather conditions. Thus, airport infrastructure is currently the main capacity limiting factor. Airports are increasingly becoming the bottleneck of the air transportation network. The main ways to increase their capacity include the expansion and modernization of airport infrastructure in general, and aircraft ground handling in particular.

Airport capacity is the results of the capacity of the passenger handling system (terminal processes) and the capacity of the aircraft handling system on the apron. These volumes result from: number of passengers, number and types of aircraft, and airport location (geographic location, temperatures, etc.).

The primary factors affecting airport capacity are:

– the number and performance characteristics of the maneuvering area and apron structure elements,
– navigation instrumentation category,
– efficiency of ATC services in terms of praxeological efficiency and established procedures of airport traffic,
– aircraft fleet.
– weather conditions and flight rules (VFR or IFR).

The optimum (taking into account forecasts) number of aircraft landings and take-offs in specific infrastructure conditions is the basic parameter that determines the scope of airports expansion with new taxiways, runways and aircraft parking areas.

(1) The forecasts prepared for the European Commission conclude the following for air transport (EC): European airports face challenges due to limited capacity and quality.
(2) Air traffic in Europe will almost double by 2030. Europe will not be able to meet much of the demand due to limited airport capacity.
(3) Five major European hubs - Düsseldorf, Frankfurt, London (Gatwick and Heathrow airports), and Milan (Linate) - are operating at maximum capacity (according to Euro-control data), and by 2030, 19 major airports in Europe are projected to reach similar loads.
(4) **Airport throughput capacity needs to be optimized.**
(5) **Service quality and efficiency at airports need improvement. 70% of all delays are caused by problems at the point where the aircraft is parked at the airport.**
(6) The quality of ground handling services is not commensurate with needs, in particular in terms of reliability and resilience as well as safety and security. Increased coordination of ground operations by European airports and the network as a whole (due to the chain effect) is needed to ensure continuity of airport operations.

According to the authors of the article, the current situation related to the COVID-19 pandemic will not affect the 2030 projections. When a vaccine is invented and a large portion of the population is vaccinated, the demand for flights will increase dramatically. Just as after the crisis of 2008 and the collapse of container sea freight, after 2 years the volume increased to its previous level.

Effective implementation of airport operations requires proper selection of infrastructure necessary for the tasks performed at the airport. The rational operation of an airport requires large investments in infrastructure and significant shares of fixed costs in the total cost of maintaining it. This is due to the fact that regardless of the amount of air traffic the airport must maintain (usually 24 hours a day) full readiness to handle landing and taking off aircraft (PL-4444, 2017). There are many aspects to consider when deciding to invest in infrastructure, both economic and technical-technological, as well as environmental. In summary, the issue of airport infrastructure selection is a complex decision-making problem. Therefore, decisions should be based on a sound evaluation of multiple criteria.

The authors presented a proprietary approach to evaluating airport infrastructure siting options using the SAW method. This approach has not been presented in the literature be-fore. The purpose of this paper is to present the feasibility of the SAW method with fixed weights used as a decision support in the choice of a variant and selection of the type of airport equipment. The first section provides a critical analysis in the research area de-scribed. The authors of the paper then presented the proprietary decision-making model AIRSAW which includes all the important elements in the optimization of airport infrastructure. The essence of the AIRSAW method was also pointed out. The article assumes that the decision on the choice of the variant of shaping the airport infrastructure is made in two stages. In the first stage, a set of criteria values for evaluation of infrastructure alter-natives was determined and boundary conditions were set. Data for aviation calculations both in terms of demand for flights and costs associated with the purchase or modernization or construction of infrastructure elements is very often unavailable or given as estimates, so in the study range numbers were used to determine them. An additional problem with all infrastructure decisions is the estimation of weights for each. On the other hand, the evaluation of the proposed alternatives was made using a multi-criterion modified SAW method taking into account the interval numbers, while the set of weights was estimated using Shanon's entropy method.

1.2. Aerodrome infrastructure

Taking into account the systemic approach, an airport can be considered as a set of infrastructural equipment with facilities, control and traffic control systems and organization necessary to perform the tasks resulting from the take-offs and landings schedule. The airport area can be divided into two parts: the maneuvering field and the station area.

The basic elements of airport infrastructure are:
- runways (nowadays mostly concrete or asphalt),
- taxiways - intended for the movement of aircraft after a landing operation or before a take-off operation,
- aprons - places where passenger handling, loading or unloading of baggage, mail or airfreight takes place. Aircraft parking areas are divided into remote and contact - directly connected to the terminal building by passenger platforms (sleeves). The number and configuration of parking spaces affects the ground capacity of the airport.
- navigation infrastructure (flight control tower, navigation lighting, radar, etc.)
- terminal for passenger service.

Figure 1 shows the airport as a transformation of input streams into output streams.

Airport capacity results from the capacity of the airside (handling take-offs, landings, taxiing, and ground handling operations), the capacity of the landside (handling travellers and baggage in the passenger terminal), and the capacity constraints of the transportation system connecting the airport to the metropolitan area it serves. In this paper, 3 different variants of airside area design are proposed, and then multi-criteria evaluation is per-formed.

2. Literature review

Due to the research problem presented by the authors, it is necessary to review the literature in two aspects, namely:

(1) Airport throughput capacity and operations and airside air transport processes.
(2) Applications of various multi-criteria decision support (MCDM) methods to airport problems.

The literature on the analysis and evaluation of parameters in the airside area of air-ports is extensive. It mainly deals with methods and tools for organizing and evaluating airport traffic. Researchers focus on airport design and airport traffic management problems for existing airports (Gołda, 2018). Aircraft taxiing on the tarmac is extensively represented. Atkin et al. in their paper (Atkin et al., 2010) present previous research conducted in the area of ground operations at airports. The basic problems of organizing the process of taxiing aircraft on the tarmac included: minimizing the delay times resulting from congestion on maneuvering areas, reducing the time of succession of landing and takeoff operations through proper planning of aircraft sequences and

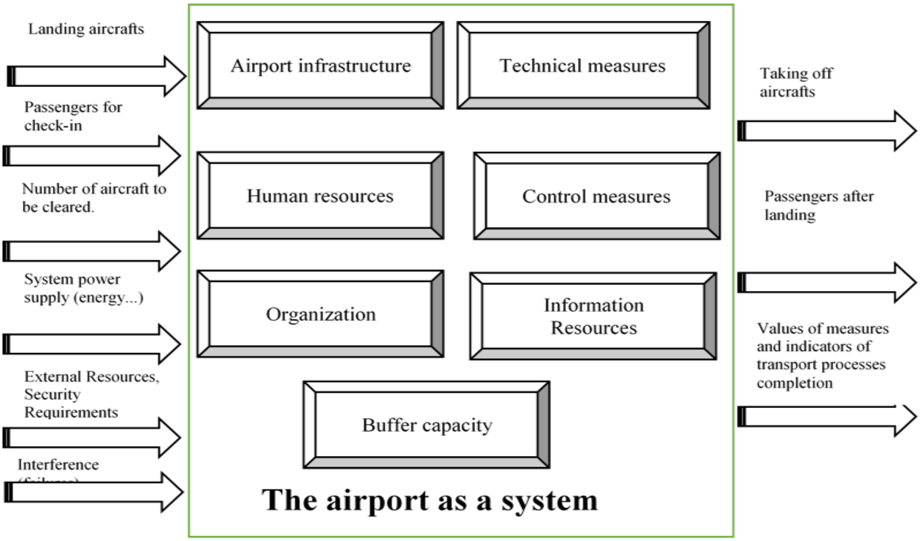

Fig. 1. The airport as a system and its environment

routes of movement, thereby increasing the efficiency of the airport, minimizing the negative impact of air transport on the environment. Similarly, Gołda et al. (Gołda et al., 2019) presented a holistic description of the airport infra-structure along with a decision model for aircraft positioning on the tarmac.

Montoya J. et al. (Montoya et al., 2011) present a detailed analysis of the emissions of harmful exhaust components during successive phases of aircraft taxiing operations. Environmental impact of airports is analyzed by many authors. Quite detailed and original approaches to the analysis of, among others, noise is presented by Wasiak et al. in their paper (Wasiak et al., 2020). Likewise, environmental pollution caused by means of transportation, including air transportation, is the subject of many researchers (Pyza et al., 2018, Jacyna et al., 2017).

Gotteland et al. (Gotteland et al., 2001) discuss the issue of ground traffic optimization using Charles de Gaulle Airport as an example. They noted that ground operations at such a busy airport are a critical factor in airport efficiency. They propose an optimization task that minimizes the time it takes for an aircraft to travel between gates and the runway taking into account the separation (time and distance) and the maximum number of takeoff and landing operations possible on the runways. The structure of the airport is represented by a graph. The task is solved using the genetic algorithm and the A* strategy: 1-to-n for an established aircraft flight plan. The correctness of the solution algorithms is verified using simulations on real data.

A rather interesting account of the use of genetic algorithms to solve decision models of aircraft operations was presented by Kowalski et al. in the paper (Kowalski et al., 2021). Solutions to decision problems using hybrid evolutionary algorithms applied to other areas of transportation e.g. (Izdebski et al., 2020, Jacyna et al., 2018, Jacyna-Gołda et al., 2018) can be applied to decision models relating to airport infra-structure optimization.

An important issue analyzed by many researchers is the risk of process execution in complex systems (Gołda, Zieja, 2015), flight safety (Zieja et al., 2015a, 2015b, 2015c) and uncertainty of information (Jacyna, Semenov, 2020).

The decision regarding the selection of a shaping option should lead to the selection of an option that should ensure the satisfaction of as many criteria as possible that realize the requirements of the decision maker. Most often, in a single decision-making process, we must accomplish multiple tasks often conflicting with each other. The solution of such problems is provided by the Multiple Criteria Decision Making (MCDM), which is used in various areas of transport (Tsamboulas et al., 2007, Sahaia et al., 2016, Cieśla et al., 2020). The first papers on MCDM appeared in the 1950s.

Multi-criteria decision support tasks depending on the situation are deterministic, stochastic or fuzzy. In each case, however, the goal is to select the option that best fits the decision maker's preferences and to rank the options (Jacyna, Wasiak, 2015). Multicriteria methods can be of different types: additive (e.g. SAW, F-SAW, SMART, SMARTER), analytic prioritization methods (e.g. AHP, REMBRANDT, F-AHP, ANP, F-ANP, MACBETH), verbal methods (e.g. ZAPROS, ZAPROS III), ELECTRE family methods (Gomes, Lima, 1992), PROMETHEE family methods, EXPROM, EXPROM II+weto, EXPROM II+weto+SD) (Brans et al., 1984), preference point methods (e.g. TOPSIS, F-TOPSIS, VIKOR, DEMATEL+ANP+VIKOR, BI-POLAR, modified BIPOLAR, BIPOLAR+SD), interactive methods (e.g. STEM-DPR, INSDECM, ATO-DPR) (Trzaskalik, 2014). Due to the variety of multi-criteria methods, the issue of selecting a multi-criteria decision support method is itself a multi-criteria problem. The starting point in these methods is to define a set of decision alternatives and a set of criteria, and to represent the decision problem by a decision matrix consisting of the ratings of the decision alternatives against the criteria, and a vector of weights determining the importance of each criterion.

The choice of the MCDM method to be used is sometimes determined by the availability of data as Dožić and Kalić point out (Dožić, Kalić, 2018). More specifically, some techniques require specific data; some require pairwise comparisons of data, while others can deal with imprecise data or imprecise pairwise comparisons. In the paper by Baltazar, et al. (Baltazar et al., 2014) based on three airports and a time horizon of several years developed predictive models for forecasting performance given traditional metrics and new constraints. The authors compared the evolution of port performance using the (Measuring Attractiveness by a Categorical Based Evaluation Technique) MACBETH approach, which showed promise compared to the (Data Envelopment Analysis) DEA approach considered as a traditional approach.

Shojaei et al. (Shojaei et al., 2018) based on airport data, presents a new model for airport performance evaluation and ranking using the integration of Taguchi loss functions, BWM's Best-Worst Method technique, and VIKOR. The VIKOR method as one of the MCDM methods is a method used to make complex decisions in situations with incommensurable and conflicting criteria, where there may not be a solution that satisfies all criteria simultaneously (Opricovic, Tzeng, 2007). The proposed model allows decision makers to set different target values and consumer tolerance thresholds for each criterion based on the ranking of airports in the country and reduce the number of pairwise comparisons using BWM. Zietsman and Vanderschuren (Zietsman, Vanderschuren, 2014), use Analytic Hierarchy Process (AHP) to evaluate airport development. The authors propose adding an additional airport served by this primary one. Transportation aspects include criteria related to airport characteristics, airport accessibility and airport capacity, while environmental protection is a very important issue today. For an airport to be sustainable, it is necessary to consider urban planning/land use as well as economic aspects that include all cost and investment data.

The current philosophy and trends indicating that airports are to function as self-sustaining service organizations providing efficient and quality services to a variety of customers cannot be ignored (Bezerra, Gomes, 2016). Liou et al. in a study (Liou et al., 2018) used the Decision-making Trial and Evaluation Laboratory's (DEMATEL) multi-criteria decision-making model (Decision-making Analytical Network Process, DANP, and VIKOR) to examine key factors for successful aerotropolis construction. They used an analytical network process based on a decision and evaluation laboratory to construct complex system and influential weights. A modified VIKOR method was then used to examine the gaps between the ambition levels and the current situation. In addition, considering the uncertainty of the decision maker, fuzzy theory was incorporated into the model. A different approach was used by Del Chiappa at al. (Del Chiappa at al., 2016) using the TOPSIS method and applying the fuzzy number approach to an under-researched research area related to (food and beverage services) F&B. The method used, in addition to qualitative values, provides useful information for airport managers about the functions of food services, which are the most important in shaping consumer satisfaction, also due to their age. Method (MCDM) using SIM cards by which passenger perception and expectation are measured on linguistic-numeric Likert-type scales, requires a significant increase in survey length and can sometimes result in an insufficient difference in service dimension scores (Lupo, 2015). Besides, large international airports are in intense competition to maximize their share of the growing non-aviation revenues, which has empowered them to enhance their perception of service quality and customer satisfaction to lure their customers and maintain their competitive advantage (Merkert, George, 2015, Pantouvakis, Renzi, 2015).

Multi-criteria decision support methods are extremely important for investment rationalization. Multifacetedness is a feature of investment projects in all areas of transport e.g. location (Izdebski et al. 2018), construction (Cartenì et al., 2018) or those related to the design of airport infrastructure. The number of classes of criteria for evaluating airport infrastructure investments can be very large, but the most common classes will include technical (e.g., safety, efficiency, reliability, flexibility), economic (inputs, maintenance costs, necessary accompanying investments), environmental, as well as socioeconomic, legal, and other aspects specific to the problem. The classes of criteria are divided into sub-criteria with different weights, nature, variability and impact on the evaluation of the decision option, which in this case mainly boil down to reducing taxi time and increasing the number of take-off and landing operations per unit time.

One of the problems occurring during the application of multi-criteria decision support methods is the use of subjectively determined weights in them, as a result of which the final assessment is also subject to the error of subjectivity. One method for determining objective weights is the entropy-based method. This paper uses a modified method proposed by Lotfi and Fallahnejad (Lotfi, Fallahnejad, 2010). The problem analyzed in this paper uses the SAW method, which reduces the need to define weights in favor of interval estimation and linguistic methods (Kacprzak, 2018). Żak et al. (Żak et al., 2019) have applied the method to evaluate the location of logistics facilities. The combination of the compartmental SAW method with objective weights obtained using compartmental entropy is the basis for the evaluation of airport infrastructure in this paper.

3. AIRSAW method

3.1. SAW method with weights from Shannon's interval entropy

In their proprietary method, the authors use the concept of interval numbers, which are one of the ways of describing and presenting imprecise and uncertain data with which we deal with data related to capacity and cost issues at airports. The closed interval number is defined as follows (Moore et al., 2009):

$$[x] = [\underline{x}, \overline{x}] = \{a \in \boldsymbol{R} :\ \underline{x} \le a \le \overline{x}\} \tag{1}$$

The interval SAW method with objective weights determined by interval Shannon entropy consists of 6 steps namely:

(1) Define a set of variants $\boldsymbol{I}$ ($i \in \boldsymbol{I}$) and a set of criteria $\boldsymbol{J}$ ($j \in \boldsymbol{J}$).

(2) Represent the option ratings for each criterion as an interval decision matrix:

$$\boldsymbol{X} = \left[[\boldsymbol{x}_{ij}] : \boldsymbol{i} \in \boldsymbol{I},\ \boldsymbol{j} \in \boldsymbol{J}\right] \tag{2}$$

(3) Normalization of the interval decision matrix,

$$\mathbf{N} = \left[[\underline{n}_{ij}, \overline{n}_{ij}] :\ i \in \boldsymbol{I},\ j \in \boldsymbol{J}\right]$$

when the *j-th* criterion is a stimulant:

$$\begin{cases} \underline{n}_{ij} = \underline{x}_{ij} / k \\ \overline{n}_{ij} = \overline{x}_{ij} / k \end{cases} \tag{3}$$

where $k = \sum_{i \in \boldsymbol{I}} \left(\underline{x}_{ij} + \overline{x}_{ij}\right)$

when *the j-th* criterion is a destimulant:

$$\begin{cases} \underline{n}_{ij} = 1 / \left(\underline{x}_{ij} \cdot l\right) \\ \overline{n}_{ij} = 1 / \left(\overline{x}_{ij} \cdot l\right) \end{cases} \tag{4}$$

where $l = \sum_{i \in I} \left(\left(\underline{x}_{ij}\right)^{-1} + \left(\overline{x}_{ij}\right)^{-1}\right)$

(4) Determination of objective weights consisting of:

a) Determine the entropy vector for each criterion:

$$\mathbf{e} = \left[[\underline{e}_j, \overline{e}_j] : j \in \boldsymbol{J}\right]$$

where:

$$\underline{e}_j = \min \left\{ \begin{array}{l} -\left(\ln \overline{I}\right)^{-1} \sum_{i \in I} \left(\underline{n}_{ij} \cdot ln\underline{n}_{ij}\right), \\ -\left(\ln \overline{I}\right)^{-1} \sum_{i \in I} \left(\overline{n}_{ij} \cdot ln\overline{n}_{ij}\right) \end{array} \right\} \tag{5}$$

$$\bar{e}_j = \max\left\{ \begin{aligned} &-\left(\ln \bar{I}\right)^{-1}\sum_{i\in I}\left(\underline{n}_{ij}\cdot ln\underline{n}_{ij}\right), \\ &-\left(\ln \bar{I}\right)^{-1}\sum_{i\in I}\left(\bar{n}_{ij}\cdot ln\bar{n}_{ij}\right) \end{aligned} \right\} \tag{6}$$

b) Determination of the criterion variation level vector:

$$\boldsymbol{d} = \left[\left[\underline{d}_j, \bar{d}_j\right] : \underline{d}_j = 1 - \bar{e}_j, \bar{d}_j = 1 - \underline{e}_j, j \in \boldsymbol{J}\right] \tag{7}$$

c) Determination of the vector of objective weights:

$$\mathbf{w} = \left[\left[\underline{w}_j, \bar{w}_j\right]:\ j \in \boldsymbol{J}\right] = \left[\left[\frac{\underline{d}_{ij}}{\sum_{j\in J}\left(\underline{d}_{ij} + \bar{d}_{ij}\right)}, \frac{\bar{d}_{ij}}{\sum_{j\in J}\left(\underline{d}_{ij} + \bar{d}_{ij}\right)}\right]:\ j \in \boldsymbol{J}\right] \tag{8}$$

(5) Determination of the linear combination of normalized scores against the criteria and the vector of weights for the variants.

$$\boldsymbol{SAW}\left(\boldsymbol{O}_i\right) = \sum_{j\in \boldsymbol{J}}\left[\underline{\boldsymbol{n}}_{ij}, \bar{\boldsymbol{n}}_{ij}\right]\cdot\left[\underline{\boldsymbol{w}}_j, \bar{\boldsymbol{w}}_j\right] \tag{9}$$

(6) Linear ordering of the results and selection of the final option. For comparison of the results obtained, the solution intervals $\boldsymbol{O_i}$ will be written in an alternative form i.e.

$$\boldsymbol{O}_i = \boldsymbol{c}\left(\boldsymbol{O}_i\right),\ \ \boldsymbol{r}\left(\boldsymbol{O}_i\right).$$

where:

$\boldsymbol{c}\left(\boldsymbol{O}_i\right) -$ middle of interval

$\boldsymbol{O}_i$, and $\boldsymbol{r}\left(\boldsymbol{O}_i\right)$ radius od the interval $\boldsymbol{O_i}$

then

$$\boldsymbol{O}_i \preceq \boldsymbol{O}_{i'} \Leftrightarrow \begin{cases} \boldsymbol{c}\left(\boldsymbol{O}_i\right) < \boldsymbol{c}\left(\boldsymbol{O}_{i'}\right) & if \quad \boldsymbol{c}\left(\boldsymbol{O}_i\right) \neq \boldsymbol{c}\left(\boldsymbol{O}_{i'}\right) \\ \boldsymbol{r}\left(\boldsymbol{O}_i\right) \geq \boldsymbol{r}\left(\boldsymbol{O}_{i'}\right) & if \quad \boldsymbol{c}\left(\boldsymbol{O}_i\right) = \boldsymbol{c}\left(\boldsymbol{O}_{i'}\right) \end{cases} \tag{10}$$

$$\boldsymbol{O}_i \prec \boldsymbol{O}_{i'} \Leftrightarrow \ \boldsymbol{O}_i \preceq \boldsymbol{O}_{i'} \wedge \boldsymbol{O}_i \neq \boldsymbol{O}_{i'}$$

3.2. Description of the decision problem

Analysing the selection of technological equipment of elements of airport systems for effective implementation of tasks, a fundamental problem is to determine both the number of elements and their load capacity in terms of tasks to be performed. It is assumed that all tasks submitted to the system in a given period must be completed. Determining the size of tasks for airports, including the necessary number of aircraft, organization of their movement depending on the number of take-offs and landings and the number of passengers handled determines the need for airport equipment in the number of runways or gates.

The calculation of the quantities concerning the capacity of aircraft service execution and the cost of aircraft service task execution was performed using a simulation program based on the formulated decision model.

Notations in problem model are given as follows:

Parameters

$\boldsymbol{A}$ - set of aircraft types operated at the airport,

a - aircraft type served, $a \in \boldsymbol{A}$

$\boldsymbol{I}$ - the set of infrastructure elements of an airport,

$\boldsymbol{A}(i)$ - the set of types of cargo streams handled at the i-th element,

$\boldsymbol{TU}(i)$ - the set of equipment types of the i-th airport equipment item,

$\tau(i, tu(i), a)$ - the service time for a-th type of aircraft by tu(i)-type of equipment i-th type of airport equipment,

$n(i, tu(i))$ - expenditures for the tu(i) -type of equipment of the i-th airport equipment item ,

$\varphi(i)$ - workload imbalance factor of the i-th piece of airport equipment,

ks(i, tu(i) - capital expenditures for tu(i)-th type of equipment and i-th piece of airport equipment, recalculated over the analysis period $\boldsymbol{T}$, and the fixed costs incurred over that period,

$kz(i, tu$(i), $a)$ - variable costs of operating tu(i) -th type of equipment i-th type of airport equipment converted per unit of aircraft a-th type,

p(i, j) - probability of transition between the i-th and j-th airport equipment item, $\boldsymbol{F_L} = \left\{p(i,j):\ p(i,j) \in \langle 0,1 \rangle,\ i, j \in \boldsymbol{I}\right\}$

$\boldsymbol{T}$ - the length of time (period) the airport is in operation,

$\boldsymbol{NI}$ - the maximum amount of investment in airports,

Decision variables

$x(i, tu(i))$ - the number of pieces of $tu(i)$ *-th* type of equipment *i-th* piece of equipment, *y(i, tu(i), a)* - load *tu(i) -th* type of equipment *i-th* type of aerodrome equipment for *a-th* type of aircraft

Objective Function

From the airport authority's perspective, the most important criteria for evaluating the quality of an aviation system are the cost criterion and the capacity criterion.

The criterion function *k1*(***Y***) throughput of aircraft service implementation takes the form:

k1(**Y**) =

$$\sum_{\boldsymbol{i}\in \boldsymbol{I}}\sum_{\boldsymbol{tu}(i)\in \boldsymbol{TU}(i)}\sum_{\boldsymbol{a}\in \boldsymbol{A}(i)}\begin{pmatrix}\boldsymbol{\tau}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}),\boldsymbol{a})\cdot\\ \boldsymbol{y}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}),\boldsymbol{a})\end{pmatrix}\longrightarrow \min \tag{11}$$

While the criterion function *k2*(**X**,**Y**) the cost of performing aircraft maintenance tasks:

k2(**X**,**Y**)=

$$\sum_{\boldsymbol{i}\in \boldsymbol{I}}\sum_{tu(i)\in \boldsymbol{TU}(i)}\begin{pmatrix}ks(i,tu(i))\cdot x(i,tu(i))+\\ \sum_{a\in A(i)}\begin{pmatrix}kz(i,tu(i),a)\cdot\\ y(i,tu(i),a)\end{pmatrix}\end{pmatrix}\longrightarrow \min \tag{12}$$

Selection of airport equipment should be determined so that the boundary conditions resulting from the implementation of the flight table and the movement of aircraft on the apron performing the tasks of take-off and landing are met.

Considering the above, the following constraints were formulated in the decision model:

$$\begin{gathered} j\in \boldsymbol{I}, a\in \boldsymbol{A}(\boldsymbol{i}), \boldsymbol{j}\in \boldsymbol{\Gamma}(i,a)\\ \sum_{\boldsymbol{tu}(i)\in \boldsymbol{TU}(i)} \boldsymbol{y}(i,tu(i),a) = q2(i,a)\cdot p((i,j),a) \end{gathered} \tag{13}$$

$$\begin{gathered} \boldsymbol{i}\in \boldsymbol{I},\ a\in \boldsymbol{A}(\mathbf{i})\\ \sum_{\boldsymbol{j}\in\boldsymbol{\Gamma}(i,a)}\sum_{\boldsymbol{tu}(i)\in \boldsymbol{TU}(i)} \boldsymbol{y}(\boldsymbol{i},\boldsymbol{tu}(i),a)\cdot \boldsymbol{p}((\boldsymbol{i},\boldsymbol{j}),a) =\\ \sum_{\boldsymbol{tu}(j)\in \boldsymbol{TU}(j)} \boldsymbol{y}(\boldsymbol{j},\boldsymbol{tu}(\boldsymbol{j}),\boldsymbol{a}) \end{gathered} \tag{14}$$

$$\begin{gathered} \boldsymbol{i}\in \boldsymbol{I}, \boldsymbol{tu}(\boldsymbol{i})\in \boldsymbol{TU}(\mathbf{i})\\ \sum_{a\in \boldsymbol{A}(i)}\begin{pmatrix}\boldsymbol{y}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}),a)\cdot\\ \boldsymbol{\tau}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}),a)\end{pmatrix}\le \frac{\boldsymbol{T}}{\phi(\boldsymbol{i})}\cdot \boldsymbol{x}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i})) \end{gathered} \tag{15}$$

$$\sum_{\boldsymbol{i}\in \boldsymbol{I}}\sum_{tu(i)\in \boldsymbol{TU}(i)} n(i,tu(i))\cdot x(i,tu(i))\le \boldsymbol{NI} \tag{16}$$

$$\boldsymbol{x}(\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}))\in \mathbf{N},\quad \boldsymbol{i}\in \boldsymbol{I}, \boldsymbol{tu}(\boldsymbol{i})\in \boldsymbol{TU}(\mathbf{i}) \tag{17}$$

$$\begin{gathered} a\in \boldsymbol{A}(\boldsymbol{i})\\ (\boldsymbol{i},\boldsymbol{tu}(\boldsymbol{i}),a)\ge 0,\quad \boldsymbol{i}\in \mathbf{I}, \boldsymbol{tu}(\boldsymbol{i})\in \boldsymbol{TU}(\mathbf{i}) \end{gathered} \tag{18}$$

Determination of the rational number of pieces of particular elements (types) of equipment of the examined object of the system and determination of their load with the traffic stream (passengers, airplanes) must be carried out with the fulfillment of certain constraints resulting from: the necessity of realization of set tasks submitted for realization (13), preservation of continuity of the traffic stream flow through the system (14), efficiency of the system equipment elements (throughput) (15), not exceeding the time and cost of task realization (16), and others, e.g. concerning the character of decision variables (17,18). Of course, the set of constraints can be modified depending on the specifics of the system under analysis and the expectations of its users. Satisfying the above constraints allows us to find a set of admissible solutions.

Figure 1 shows the general procedure of the AIR-SAW method.

4. Case study

The research presented in this paper examines three airport expansion options serving directions 12 and 30 for takeoff and landing operations. The posted data are actual data and apply to a complete analysis of the facility, however, due to an ongoing design and implementation work, they are sensitive data, and the authors are not currently authorized to provide identification details. All simulations and tests were performed on a certified simulator, whose functionalities are currently being extended and their part is presented in this paper. The methodology so adopted is also related to the source of data acquisition.

Variant 1

In the first variant, an airport with one runway with directions 12 and 30 having the following taxiways A and A1, A2 and B, C is available. Aircrafts landing from direction 12 taxi to the berths via taxiway B arriving sequentially at berths 18 in an average time of 45 seconds and 130 seconds to berth 1. Aircrafts landing from direction 30 taxi to the staging area by way of C and A, A2 at 120 s to site 1 and 205 to site 18. Taxi times for all SP types are the same (large, medium and small).

Variant 2

In the second alternative, the following taxiways are available for the same runway: A and A1, A2 and B, C, D, E. Additionally, an APRON B parking with seven additional parking spaces is available. Large aircrafts landing from direction 12 taxi to the berths via route B arriving sequentially at berths on APRON A from 18 in an average time of 45 seconds and 130 seconds to berth 1. For Plate B, the times break down as follows B1 25s, B2-30s, B3-35s, B4-40, B5- 45s, B6-50s, B7-55s. Medium aircraft land-

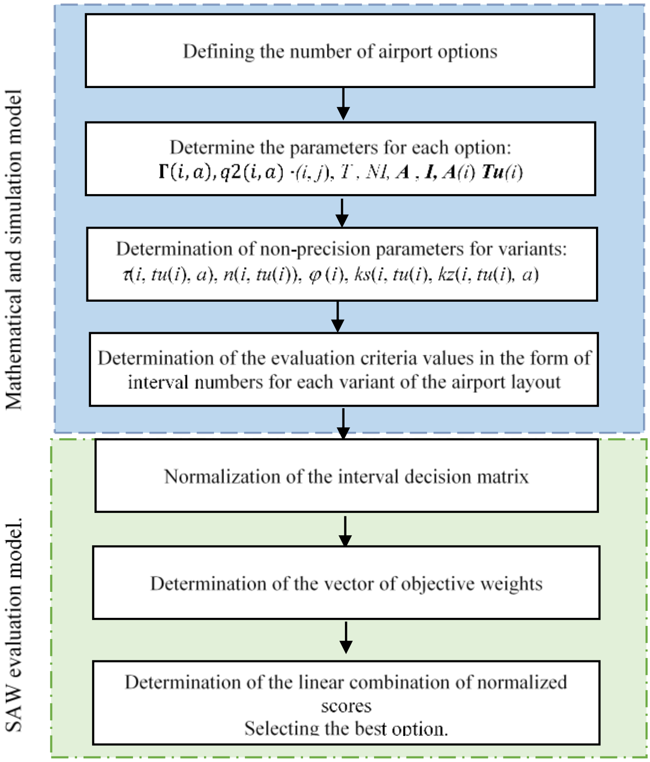

Fig. 2. AIRSAW method procedure

Table 1. Data used in the case study for option one

Option	Taxiways	Busy time taxiways	Number of seats occupied on the board	Average aircraft taxi time for takeoff and landing for direction 12	Average aircraft taxi time for takeoff and landing for direction 30
1	A	20-40min	15 - 18	205/45	45/205
	A1	2-5min			
	A2	2-5min			
	B	5-10min			
	C	4-8min			

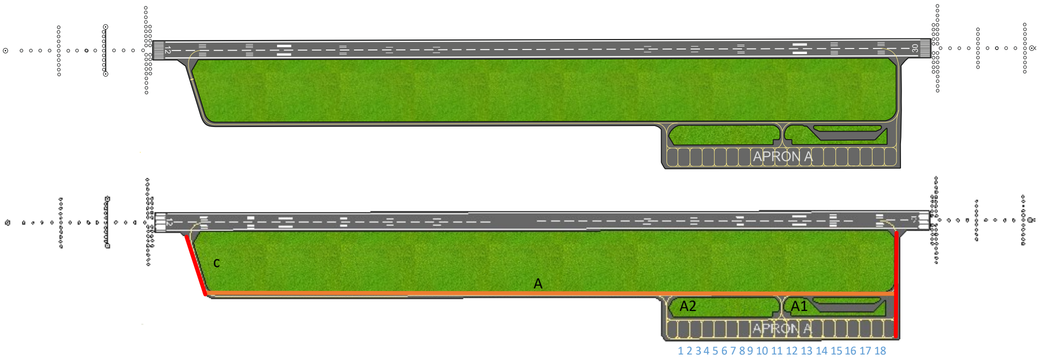

Fig. 3. Identification of parking areas and taxiways for variant one

ing from direction 12 can use road E which reduces their travel time to place 1 from 130 s to 45 s place 1 + 5s for each subsequent place. Small aircraft can additionally use taxiway D causing the runway to open earlier. Large aircrafts landing from direction 30 taxi to the berth by way of C and A, A2 in 120 s to berth 1 and 205 to berth 18. Medium aircraft landing from direction 30 can taxi via E, which reduces taxi time by 30 seconds for apron A seats. Small aircraft landing from direction 30 can taxi via D, which reduces taxi time by 30 s for apron A seats. Small Sp's, after turning onto Taxiway E, shorten lane occupancy time as well as taxi time to apron A parking spots by 35 sec A1 spot and every next 5 sec.

Table 2. Data used in the case study for variant two

Option	Taxiways	Busy time taxiways	Number of parking spaces occupied on the tarmac	Average aircraft taxi time for takeoff and landing for direction 12	Average aircraft taxi time for takeoff and landing for direction 30
2	A	20-35min	26 - 40	205/20	20/205
	A1	2-5min			
	A2	2-5min			
	B	5-8min			
	C	4-7min			
	D	2-5min			
	E	2-5min			

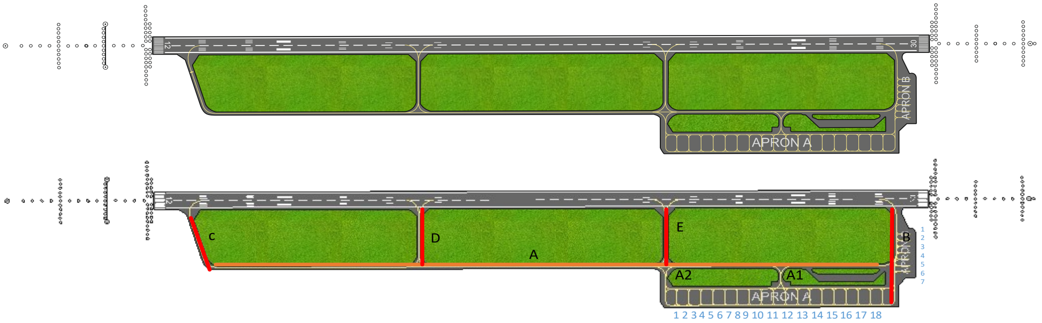

Fig. 4. Identification of parking areas and taxiways for variant 2

Variant 3

In the third variant the following taxiways are available A and A1, A2 and B, C, E, F, G. Large aircrafts landing from direction 12 taxi to berths via route B arriving sequentially at berths on APRON A from 18 in an average time of 45 seconds and 130 seconds to berth1. Large aircrafts landing from direction 12 taxi to the berths via G arriving sequentially at the berths on APRON A from12 in an average time of 45 seconds +5 seconds to the next berths located to the left and right of site A12. For large aircrafts taxiing at APRON B, the times break down as follows B1-25s, B2-30s, B3-35s, B4-40, B5- 45s, B6-50s, B7-55s. Medium aircrafts landing from direction 12 can use road E which reduces their travel time to place 1 from 130 s to 45 s place 1 + 5s for each subsequent place. Medium aircrafts landing from direction 12 can use road F which reduces their travel time to place 1 from 130 s to 40 s place 1 + 5s for each subsequent place. Small aircrafts additionally can use taxiway D causing the runway to open earlier. Small aircrafts landing from direction 12 can use road F which reduces their travel time to place 1 from 130 s to 40 s place 1 + 5s for each subsequent place. Large aircrafts landing from direction 30 taxi to the staging area by way of C and A, A2 in 120 s to site 1 and 210 to site 18. Medium aircrafts may taxi via Taxiway D, which shortens taxiing time to apron A by 60 seconds. Small Sp's, on the other hand, after turning to taxiway E, shorten the time of occupancy of the runway as well as the time of taxiing to parking places on apron A by 30 sec. for place A1 and every next 5 sec.

For the identified variants, the airport throughput capacity *k1*(**Y**) and *k2*(**X**, **Y**), cost of construction and equipment were determined. Airport throughput capacity in terms of passengers and the number of seats occupied on the tarmac was estimated based on forecasted flight demand. For each variant, the data were presented as interval numbers indicating the best and worst values (e.g., changes in the purchase price of airport infrastructure elements, uncertain tender results, etc.). Table 4 lists the results obtained.

Table 3. Data used in the case study for variant 3

Option	Taxiways	Busy time taxiways	Number of parking spaces occupied on the tarmac	Average aircraft taxi time for takeoff and landing for direction 12	Average aircraft taxi time for takeoff and landing for direction 30
3	A	15-30min	37 - 50	125/20	20/125
	A1	2-4min			
	A2	2-4min			
	B	5-7min			
	C	4-6min			
	D	2-5min			
	E	2-5min			
	F	2-5min			
	G	2-5min			

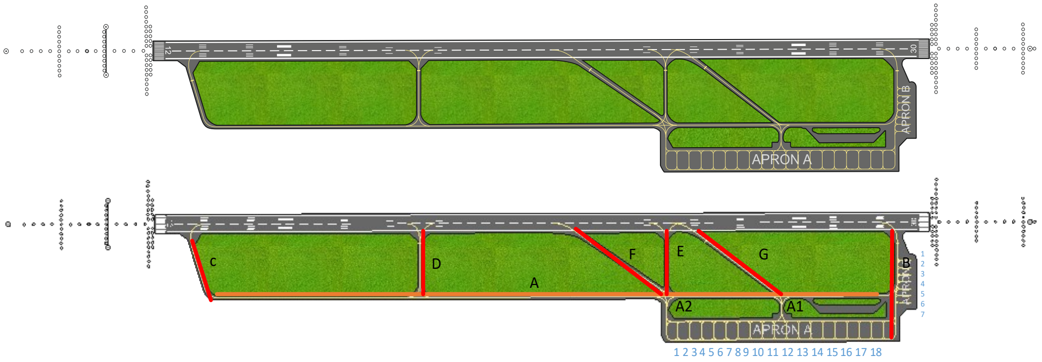

Fig. 5. Identification of parking areas and taxiways for variant 3

Table 4. Partitioned decision matrix

Option	Airport throughput capacity calculated in number of take-offs and landings[operations] **Criterion 1**	Airport throughput capacity in terms of passengers **Criterion 2**	Estimated construction cost **Criterion 3**	Number of seats occupied on the tarmac **Criterion 4**
I1	[5. 35]	[5.30]	[400. 600]	[15. 25]
I2	[8. 55]	[10.20]	[400. 600]	[26. 40]
I3	[14. 80]	[12.45]	[850. 1100]	[40. 65]
	stimulant	**stimulant**	**destimulant**	**destimulant**
after normalization				
I1	[0.025; 0.178]	[0.002; 0.204]	[0.185; 0.277]	[0.190; 0.317]
I2	[0.041; 0.279]	[0.003; 0.320]	[0.123; 0.185]	[0.119; 0.183]
I3	[0.071; 0.406]	[0.005; 0.466]	[0.101; 0.130]	[0.073; 0.119]

Based on the normalized interval decision matrix, entropy (e), level of variation (d) and objective criteria weights (w) were determined as shown in Table 5.

Table 5. Entropy, level of variation and criteria weights

Option	Measure	Criterion 1	Criterion 2	Criterion 3	Criterion 4
I1	**e**	[0.297; 0.742]	[0.042; 0.754]	[0.578; 0.673]	[0.548; 0.669]
I2	**d**	[0.258; 0.703]	[0.246; 0.958]	[0.327; 0.422]	[0.331; 0.452]
I3	**w**	[0.070; 0.190]	[0.067; 0.259]	[0.088; 0.114]	[0.089; 0.122]

The results obtained by the proposed interval SAW method with objective weights are shown in Table 7. where the results of the linear combinations. the elements of the normalized interval decision matrix (Table 5) and the objective criteria weights (Table 6), and the ranking of the decision alternatives can be seen. Figure 6 shows the results of the linear combination of normalized scores SAW.

Table 6. Results obtained.

Variant	Linear combination of normalized scores SAW	c(Oi)	r(Oi)	Ranking
I1	[0.035; 0.157]	0.096	0.061	3
I2	[0.025; 0.180]	0.102	0.077	2
I3	[0.021; 0.227]	0.124	0.103	1

The calculations showed that variant I3 should be selected, i.e., the one characterized by the best capacity parameters, but at the same time the most expensive.

5. Conclusions

This paper proposes a compartmental extension of the classical SAW method with weights obtained using the compartmental Shannon entropy. The use of interval numbers in the SAW method allows to support decision-making processes in which data may be incomplete, imprecise or difficult to measure, which is often the case in problems concerning airport operations. In contrast, the use of Shannon's

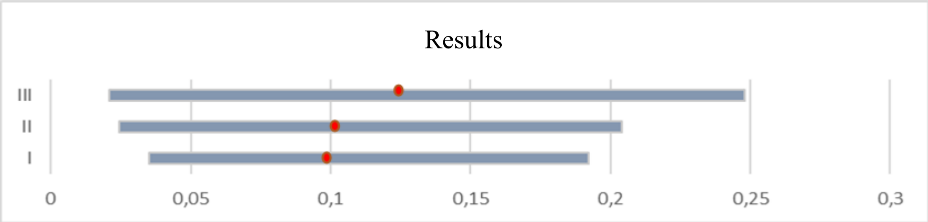

Figure 6. Linear combination of normalized SAW scores.

interval entropy to determine criteria weights allows the optimal decision option to be selected more objectively, in a way that is independent of the preferences, judgments, and experience of the decision maker or expert. The proposed approach enables analysis and evaluation of the implementation of operations in the context of, among other things:

– increase airport throughput capacity,
– taxiway expansion,
– selection of the number of runways,
– analyze rapid exit routes,
– maintaining security,
– efficiency and effectiveness of airport processes in the context of safety of airport operations.

The proposed AIRSAW method verified on practical examples enables analysis and evaluation:

– airport throughput capacity,
– opportunities to improve service quality and efficiency at airports,
– opportunities to improve the quality of ground handling services, particularly in terms of reliability and resilience, as well as staff and passenger safety in airport processes.

The presented numerical example shows that the proposed method is an excellent tool to assist in solving complex decision problems where the data are imprecise and represented by interval numbers.

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