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Article

ENTROPY-BASED MODEL FOR AERODROMES SAFETY RISK ASSESSMENT TO IMPLEMENT SAFETY MANAGEMENT SYSTEMS

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Abstract.

All certified Aerodromes require to implement Safety Management System (SMS) from November 2005 according to the International Civil Aviation Organization (ICAO) requirements. Nowadays safety risk assessment in aerodromes with main operational scopes has been a critical issue in the aviation industry. The current SMS model is no more sufficient to comply with this complexity and cover all aspects of aerodrome factors quantitatively. A new model for aerodrome safety risk assessment to evaluate Aerodrome's safety risk based on the Entropy method is developed in this research. In this new method, critical criteria and their sub-criteria are developed and then assess the safety risk. One Aerodromes (as a case study) is considered and the weight of criteria and sub-criteria are measured based on Entropy technique and aerodrome safety performance is assessed. The first phase was the weight measurement of criteria by the Entropy method, and then evaluate related safety performance. Based on the safety risk assessment result, the aviation experts were interviewed to verify the result, which supported our research outcomes. The result of this research should guide aviation SMS experts to take proper safety mitigations to prevent any safety events in aerodromes.

Keywords: Entropy, Safety Risk Assessment, Aerodrome, Aviation and SMS.

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1. Introduction

The aviation industry has a noteworthy role in the world's economy and airports play the main role in the socio-economic aspects of the aviation industry [1]. Aerodrome Safety Management Systems (SMS) are significant for safety management. Many runway occurrences not only do not comply with the standards of International Civil Aviation Organization (ICAO) but also reduce aerodrome safety levels. ICAO has proposed safety objectives which include accidents, serious incidents, and collisions increment. Therefore, all certified aerodromes have had to implement a Safety Management System (SMS) as of November 2005. A Safety Management System (SMS) is a management tool for safety managers. And an aerodrome SMS is the implementation of a safety management system for aerodromes. The aerodrome SMS structure consists of four components and twelve elements.

The aerodrome size and complexity of the service provider are the main issues to implement the SMS framework [2]. A safety management system as a systematic approach tries to manage safety by using proper organizational structures, accountability, responsibilities, policies, and procedures. ICAO has proposed a structure in Annex 19 as a Safety Management System (SMS) for the full inclusion of safety-related problems. The main goal was safety risks assessment and monitoring safety performance. Safety Policy and Objectives, Risk Management, Safety Assurance, and Safety Promotion are dependent on safety risk evaluation. Moreover, SMS establishment is the responsibility of the operator, which is monitored by their State. ICAO has generated SMS frameworks which include the following components and elements [2]:

➢ **Safety policy and objectives**

- Management commitment and responsibility
- Safety accountabilities
- Appointment of key safety personnel
- Coordination of emergency response planning
- SMS documentation

➢ **Safety risk management**

- Hazard identification
- Safety risk assessment and mitigation

➢ **Safety assurance**

- Safety performance monitoring and measurement
- Management of change
- Continuous improvement of SMS

➢ **Safety promotion**

- Training and education
- Safety communication

According to acceptable Means of Compliance (AMC1 ORO.FC.105 (b) (2); (c) Designation as pilot-in-command/commander - Subpart FC-Flight Crew) and Guidance Material (GM) from Annex III – Part-ORO, the environmental knowledge related to the prevention of airplane occurrences should include [3]:

- The relevant environmental hazards, such as:
- Clear Air Turbulence (CAT),
- Inter-tropical Convergence Zone (ITCZ),
- Thunderstorms,
- Microburst,
- Wind Shear,
- Icing,
- Mountain Waves,
- Wake Turbulence, and
- Temperature changes at high altitudes.
- The assessment and monitoring of the related safety risks of their hazards in the above items, and
- Mitigation of the identified hazards in the above items, regarding the special route, route area, or aerodrome used by the operator.

Additionally, according to ICAO Annex 14 (Standards and Aerodrome Certification), “A certified aerodrome shall implement a safety management system” [2, 4]. Therefore, to comply with the ICAO’s and European Aviation Safety Agency requirements, all certified aerodromes require implementing SMS. Current aviation SMS research focuses on the SMS implementation, but there is not any proper model to evaluate the level safety risk aerodromes. Current academic SMS studies in the aviation industries were intended to establish SMS components in the airline. A small number of them were associated with aerodrome safety indicators and aerodrome SMS. After research into different operators to figure out how airlines categorize their operating destination aerodromes (i.e. CAT A and CAT B and CAT C), we found out that there is almost no systematic process for safety evaluation of Destination Aerodromes which is a requirement for operators according to EASA-Air Ops. The present study aims at developing aerodrome safety measurement and establishes an SMS- based criterion that evaluates the aerodromes. Firstly, the main criteria and sub-criteria are extracted in accordance with the literature review and the flight safety experts’ opinions, and secondly, the weights of criteria and sub-criteria are measured. Finally, the aerodrome safety risk is evaluated. The main benefit of the Entropy usage is

- avoidance of the subjectivity of weight selection,
- usage of sample data for the weight measurement and
- consideration of group utility to rank alternatives. In general, the following aims are considered in paper:
- Establishment of a safety management system for aerodromes operations
- Criteria and sub-criteria development and categorization (Entropy Weight Method implementation)
- The aerodromes categorization according to aerodrome characteristics

There is a small number of studies to assess aerodrome safety risks and rank them via criteria and sub-criteria. This paper initializes a new method for the safety risk assessment of aerodromes and highlights an overall safety index for usage of the aerodrome for safety managers. From an aviation expert's point of view, implementation of the entropy method with questionnaires can be an efficacious approach to determining the importance of each criterion and sub-criteria. As a case study, here. One aerodrome has been considered and assessed. The safety risk assessment results were reviewed by aviation experts and they verified our results.

For the purpose mentioned, in this research, following steps are taken:

- Criteria and sub-criteria identification for a risk assessment model
- Safety risk assessment for aerodromes
- Case study: Implementation model

The paper is developed into several sections. The second section contain a literature review about a complete safety management system in aerodrome management. The third section proposed the methodology and description of the new method. In the fourth section, a case study is presented with detailed explanations of the results. Finally, conclusions and future investigations are suggested.

2. Literature

The SMS subject in aerodrome is a new concept; therefore, there are some limitations in the literature review [5]. In this section, aerodrome SMS legislation history, regulations, and some investigations carried out recently are discussed. Previous studies regarding aerodrome safety assessment are reviewed as well. A review of the research was done by Netjasov, et al. (2008) [6] which focused on four categories of methods/models for risk and safety assessment: causal for Aircraft and Air Traffic Control/Management (ATC/ATM) operations, collision risk, human factor error and third-party risk [6]. Chen, et al. (2011) [7] developed a total environmental risk assessment model for airport by using ANP method with consideration of Social, Technical, Economic, Environmental and Political (STEEP) criteria related to the Built, Social and Natural (BSN) trinity environment of international airport projects [7]. Attaccalite, et al. (2012) [8] present a standard individual risk calculation method for the definition of Public Safety Zones around airports [8]. Xianfenga et al. (2012) [9] provided a general aerodrome safety management method based on performance and the maximum effect of safety management factors. Aerodrome safety risk assessment method is divided according to interdependence of management indexes and other indicators in the assessment method which emphasize the effect of several safety management factors on aerodrome overall safety and take advantage of the assessment indicator data and safety management system efficaciously [9]. Skouloudis et al. (2012) [10] evaluated the comprehensiveness and quality of corporate social responsibility reports issued by airports [10]. Pacheco et al. (2014) [11]designed each item of airport infrastructure to re-identify environmental specifications and developed a fuzzy-logic method for the assessment of accident safety risks at airports and also studied two airports as the case study for the methodology proposed [11]. Based on the SMS theory, Chang et al. (2015) [5] assessed the SMS operations performance by using two-stage instructions at four aerodromes. The first step was the weights calculation and categorization of all SMS components and elements by the Analytic Network Process (ANP). The second step was their performance evaluation via the fuzzy method with the ideal solution (TOPSIS) likeness. The most crucial components of SMS are safety risk management, safety policy and objectives, safety promotion, and safety assurance, respectively. In the next step, the analysis of the components was carried out [5]. Allan, et al. (2016) [12] studied the impact of differential reporting of damaging and non-damaging strikes on the risk assessment process (birdstrike risk at UK airports) [12]. Cheng Chao et al. (2017) [13] proposed a model for aerodrome environmental performance evaluation. Indexes in this model were compatible by using the FDM, AHP and analyzed by experts to evaluate the weights and the values of indicators. Cheng Chao et al. showed that the scopes in descending order are energy conservation, carbon reduction in aerodrome operations, green aerodrome design, aerodrome environmental sustainability management, and use of renewable resources. Among the 16 indexes, energy-saving control, easy aerodrome access by public transport, and aircraft carbon management have the highest weight [13]. Potente, Carmine, et al. (2018) [14] analyzed the impact of temporary hazards on safety areas and then evaluated the safety risk level of runway [14]. Potente, et al. (2018) [14] analyzed the impact of temporary hazards (for example worksites) in the safety areas by using a performance approach [14]. Eshtaiwia et al. (2018) [15] developed key performance indexes (KPIs) to monitor and evaluate the Libyan aerodrome's safety performance. Findings showed that the indexes associated with safety and security, passenger services, and airside area are most significant. The Analytic Hierarchy Process (AHP) method was implemented by an expert's judgment [15]. Bezerraa et al. (2018) [16] suggested a model for the assessment of practices in aerodromes. The conclusion indicated that this research still highlights operational subjects such as safety, economic-financial, and service quality. Moreover, performance measurement was not clear based on a broader perspective of the aerodrome business, including competition, long-term economic results, and the environmental and social outcomes of the aerodrome activities. According to the results of cluster analysis conducted in Brazilian aerodromes, this research highlighted operational aspects such as safety, economic- financial, operational, and service quality dimensions. Balthazar et al. (2018) [17] measured aerodrome performance and efficiency by using GDS (Global Decision Support) and MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) methods. In this research, a hierarchical additive value approach was presented with different reference levels and performance profiles comparison [16]. A Multi-attribute decision-making tool was applied by Baltazar et al. (2020) [18] to evaluate Spanish aerodromes performance by using MACBETH (with PESA-AGB). Several aerodrome key areas such as safety and security, quality service, productivity and effectiveness, finance, and environment for performance and efficiency improvements were studied [17]. Balthazar et al. (2020) [18] in their research achieved improvements in lots of key airport areas, such as core, safety, and security, quality service, productivity and effectiveness, finance and environment, costs reduction to improve satisfaction. They applied MCDA-MACBETH (with PESA-AGB) methodology in 4 Spanish airports [18]. The effect of aerodrome surface weather conditions on the flight delays for the Brazilian domestic air transportation system was explored by de Oliveira et al. (2021) [19]. This study analyzed the impact of different meteorological variables at the aerodrome on the probability of delayed arrivals [19]. Cunha et al. (2021) [20]developed a multi-criteria methodology to monitor runway maintenance by using a safety risk approach at airports. They interviewed some experts in the airport maintenance and operations based on their judgment and technical knowledge to confirm the results. The results indicated that the seven factors could support about 80% of the identified risks through the expert's judgment, and denoted that the essential resources section of the infrastructure operations at the airport mentioned can be redirected towards a more rational implementation [20]. The aircraft veer-off probability for different operating conditions was computed by Galagederaa, et al. (2020) [21] to assess the relative risks of veer-off incidents at high speed which occur in runways [21]. The criteria and methods which were applied in the literature review to evaluate and rank Aerodromes are summarized and presented in Table 1.

Table 1. Criteria used for Aerodrome performance evaluation

Criteria	Author	Method
- Energy protection and carbon decrement in aerodrome operations, - Green aerodrome, - Aerodrome environmental sustainability management, - Renewable resources usage	Cheng Chao et al. (2017) [13]	FDM and AHP
- Safety and security - Passenger services - Airside area	Eshtaiwia et al. (2018) [15]	AHP
Operational scopes: - Safety - Economic-financial - Operational and Service Quality	Bezerraa et al. (2018) [16]	PESA-AGB
- Quality and Safety, - Productivity /cost-efficacy, - Service quality, - Financial /commercial, - Environmental	Bezerraa et al. (2018) [16]	MACBETH
- Impacts of aerodrome surface weather conditions	Oliveira et al. (2021) [19]	
- Human factors, - Facility and equipment factors, - Environment factors, - Management factors	Xianfenga et al. (2012) [9]	Quantitative SMS Modification Model
- Safety risk management, - Safety policy and objectives, - Safety promotion, - Safety assurance	Chang et al. (2015) [5]	ANP, TOPSIS
- Structural Condition - Functional Condition - Operational Condition	Cunha et al. (2021) [20]	MCDA-C
- Visibility - Visible - Ceiling - Ceil - Temperature - Temp - Tailwinds - Twined - Crosswinds - GWind - Rain – Rain	Pacheco et al. (2014) [11]	A fuzzy-logic methodology
o Economic: - Economic performance - Market presence - Indirect economic impacts o Environmental: - Materials - Energy - Water - Biodiversity - Emissions, effluents, and waste - Products and services - Compliance	Skouloudis et al. (2012) [10]	Airports' CSR reports assessment

Criteria	Author	Method
- Transport e Logistics Overall o Social: - Labor practices and decent work - Human rights - Society - Product responsibility		
- Core - Safety - Service Quality - Productivity-Cost efficacy - Financial-Commercial - Environmental	Baltazar et al. (2020) [18]	MCDA-MACBETH (with PESA-AGB)
- Evaluation of Operational Risk Factors at Runway High Speed Exits	Galagederaa, et al. (2020) [21]	Risk Assessment

There are some gaps in modeling of the studies (for the purpose of safety aerodrome's performance assessment by using a hybrid decision-making) that have been carried out and described above. These gaps motivated us to create a new model to assess aerodrome safety. One of the main concerns in the current studies (about aerodrome safety risk management systems) is the KPIs which are not able to highlight a model for integrated safety risk assessment in different aerodrome areas by reliable and quantitative overall safety risk indexes. They could also not monitor the overall aerodrome safety risk of the hazards and define the proper mitigation to increase the safety risk index to an acceptable level. Now the gaps in the current approach could be enumerated as below:

- Initially, there are not any integrated models to recognize all criteria to determine Aerodrome safety level.
- Secondly, lack of proper comparison with others aerodrome safety performances for reliable selection to consider the safer in-flight network.
- Thirdly, lack of a systematic assessment model to categorize Aerodromes.
- Fourthly, there are not proper prioritizing models for aerodromes safety risk assessment.

Moreover, according to safety risk assessment procedure which is mentioned in DOC9859, overall evaluation of aerodrome safety indicators through a mathematical approach has never been done [2]. In this paper, the critical factors and criteria are suggested in the aerodrome's safety assessment scope as the new approach. Therefore, the developed criteria are reviewed and classified by a mathematical model and finally the model is implement as a case study.

3. Model

The main contribution of this paper is introduction of a quantitative model for aerodrome safety risk assessment by using Multi-Criteria Decision-Making (MCDM) methods. MADM is used for continuous and discrete decision-making conditions. Most recent studies have focused on the MCDM methods to evaluate performance [5].

3.1 Entropy Weights Method (EWM)

EWM provides an efficient method to measure a disordered degree of a system as an uncertainty measurement tool [22]. Shannon and Weaver developed EWM in 1947, and Zeleny developed the concept in 1982 for the purpose of objective weights of the attributes and uncertain information calculation by using the probability concept. In the first step, the objectives and decision matrix are determined and then normalized. There is some advantage in using EWM which are: an easy and simple calculation of weights, applicability of the method if the information is inadequate or not, quantitative approach to make effectiveness and benefit/cost responses and supervision of the essential disagreement between the responses as a plan for decision-making [23]. According to the algorithm below (Figure. 1), the weight of each criterion are measured:

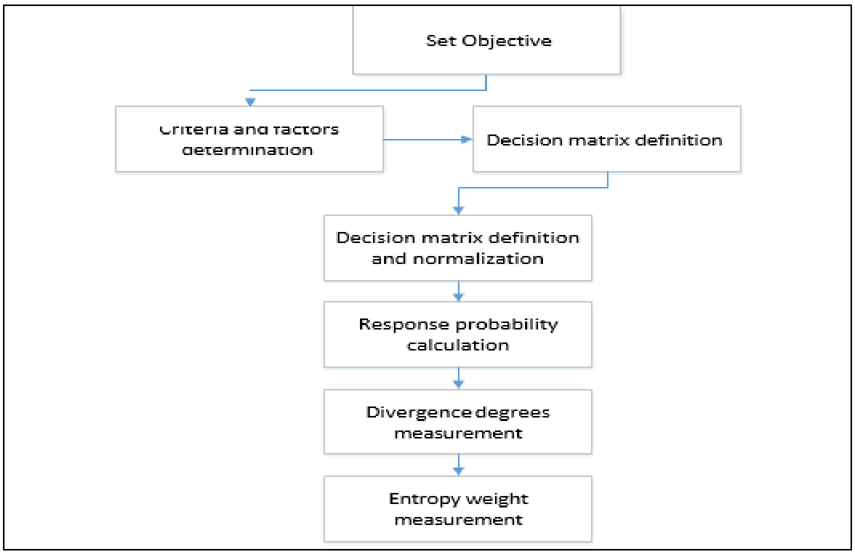

Figure 1. The entropy algorithm for weight measurement.

The entropy method uses the following steps for weights measurement [22]:

- **Step 1: Objective**

The proper objectives are determined with suitable evaluation criteria.

- **Step 2: Decision Matrix**

The decision format is defined in Eq. (4). The decision matrix A of a multi-criteria problem with m factor and n criteria is shown as the following equation. Each row specifies one experiment and each column one response.

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{4}$$

where x ij (i = 1, 2, . . . , m; j = 1, 2, . . . , n) is the performance value of the ith factor to the jth criteria.

- **Step 3: Normalization**

Pij as a relative frequency is measured by the set projection of the factor:

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{5}$$

- **Step 4: Entropy**

Entropy: according to the information theory, the output entropy of the jth criteria is given in the following equation:

$$E_j = -k \sum_{i=1}^{m} P_{ij} \ln(P_{ij}) \qquad j = 1, 2, \ldots, n \tag{6}$$

Where k represents a constant: k = 1/ ln m, which guarantees that $0 \leqslant E_j \leqslant 1$

➢ **Step 5: Calculate the Weight of Entropy**

The degree of diversification dj of the information provided by the factor j can be defined as the following equation:

$$d_j = \left|1 - E_j\right| \quad \forall j \tag{7}$$

Then the weight of entropy of jth criteria could be defined as:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad \forall j \tag{8}$$

4. Case Study of an Aerodrome:

Lack of integrated criteria and also having qualitative criteria is the main aim to develop a comprehensive safety risk management system for aerodromes. Such lack forces the safety manager to decide inefficiently due to lots of unit safety risk scales. So the decision-making approach will be an efficacious tool to reach an expert judgment for aerodrome safety risk assessment. Presentation of an overall safety risk index to assess the aerodrome, identification of the weaknesses, suggestion of proper corrective actions and continuous supervision of the impact of the decisions are the special objectives of this research. In this paper, the new approach also applies a decision-making method, because this method allows for the paired comparison of all criteria and selective aerodromes, something that is not carried out in the current safety risk analyses. Via this method, two targets are obtained. Firstly, by making the comparison prioritization takes place, which could be done by the management and only then the overall safety risk criteria are assessed. The method which is used in this paper includes the following steps:

- Developing the criteria and sub-criteria for aerodrome safety risk assessment.
- Inclusion of quantitative methods (Entropy)
- Development of a model for Aerodrome Safety risk assessment

To comply with the ICAO's standards, all certified aerodromes have had to implement and operate an SMS since November 2005. According to the ICAO framework for SMS (which includes Safety risk management), a safety risk assessment model shall be developed. Considering the mandatory requirements mentioned, this paper (based on ICAO, EASA standards), has proposed the following criteria and sub-criteria for airdrome safety risk evaluation (as given in table.2)

Table 2. Criteria and sub-criteria for Airdrome safety risk assessment

Criteria	Code	Sub Criteria	Code
Topology	C1	Mountainous Area	C1-1
		Remote Area	C1-2
		Flight Over Water	C1-3

Communication, Navigation, Surveillance (CNS) /Air Traffic Management (ATM)	C2	RADAR System		C2-1
		Air Move Display (AMD)		C2-2
		Uncontrolled Aerodrome (UN/Controlled AD)		C2-3
		Uncontrolled Airspace (UN/Controlled Airspace)		C2-4
Instrument Approach Operations and Procedure /Instrument Departure/Instrument Arrival (INS APP OPS/DEP/ARR)	C3	Arrival		C3-1
		Departure		C3-2
		Instrument Approach Operations And Procedure (PA/VPA/Circling Steep/STEEP Approach)		C3-4
		Missed Approach		C3-5
		Performance Behavior		C3-6
Environmental Effect	C4	Bird Congestion		C4-1
		Local Weather Phenomena	Average Annual Thunderstorm	C4-2
			Gusty Wind/Wind Show	C4-3
			Icing Condition	C4-4
			Marginal Weather Condition	C4-5
Aerodrome Physical Factors	C5	Short Field Operations		C5-1
		Runway Widths >45 M		C5-2
		Pavement Classification Number (PCN) Vs Aircraft Classification Number (ACN) Ok?		C5-3
		Approach Lighting System		C5-4
		Runway/TAXI Way/Apron Lighting		C5-5
		Runway/TAXI Way/Apron Marking		C5-6

Following the results of the literature review and also aviation experts' comments, some criteria were selected. The recommended definition of the criteria proposed (which are grouped into 6 types) and the sub-criteria are as the following:

- **Topology:**

- Mountainous Area:
- Changing terrain profile area where the changes of terrain elevation exceeds 900m (3000ft) within a distance of 10 Nautical Mile (NM).
- Remote Area:

- A standard aerodrome shall meet all applicable requirements. So additional considerations shall be taken to locating any obstacles that might be in the approach/departure route.
- Flight over water:
- A flight operated over water at a distance of more than 93 km (50 NM), or 30 minutes at normal cruising speed, whichever is the lesser, away from land suitable for making an emergency landing.

➢ **Communication, Navigation, Surveillance (CNS) /Air Traffic Management (ATM)**

- RADAR system:
- Air Traffic Control (ATC) uses a radar system. This tool discovers and identifies the aircraft's location and additional information from the aircraft itself which is demanded.
- Air Move Display (AMD):
- Air move display, almost like radar, receives a signal from a radar unit so it can have access to the position of an aircraft. Radar service is not provided by air move display.
- Uncontrolled Aerodrome (UN/controlled AD):
- An uncontrolled aerodrome is an aerodrome with uncontrolled tower specification or one where the operation of the tower is not available. There is no clearance issued by AFIS in such fields.
- Uncontrolled Airspace (UN/ Controlled Airspace):
- Air Traffic Control (ATC) service is not necessary for uncontrolled airspace or cannot be presented for practical reasons. According to the ICAO requirement about the airspace classes, both class F and class G airspace are uncontrolled.

➢ **Instrument Approach Operations and Procedure/Instrument Departure/Instrument Arrival (INS APP OPS/DEP/ARR)**

- Arrival
- The air navigation service provider publishes a flight route as a STAR which supports the phase of a flight that allocates between the last point of the route filed in the flight plan and the first point of the approach to the aerodrome, normally the Initial Approach Fix (IAF). In other words, a STAR links the En-route phase with the approach phase of the flight.
- Departure
- A Standard Instrument Departure Route (SID) is identified as a standard ATS (Air traffic service) route.
- Instrument approach operations and procedure:
- The lateral and vertical navigation guidance is used for a three-dimensional (3D) instrument approach operation as an instrument approach operation. An instrument approach or instrument approach procedure (IAP) are prearranged maneuvers for the orderly aircraft transformation under instrument flight conditions.
- Missed approach
- Pilot performs the missed approach procedure when an instrument approach cannot be completed to a full-stop landing.
- Performance behavior:

- Study of performance capabilities of an aircraft through the instrument approach procedure funnel in normal and OEI (one engine inoperative) conditions.

➢ **Environmental Factors:**

- Bird congestion:
- Accumulation of bird or types of species in that particular environment which can pose a hazard to operations of an aircraft.
- Marginal weather phenomena:
- Study of the local weather (climatologically) for a particular airfield in terms of icing, wind, visibility, etc.
- Average annual thunderstorm:
- Study of several local thunderstorms with the severity of moderate to heavy in the particular airfield.
- Gusty wind:
- Constant and variable change of wind direction and speed more than 30 degrees and 20 knots.
- Icing condition:
- Ground operations with the presence of moisture and outside air temperature less than 10 degrees Celsius.

➢ **Aerodrome Physical Factors:**

- Short field operations: Here in this model by short field operations, we mean the situation when a landing distance required is close or equal to the required landing distance by less than 15% margin without increased additional margin.
- Runway widths > 45 M
- Pavement classification number (PCN) vs aircraft classification number (ACN)
- Approach Lighting System
- Runway/TAXI way/Apron Lighting
- Runway/TAXI way/Apron Marking
- By integration of the criteria proposed within the risk management system, this method should be a more effective tool for aerodrome management. Safety risk assessment has a key component as SMS from a hazard identification or situation. Some definitions used in this area are as follows:

- Safety risk probability: The likelihood or frequency of safety consequence or outcome.
- Safety risk severity: The amount of damage or harm that a hazard could cause.
- Safety risk tolerability: The index is the combination of the probability and severity assessments results.
- The safety risk assessment matrix (the severity/probability combinations) is demonstrated in Fig. 2. Then the safety risk tolerability is evaluated. (Fig.3) (ICAO, Doc.9859, 2018).

Risk probability		Risk severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Tolerability description	Assessed risk index	Suggested criteria
Intolerable region	5A, 5B, 5C, 4A, 4B, 3A	Unacceptable under the existing circumstances
Tolerable region	5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Acceptable based on risk mitigation. It may require management decision.
Acceptable region	3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable

Figure 2. Safety risk assessment matrix

Risk index range	Description	Recommended action
5A, 5B, 5C, 4A, 4B, 3A	High risk	Cease or cut back operation promptly if necessary. Perform priority risk mitigation to ensure that additional or enhanced preventive controls are put in place to bring down the risk index to the moderate or low range.
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Moderate risk	Schedule performance of a safety assessment to bring down the risk index to the low range if viable.
3E, 2D, 2E, 1B, 1C, 1D, 1E	Low risk	Acceptable as is. No further risk mitigation required.

Figure 3. Safety risk tolerability matrix

4.1 Findings and Discussions

For mutual comparison of the index, a few experts in the airport must join one another, and their viewpoints should be shared. To provide this group, some criteria such as proper knowledge for decision-making and being an aviation expert will be on top of all. To complete matrices, experts will have to make pair comparisons by the entropy method. Finally, each criterion and sub-criteria's importance and the safety risk (according to the definition of severity and probability of each index mentioned in DOC9859 above) of each of them are extracted according to the entropy method. The proposed model is demonstrated in Table. 3. All numbers in the table are as a numerical example and it is filled out as a sample to calculate the safety risk of each index by the methodology of implementation proposed. The developed model is conducted via the following stages to evaluate the safety of an aerodrome:

- Firstly, the weight of each criterion is calculated by using the ENTROPY model.
- Secondly, the safety risk assessment results are categorized.

The safety risks from different criteria are summed up to result in the Overall Safety Index of the aerodrome:

$$Safety\ risk\ Factor = Si = wi * FRi \tag{9}$$

in which

FRi = Safety risk Factor.

Wi = Corresponding weighing coefficients for each factor derived by ENTROPY method.

P = Number of operational (Aerodrome) fields.

$$Overal\ \text{Safety Risk index} = \frac{(\sum_{i=0}^{p}(\text{Si}))}{p} \tag{10}$$

The results show that INS APP OPS/DEP/ARR and Topology are the main factors to assess aerodrome safety risk. Moreover, the three factors of CNS/ATM, Environmental effect and Aerodrome physical factors together are of the same weight to assess safety risk. The managers who decide on their in-flight network can use the method to assess the safety level of aerodrome which will be operated. The model is developed as a numerical and decision-making framework to assess the safety performance of aerodrome by the Entropy approaches.

Table 3. The framework for the aerodrome risk assessment model based on the model proposed (As a numerical example)

Criteria	Weight	Sub Criteria	Weight	Risk Value		Safety Risk Value	Overall Safety Risk Index
Topology	0.25	Mountainous Area	0.333	HIGH	20.5	20.5	5.125
		Remote Area	0.333				
		Flight Over Water	0.333				
Communication, Navigation, Surveillance (CNS) /Air Traffic Management (ATM)	0.125	RADAR System	0.1	LOW	3	3	0.375
		Air Move Display (AMD)	0.3				
		Uncontrolled Aerodrome (UN/Controlled AD)	0.3				
		Uncontrolled Airspace (UN/Controlled Airspace)	0.3				
Instrument Approach Operations and Procedure /Instrument Departure/Instru	0.375	Arrival	0.1	LOW	3	3	1.125
		Departure	0.15	LOW	3		
		Instrument Approach Operations and Procedure (PA/VPA/Circling Steep/STEEP Approach)	0.35	LOW	3		
		Missed Approach	0.4	LOW	3		

m ent Arrival (INS APP OPS/DEP/A RR)		Performance Behavior						
Environmental Effect	0.125	Bird Congestion		0.3	LOW	3	3	0.50625
		Local Weather Phenom ena	Average Annual Thunderstorm	0.28	MED IUM	10.5	5.1	
			Gusty Wind/Wind Show	0.28	LOW	3		
			Icing Condition	0.28	LOW	3		
			Marginal Weather Condition	0.16	LOW	3		
Aerodrome Physical Factors	0.125	Short Field Operations		0.3	LOW	3	5.7	0.7125
		Runway Widths >45 M		0.3	LOW	3		
		Pavement Classification Number (PCN) Vs Aircraft Classification Number (ACN) Ok?		0.15	LOW	3		
		Approach Lighting System		0.15	LOW	3		
		Runway/TAXI Way/Apron Lighting		0.5	LOW	3		
		Runway/TAXI Way/Apron Marking		0.5	LOW	3		
FINAL RISK INDEX								7.84375

5. Conclusion:

In the aviation industry, the proper model implementation (by applying experts' viewpoints) is a critical issue in all aerodrome safety management. Safety risk assessment in aerodrome with critical operational scopes is the main issue. The current Safety Risk Management model for aerodromes is not adequate to adapt to the complexity and consider all aspects of aerodrome criteria that have a positive impact on a safety level. In this study, 6 criteria and 23 sub-criteria were suggested and their weights were calculated (considering experts' opinions). Then, these weights were measured and the overall safety risk index was measured. This approach can provide an integrated method for the Safety Risk Assessment of aerodromes. The safety expert can monitor the safety levels by assessment of the main criteria performance and provide feedback for improvement. As a case study, one Aerodrome was considered. Based on the safety risk assessment results, the aviation experts were interviewed to verify the results and accept our model outcomes. The introduction of an integrated model for the assessment of safety risk is the new approach that was developed in this research. This research employs an Entropy methodology to apply to quantify judgments. The selected approach showed flexibility while at the same time promising robustness in modeling the qualitative assessments and judgments.

It has also been proposed to apply Fuzzy concepts like Fuzzy Promethee, Electre Promethee, Electre Fuzzy, Fuzzy Topsis and compare and select the proper and optimized method.

Declaration of Conflicting Interests

The author(s) hereby declare no potential conflicts of interests for the research, authorship, and/or publication of this article.

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