WUT Journal of Transportation Engineering

PRACE NAUKOWE - POLITECHNIKA WARSZAWSKA. TRANSPORT

ISSN: 1230-9265
DOI: 10.5604/01.3001.0016.3201

vol. **136**
2023

Review of risk assessment tools and techniques for selected aspects of functioning aerodrome operator

Dominika Marzec [1], **Radosław Fellner** [2,*]

[1] Warsaw University of Technology, Doctoral School no. 5, Warsaw, Poland
[2] Main School of Fire Service, Institute of Internal Security, Warsaw, Poland

Abstract: Safety risk management is crucial for aviation industry companies. Each aviation organization (i.e., airlines, aerodrome operators, General Aviation entities, etc.) has different specificity and deals with other factors. Numerous studies on safety risk management have been conducted. However, the authors of the presented paper have seen a need to review one of its multiple aspects - the risk assessment from the perspective of an aerodrome operator. The variety of risk assessment tools and techniques gives many possibilities but can also cause disarray if rules or selection criteria are not developed. The paper aims to present the risk assessment tools and techniques that may be the most beneficial for selected safety aspects of aerodrome functioning. For this purpose, existing risk assessment techniques and tools were collected and briefly reviewed. Their usefulness for the aerodrome operator was verified according to the proposed issues related to the safety of aerodrome operations. Analysis has shown that a manual summarizing and reviewing risk assessment tools and techniques could be helpful for aerodrome operators.

Keywords: safety risk analysis, risk assessment, aerodrome safety management system, airport, aviation safety

1. Introduction

Safety risk management is crucial for aviation companies (i.e., airlines, aerodromes operators, and General Aviation entities). That is why widely implementing Safety Management System (SMS) is required [17]. SMS elements may be subject to scientific analysis within the Safety I, II, or III approaches. While Safety I is commonly defined as the absence of accidents and incidents, in Safety II approach emphasizes the ability to succeed under varying conditions. Safety III highlights freedom from unacceptable losses and the design process of the system [36]. Regardless of the adopted perspective, the critical aspect is undoubtedly risk assessment.

Article citation information:

Marzec, D., Fellner, R. (2023). Review of risk assessment tools and techniques for selected aspects of functioning aerodrome operator, WUT Journal of Transportation Engineering, 136, 5-22, ISSN: 1230-9265, DOI: 10.5604/01.3001.0016.3201

*Corresponding author
E-mail address: maarzecdominika@gmail.com (D. Marzec), rfellner@sgsp.edu.pl (R.Fellner)
ORCID: 0000-0001-8744-7662 (D. Marzec), 0000-0002-9095-4996 (R. Fellner)

Received 16 September 2022, Revised 13 February 2023, Accepted 19 February 2023, Available online 2 March 2023

In addition to those highlighted in the scientific literature perspectives towards safety analyses, investigations, and management, those such as System-Theoretic Accident Model and Processes (STAMP) model and its accompanied methods, namely the System-Theoretic Process Analysis (STPA) and Causal Analysis based on System Theory (CAST) must not be neglected.

Our paper focuses on one of numerous elements of SMS: risk assessment because itself has many benefits [33]:

- derive the information and values of likelihood and severity of consequence for each identified hazard,
- allow use above information to prioritize actions, i.e., which hazard requires the most work and should be tackled first?
- enable specific mitigating features as appropriate to each hazard,
- help predict the effectiveness of those features in reducing the risk.

It is justified to say that risk assessment (RA) allows better preparation for threats, identifies areas in which it is necessary to develop or adjust internal procedures, and, last but not least, facilitates work organization or resource planning. Maintaining the continuity of aviation operations and resistance to external disturbances is essential. In scientific literature, entities from the aerospace industry or civil aviation - such as airlines, national aviation authorities, Air Traffic Control services, and even aircraft carriers, are successfully examined through the prism of the High-Reliability Organization (HRO) paradigm [20]. HROs "perform missions involving processes that require extraordinary measures to maintain low risk in the presence of disruptions that could result in catastrophic events" [25]. There are also "ready to increase performance to peak load at any time and, in doing so, avoid any crippling operational failures" [32], as well as "operate in a nearly error-free manner for long periods" [26]. Such a definition enables the classification of the aerodromes exactly as HRO. Even entire aviation is seen as High-Reliability System [30]. HROs are sites where the culture of safety, improving procedures, and event preparation are prioritized. In the case of aviation entities, this culture is shaped within and based on the above-mentioned safety management system [12].

It is worth emphasizing that each aviation organization has different specificity and deals with other factors and risks. The authors are aware of the broadness of the topic. Many types of research on this matter have been conducted [1, 9, 11, 33, 23, 35]. We claim that a detailed review from the perspective of the aerodrome operator is needed. The study considered the requirements of applicable law and the nature of the aerodrome management activities.

There are many different risk assessment tools and techniques [34]. These various choices give many possibilities but can also cause disarray if rules for their use have not been developed. The paper aims to present the methods and techniques of risk assessment that are most beneficial and useful for selected crucial safety aspects of the aerodromes' functioning. For this purpose, the existing risk assessment techniques were collected and reviewed. Exemplary areas and issues related to the safety of airport operations have been defined, for which risk assessment may be required or necessary. Next, official publications of selected aviation authorities were analyzed in terms of the techniques they recommend. A compilation has been made based on which highlighted methods and techniques that are most beneficial for the defined example issues have been identified and briefly described.

The authors analyzed the literature and conducted participant observations. The research considered the experience of representatives of civil aviation organizations described in previous research by one of the authors [28, 29].

2. Aerodrome operator perspective

A thorough and detailed analysis of the areas of airport operation deserves a separate, in-depth study, which goes far beyond the scope of this study. However, it is already worth mentioning that in such broad issue as "aerodromes and ground handling", there are 33 safety issues, i.e. [2]: aircraft movement, control of airside works, bird/wildlife control, ground staff movement around aircraft, experience, training and competence of individuals.

The European Risk Classification Scheme provides 10 "key risk areas", but only a few may apply to aerodrome operators [5].

Furthermore, a risk assessment framework was created to assess airport climate change risks [6]. The risk was defined as a "function of hazard, exposure, and vulnerability (sensitivity and adaptive capacity)". Further, special to tackle the Covid-19 pandemic in airports, the generic baseline model for multi-layered risk assessment and determining mitigation measures (a four-step process) was developed [16].

As it follows from previously described approaches to Safety I-III, aerodrome operators reactively and proactively analyze safety. While managing the safety of daily activities or upcoming changes, the operator needs tools and techniques to identify hazards and proactively assess risks. The reactive methods are required once the task is to investigate an event.

Safety procedures of an airport have to be coordinated and interfaced with safety procedures of other relevant organizations that are active at the aerodrome. These organizations are (among others): aircraft operators, air navigation service providers, providers of apron management services, ground handling service providers, providers of services to persons with reduced mobility, aircraft maintenance organizations, flying training organizations, public authorities that operate on the movement area, as well as other organizations that perform activities independently at the aerodrome [7]. The multiplicity of stakeholders is another determinant of the safety assessment technique.

The authors of the article distinguished examples of the aerodrome's risk assessments topics of different natures:

- change of aerodrome equipment – new radio communication system introduction, present radio communication system withdrawal,
- change of aerodrome equipment – a process of transition to the new radio communication system,
- demonstration of compliance when alternative means of compliance to those adopted by the European Union Aviation Safety Agency are used by an aerodrome operator,
- wildlife risk assessment,
- apron design change,
- apron construction work,

– incorrect taxing (passed event) analysis.

Our study will provide various insights for aerodrome safety assessment. In the chapter *Applicability of the techniques and tools for the aerodrome operator*, we present the above safety assessment topics and evaluate the applicability of chosen techniques and tools to them.

3. Review of techniques

Safety management system (SMS) implementation is required by law. Aerodrome operators must implement, maintain and continuously develop it. The International Civil Aviation Organization defines four components of the SMS: safety policy and objectives, safety risk management, safety assurance, and safety promotion. This paper focuses on the second component: safety risk management, which consists of two elements: (1) hazard identification and (2) safety risk assessment and mitigation.

There are many aspects to the functioning of an aerodrome operator. The main purposes of an aerodrome activity are to maintain its' infrastructure in good condition and to provide operational services. Most airport operators provide apron management services. Some are air navigation service providers – in these cases, SMS has to cover all activities in the scope of certificates held by the aerodrome operator.

Even when aerodrome operator does not have different certificates, the subjects of performed safety risk assessments are very different; they vary from engineering issues to wildlife, from human factors to emergency management.

In this case, inspecting the condition of the ground infrastructure elements (i.e., movement area, terminals, navigational aids) cannot be ignored. One of the prospective tools whose application is related to risk assessment is Unmanned Aircraft Systems (UAS). Their usage in conditions beyond the EU standard scenarios requires an additional risk assessment. EASA indicates Specific Operations Risk Assessment (SORA) as an acceptable means to demonstrate compliance with Commission Implementing Regulation (EU) 2019/947 of 24th May 2019 on the rules and procedures for the operation of unmanned aircraft [40]. Research has shown that SORA may be used for airframe inspections in an airport [27].

There are many risk assessment tools and techniques which aerodrome operators can use. The authors of this paper identified a total of 58 of them: 41 specified in the ISO IEC 31010:2019 standard [18], nine focused on the human factor [24], two related to UAS operations [10], and six others. Some tools and techniques are universal (applicable to most cases and to most steps of the RA process); however, some have particular uses.

Both are required for aerodrome operators certified according to the Commission Regulation (EU) No 139/2014 of 12th February 2014, laying down requirements and administrative procedures related to aerodromes according to Regulation (EC) No 216/2008 of the European Parliament and the Council. Executive Director of the European Aviation Safety Agency (EASA), in Annex to Decision 2014/012/R, recommends in PART-ADR-OR SUBPART D – MANAGEMENT 5 five hazard identification tools and techniques [7,8]: brainstorming, Hazard and Operability (HAZOP) Study, checklists, Failure Modes and Effects Analysis (FMEA) and Structured What-If Technique (SWIFT). In the same document, it is pointed out that the methods used for hazard identification depend on the resources and constraints of each particular aerodrome operator and the size and complexity of the operations. A few years before, the same techniques were mentioned in the guidance of the European Commercial Aviation Safety Team (ECAST) [13]. For comparison, in official publications, FAA and UK CAA suggest only one technique: Bow-tie [37, 38]. This comparison is presented in Table 1.

Based on the techniques indicated in official publications of selected aviation authorities, the authors propose to focus on five techniques (Brainstorming, HAZOP, Checklists, FMEA, Bow tie). They will be described in the further part of the article.

Table 1. RA techniques recommended by selected aviation authorities and authors` proposal

EASA	**FAA**	**UK CAA**	**Authors proposal**
Brainstorming	-	-	Brainstorming
Hazard and Operability	-	-	Hazard and operability studies
Checklists	-	-	Checklists
Failure Modes and Effects Analysis	-	-	Failure modes and effects analysis
Structured What-If Technique	-	-	-
-	Bow tie analysis	Bow tie analysis	Bow tie analysis

3.1. Bow tie analysis

A bow tie is one of the techniques for analyzing controls. It bases on a diagrammatic way of describing the pathways from sources of risk to outcomes and reviewing controls. Bow tie diagrams are easy–to–understand. It is one of many available methods of presenting barrier models allowing for the gradual and targeted elimination or isolation of sources of hazards and minimization of the risks.

Bow tie combines the fault tree (left side of the diagram) and the event tree (right side of the chart) into one risk scenario. The construction of a bow tie diagram is presented in figure 1.

The main advantage of the Bow tie method is the visualization of individual roles, tasks, procedures, and risk mitigation processes. The diagram allows us to look at organizational processes through the prism of relating them to the identified hazards. The method is also used to examine the occurring events and conduct safety audits [3]. Bow tie models can support the following:

– an enhanced, graphic representation of risk,
– a balanced and cross-domain risk overview for the whole aviation system between internal and external stakeholders (including third-party risks and exposure),
– increased awareness and understanding of the safety risk leading to the 'Key Risk Areas as stipulated by EASA,
– the comprehensive and wide-ranging practical guidance material for safety risk management at an operational and regulatory level,
– identification of critical risk controls and an assessment of their effectiveness,
– an identification of SPIs to monitor the performance of risk control [15].

Table 2 presents tasks where bow tie finds use listed by UK CAA.

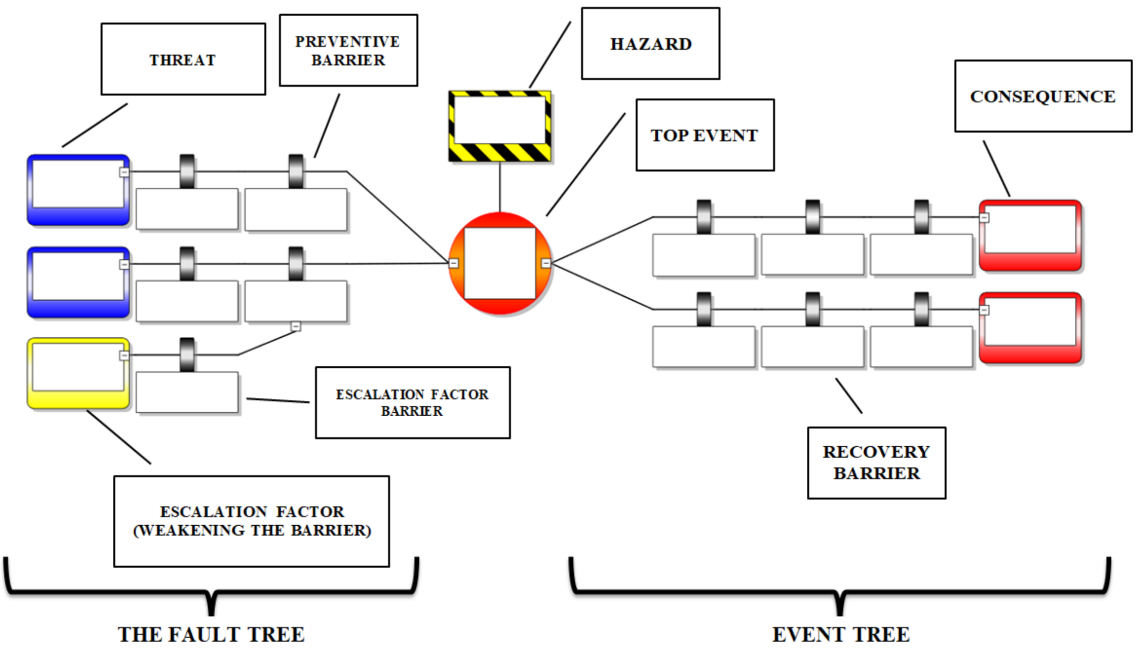

Fig. 1. Bow tie diagram construction (source: own resources)

Table 2. Variety of tasks where bow tie finds use

Group of tasks	Task	Description
INTERFACES	Problem-solving on Hot Topics	Constructing specific bow ties to assess a particular issue/ event
	Performance Based Oversight Audits	Focus on underperforming controls on oversight audits
	Debriefing Aid	Running safety events through the bow tie to appreciate the severity
	Incident/ Accident Investigation	Total system approach considered during an investigation
	Critique of Industry Bow Ties	To review practicality and whether critical controls have been considered
SAFETY REPORTING AND CLASSIFICATION	Risk Classification	Identifying high-level controls to allocate risk grading to mandatory occurrence reports (MORs)
	Safety Event Reporting	Using the controls to drive the questions on a MOR form
SAFETY MANAGEMENT SYSTEM	Hazard Identification	Identifying threats and top events in the safety system
	Risk Assessment	Qualitative assessment of controls
	Risk Mitigation	Taking actions to improve the controls
	Safety Assurance	Identify and monitor safety performance indicators to measure the success of the actions

An example of a hazard to be analyzed with the use of the bow tie method given by the United Kingdom Civil Aviation Authority (UK CAA) is "Large CAT fixed-wing aircraft operating on the ground in or close to the protected area of an active runway", where the top event is 'Incorrect presence of aircraft on the protected area'). Bow tie does not require a high level of expertise to use; it is easy to understand and gives a clear pictorial representation of an event and its causes and consequences. As every method bow tie has its own limitations: it can over-simplify the analyzed issue, and it cannot depict a situation where pathways from causes to the top event are not independent

3.2. Brainstorming

Brainstorming elicits views from stakeholders and experts; it is used in workshops to encourage imaginative thinking. This technique is very popular. However, it often is not used methodically (the term 'brainstorming' is often used to name any type of group discussion).

The technique is based on the idea that groups generate fewer ideas than the same people working individually. The brainstorming session's goal is to encourage people working in a group to develop individual ideas without being constrained by others. A skilled facilitator is able to get a great number of ideas and solutions by stimulating the creativity of a group of people having their individual expertise, experience, and range of viewpoints

The variety of applications of this technique is great: it can be used at any level of an organization to identify causes, consequences, failure modes, success modes, or criteria. Usually, a brainstorming session follows three steps: preparation of the group, presentation of the problem, and guided discussion. A very important rule of a brainstorming session is not to critique or analyze ideas. This is carried out separately from the session, which helps not to limit thinking. Mind maps (Fig. 2) can be used to arrange and develop ideas during a brainstorming session.

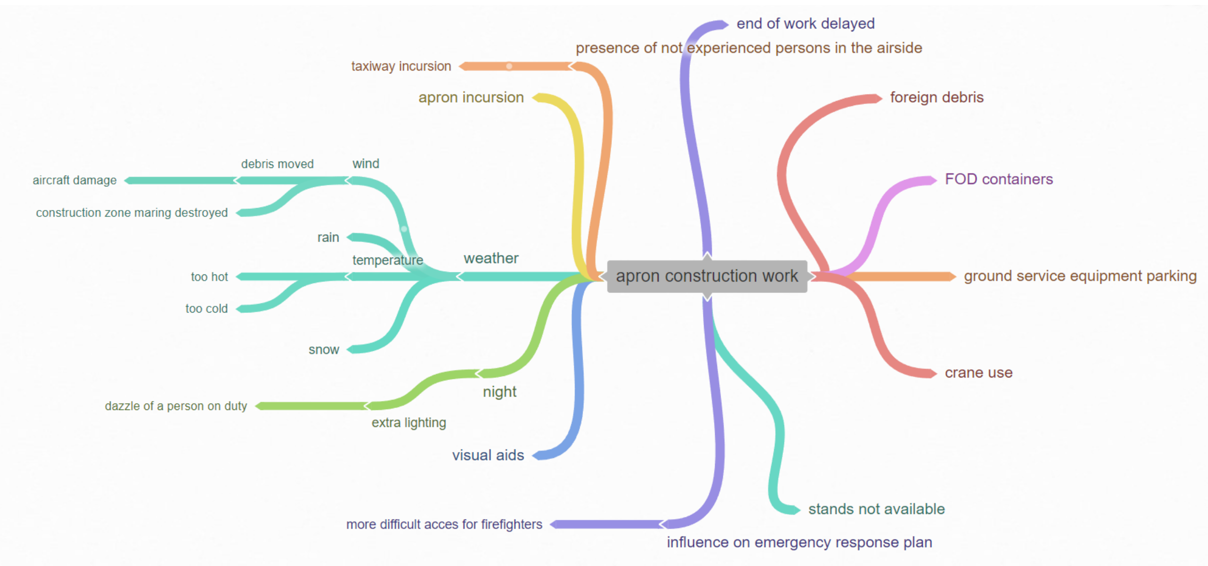

Fig. 2. Example of the mind map (source: own study)

A mind map helps to document the results and to stay focused on the problem [39]. Taking notes in the form of a mind map lets one analyze a few ideas simultaneously. The mind map design corresponds to how the human brain works. This form of meeting notes keeps every idea expandable; experts can easily return to the previous thread. Only single words or simple expressions are noted (saving time), but the reader can recreate the inference made by the group. The mind map below shows how the risk of aircraft damage was identified by analyzing possible weather conditions during the apron construction work.

Brainstorming encourages creativity and imagination; it breaks away from the schemes. Anytime we do not know "where to start", a brainstorming session comes to help. This method is relatively quick and does not require any specific preparation. The key to success is preventing people with valuable ideas from staying quiet - this is one of the facilitator's tasks. This person should spend time and energy supporting the team and guiding the discussion (e. g. refocusing the group if people become side-tracked).

3.3. Checklists

Checklists are one of the techniques for identifying risk. Lists based on experience or on concepts and models that can be used to help identify risks or controls. Checklists are lists of known hazards or hazard causes derived from experience. The experience could be previous risk assessments, similar systems, operations, or actual incidents that have occurred in the past. The technique involves systematically using an appropriate checklist and considering each item on the checklist for possible applicability to a particular system. Checklists should always be validated for applicability before use [10].

Most literature published to date regarding using checklists in the workplace focuses on aviation and aeronautics (Table 3). Primarily because of the high-risk environment in which pilots and astronauts find themselves, these industries have adapted paper and electronic checklists to help decrease human error [14]. Checklists are often named with acronyms representing types of factors considered by the checklist, e.g., the IM SAFE checklist, which pilots may use:

- Illness: Do you have current or recent illnesses that could affect flight?
- Medication: Have you taken any meds that could impair your ability to fly?
- Stress: Are you experiencing unusual psychological pressure and/or anxiety?
- Alcohol: Have you had any alcohol in the last eight hours? Are you hungover?
- Fatigue: Are you tired and/or not adequately rested?
- Emotion: Are you emotionally upset about anything?

IEC 31010:2019 lists the strengths of checklists [18]:

- They promote a common understanding of risk among stakeholders,
- When well-designed, they bring wide-ranging expertise into an easy-to-use system for non-experts,
- Once developed, they require little specialist expertise.

According to the same standard, limitations include the following:

- Their use is limited in novel situations where there is no relevant past history or in situations that differ from that for which they were developed,
- They address what is already known or imagined,

– They are often generic and might not apply to the particular circumstances being considered,
– Complexity can hinder the identification of relationships (e.g., interconnections and alternative groupings),
– Lack of information can lead to overlaps and/or gaps (e.g., schemes are not mutually exclusive and collectively exhaustive),
– They can encourage "tick the box" behavior rather than exploring ideas.

Table 3. Example of an aerodrome works safety checklist

Criterium	Applicable	Nonapplicable	Remarks
Work on the movement area			
Influence on aerodrome operations			
Runway pavement work			
Fencing of the work area in proximity to an active taxiway			
Reduction of runway length available			
Use of a crane			
Influence on an emergency response plan			
Night work			
Influence on aerodrome marking			
Influence on aerodrome lighting			
Influence on radar			
Influence on ILS			

3.4. Failure modes and effects analysis FMEA

Failure modes and effects analysis (FMEA) is also a technique for identifying risk. It considers how each system component might fail and the failure causes and effects (failure means not performing the design intent). The input for this technique is a detailed system description. The system is divided into sub-components. For each of them, the following aspects are considered during the FMEA:
– all the potential ways that the component could fail,
– the effects that each of these failures would have on the system's behavior,
– the possible causes of the various failure modes, and
– how the failures might be mitigated within the system or its environment.

Depending on the nature and complexity of the system, the analysis could be undertaken by an individual system expert or by a team of system experts acting in group sessions [8].

To run FMEA following steps should be taken:
1. Detailed description/ review of the system/ design/ process/ service/ software to be analyzed,
2. Identification of potential failure modes,
3. Identification of the effects of each failure mode,
4. Rating of severity (SEV) for each effect,
5. Rating of occurrence (OCC) for each effect,
6. Rating of detection (DET) of each failure mode and effect,

7. Calculation of the risk priority number (RPN) for each effect,
8. Prioritization of the failure modes for action,
9. Action to eliminate or reduce the high-risk failure modes,
10. Calculation of the Resulting RPN as the failure modes are reduced or eliminated.

The Authors present an example of FMEA analysis in tables 4, 5, 6, and 7.

Table 4. FMEA severity rating scale example

Value	Severity	Meaning
1	None	No consequences for safety or profitability
2	Negligible	Few consequences for safety or profitability
3	Very minor	Nuisance Operating limitations Use of emergency procedures Minor incident Mission slightly delayed
4	Minor	Many nuisances Significant operating limitations
5	Moderate	Mission delayed Use of emergency procedures Minor incident
6	Major	Mission partly completed Use of emergency procedures A reduction in safety margins, a reduction in the ability of operational personnel to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency Minor incident
7	Very major	Mission not completed A significant reduction in safety margins, a reduction in the ability of operational personnel to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency Serious incident Injury to persons
8	Hazardous	A significant reduction in safety margins, physical distress, or a workload such that operational personnel cannot be relied upon to perform their tasks accurately or completely Serious injury Major aerodrome infrastructure/ UAS damage
9	Very hazardous	Aerodrome infrastructure was partly destroyed UAS destroyed few deaths
10	Catastrophic	Aerodrome infrastructure/ UAS destroyed Multiple deaths

Table 5. FMEA occurrence rating scale example

Value	Severity	Meaning
1 2	Extremely improbable	Almost inconceivable that the event will occur
3 4	Improbable	Very unlikely to occur (not known to have occurred)
5 6	Remote	Unlikely to occur, but possible (has occurred rarely)
7 8	Occasional	Likely to occur sometimes (has occurred infrequently)
9 10	Frequent	Likely to occur many times (has occurred frequently)

Table 6. FMEA detection rating scale example

Value	Detection
1	Excellent; Control mechanisms are foolproof
2	Very high; Some questions about the effectiveness of control
3	High; unlikely cause or failure will go undetected
4	Moderately high
5	Moderate; control effective under certain conditions
6	Low
7	Very low
8	Poor; control is insufficient, and causes or failures are extremely unlikely to be prevented or detected
9	Very poor
10	Ineffective; causes or failures almost certainly not prevented or detected

Table 7. FMEA sheet fragment of analysis for an unmanned aerial vehicle's flight above a controlled aerodrome

Process step:	Flight preparation
Failure mode:	No approval for the flight
Potential Effect:	Violation of aerodrome airspace
Severity:	6

Potential cause	Occurrence	Prevention	Detection	RPN
UAS pilot is not aware of the rules	5	Safety Promotion actions The training system of UAS pilots Experienced UAS pilot Secondary Surveillance Radar Aerodrome services personel observation Report of other a/c Drone detector Pre-flight checklist	2	60
Human error	5	as above	2	60
UAS pilot intentionally violates the rules	6	Aerodrome security system Secondary Surveillance Radar Aerodrome services personel observation	5	180

		Report of other a/c Drone detector		
Process step:	Flight preparation			
Failure mode:	Flight safety hazards not identified			
Potential Effect:	Use of emergency procedures			
Severity:	3			
Potential cause	**Occurrence**	**Prevention**	**Detection**	**RPN**
Safety analysis not conducted	4	Regulations The training system of UAS pilots UAS Manual Pre-flight checklist	1	12
Process step:	UAS take-off			
Failure mode:	UAS failure			
Potential Effect:	Mission not completed			
Severity:	7			
Potential cause	**Occurrence**	**Prevention**	**Detection**	**RPN**
Battery capacity alert failure	6	Spare battery Pre-flight check of UAS	3	126
Process step:	UAS take-off			
Failure mode:	The software refuses the take-off			
Potential Effect:	Mission not completed			
Severity:	6			
Potential cause	**Occurrence**	**Prevention**	**Detection**	**RPN**
‚No fly zone' limitation	8	Experienced UAS pilot Pre-flight research	2	96

According to IEC 31010:2019, the strengths of FMEA/FMECA include the following:

– It can be applied widely to human and technical systems, hardware, software, and procedures.
– It identifies failure modes, their causes, and their effects on the system and presents them in an easily readable format.
– It avoids the need for costly equipment modifications in service by identifying problems early in the design process.
– It provides input to maintenance and monitoring programs by highlighting key features to be monitored.

Limitations include the following:

– FMEA can only be used to identify single failure modes, not combinations of failure modes.
– Unless adequately controlled and focused, the studies can be time-consuming and costly.
– FMEA can be difficult and tedious for complex multi-layered systems.

FMEA can be followed by a criticality analysis defining each failure mode's significance (FMECA).

The authors noticed that FMEA was highly popularized in aviation organizations' safety management systems by ICAO Safety Management Manual [17], which gives examples of severity and probability rating scales ready to use in described technique. Conducted participant observations revealed that this technique is often used to analyze issues for which another would be more appropriate. We concluded that many aviation organizations did not consciously choose this technique (by exploring its features, advantages, and disadvantages) but used it because it is proposed in ICAO Manual and used by organizations with more experience.

3.5. Hazard and operability studies (HAZOP)

Hazard and operability studies (HAZOP) are another creative technique for identifying risk. It is a structured and systematic examination of a planned or existing process or operation to identify and evaluate problems that might risk personnel or equipment or prevent efficient operation.

HAZOP uses parameter and deviation guidewords. This technique relies on a very detailed system description being available for study. Usually involves breaking down the system into well-defined subsystems and functional or process flows between subsystems. Each system element is then subject to discussion within a multidisciplinary group of experts against the various combinations of the guidewords and deviations [10]. An example of the HAZOP application is presented in table 8.

Table 8. HAZOP application example

Deviation type	**Guide word**	**Example interpretation for a change of aerodrome equipment – a process of transition to the new radio communication system**
Negative	NO	Aerodrome services have no radiotelephones
Quantitative modification	MORE	Normally not relevant
	LESS	Less than ordered radio telephones delivered
Qualitative modification	AS WELL AS	The new system does not work The previous system is withdrawn (and not possible to reimplement)
	PART OF	Only part of the elements of a new system is operational
Substitution	OTHER THAN	The signal broadcasted by a new system has a different frequency than planned
Time	EARLY	The hardware elements of a new system were delivered too early with reference to clock time
	LATE	The hardware elements of a new system were delivered too late with reference to clock time
Order or sequence	BEFORE	The previous system with withdrawn before the end of the implementation of the new system
	AFTER	The new system training too late in a sequence (e. g. it takes place after the date of implementation of the system)

Guide word/property combinations can be interpreted differently in studies of different systems, at different phases of the system life cycle, and when applied to different design representations. Some combinations might not have meaningful interpretations for a given study and should be disregarded. Generally, the study leader (facilitator) will predefine the appropriate guide word/ property combinations for the study [19].

A final HAZOP worksheet usually consists of a table with each row dedicated to one guide word and columns containing the results of its analysis, e.g.:

1. Guide word: NO
2. Element: radiotelephones
3. Deviation: no radiotelephones
4. Possible causes: delivery disruptions
5. Consequences: transition to the new radio communication system is not possible
6. Existing controls: maintaining the previous system until the new one is implemented
7. Comments: considered acceptable
8. Action required: consider a local supplier of the radiotelephones
9. Action allocated to the technical manager

This method has numerous strengths: most importantly, it supports a reliable and methodical examination of a system, process, or procedure. That is time-consuming. However, it allows us to identify potential hazards at the design stage of the analyzed project. Using this technique, we must remember that it focuses on details, not wider or external issues.

4. Applicability of the techniques and tools for the aerodrome operator

The authors choose six examples of risk assessments that an aerodrome operator may conduct. The examples correspond to EASA requirements for aerodrome operators [10].

Each example of risk assessment is an assessment in the scope of the safety management system, so it focuses on the hazards that are directly pertinent to aviation safety and not on the general/ industrial hazards.

The applicability of techniques and tools for the aerodrome operator was evaluated by comparing the examples of the aerodrome's risk assessments (Table 9) to the characteristics of chosen techniques and tools (Table 10).

Table 9. Examples of the aerodrome's risk assessments

No.	Description	Purpose
1	Change of aerodrome equipment – new radio communication system introduction, present radio communication system withdrawal	Assessment of the impact of the change of aerodrome equipment on identified hazards and risk mitigation strategies before its implementation.
2	Change of aerodrome equipment – a process of transition to the new radio communication system	Assessment of safety risks related to the new radio communication system introduction process.
3	Demonstration of compliance when alternative means of compliance to those adopted by the European Union Aviation Safety Agency are used by an aerodrome operator	Assessment should demonstrate that an equivalent level of safety to that established by the Acceptable Means of Compliance (AMC) adopted by the Agency is reached.

4	Wildlife risk assessment	Assess the wildlife risks in and in the surroundings of the airport.
5	Apron design change	Assessment of the impact of the change of layout of an apron on identified hazards and risk mitigation strategies before its implementation.
6	Apron construction work	Assessment of safety risks related to the construction work on an apron.
7	Incorrect taxing (passed event) analysis	Event investigation. Assessment of the safety barriers.

Table 10. Characteristics of selected techniques and tools

	Bow tie	**Brainstorming**	**Checklists**	**FMEA**	**HAZOP**
Application	analyze risk analyze controls describe risk	elicit views	identify risks or controls	identify risks	Identify and analyze risks
Scope	dep, equip /proc	any	dep, equip /proc	dep, equip/ proc	equip/ proc
Time horizon	Short, medium	any	any	any	medium, long
Decision level	any	any	any	tactical, oper	tactical, oper
Starting info/data needs	low	none	high to develop, low to use	depends on application	medium
Specialist expertise	low, moderate	low, moderate	low/ moderate	moderate	Facilitator: high; Participants: moderate
Qualitative-quantitative	Qual, semi-quant	qual	qual	Qual, semi-quant, quant	Qual
Effort to apply	low	low	low/ medium	low/ high	Medium/ high

The characteristics of techniques originate from IEC 31010:2019:

- Application (how the technique is used in risk assessment): elicit views, identify, analyze cause, analyze controls, etc.,
- Scope (applies to risk at an organizational level, departmental or project level, or individual processes or equipment): level organization (org), project/department (dep), equipment/process (equip/proc),
- Time horizon (looks at short-, medium- or long-term risk or is applicable to any time horizon): short, medium, long, any,
- Decision level (applies to risk at a strategic, tactical, or operational level): strategic, tactical, operational (oper), any,
- Starting info/data needs (the level of starting information or data needed): high, medium, low,

- Specialist expertise (level of expertise required for correct use): low: intuitive or one to two days' training; moderate: training course of more than two days; high: requires significant training or specialist expertise,
- Qualitative – quantitative (whether the method is qualitative, semiquantitative or quantitative): quantitative (quant), qualitative (qual), semiquantitative (semi-quant), can be used qualitatively or quantitatively (either),
- An effort to apply (time and cost required to apply technique): high, medium, low.

The proposition of applicability of chosen techniques and tools to examples of the aerodrome's risk assessments, based on own authors' experience and literature review, is presented in Table 11.

Table 11. Applicability of chosen techniques and tools to examples of the aerodrome's risk assessments

No.		**Bow tie**	**Brainstorming**	**Checklists**	**FMEA**	**HAZOP**
1	Change of aerodrome equipment – new radio communication system introduction, present radio communication system withdrawal		x		x	x
2	Change of aerodrome equipment – transition to the new radio communication system	x	x	x	x	x
3	Demonstration of compliance when alternative means of compliance to those adopted by the European Union Aviation Safety Agency are used by an aerodrome operator		x		x	
4	Wildlife risk assessment	x	x		x	x
5	Apron design change		x			
6	Apron construction work	x	x	x	x	x
7	Incorrect taxing (passed event) analysis	x	x		x	x

5. Conclusions

It is worth continuing studies on aerodrome safety management systems. The paper reveals numerous techniques and tools for safety risk assessment. In this study, we have examined various of them, focusing on their applicability to aerodrome operator needs. The authors also proposed a choice of technique, for example, safety issues.

Considering the results of this study, we concluded that a manual on risk assessment tools and techniques dedicated to aerodrome operators would be useful. Aerodrome operators could profit from easy-to-implement risk assessment tools and solutions; this would help to ensure compliance with the requirements and as low as reasonably practicable safety risks levels.

The article presents one of the possible approaches to the paper on risk assessment tools and techniques. A further research direction may be using a systematic literature review (SLR), which would help answer the question of what techniques and tools researchers use, which methods are relatively popular, and which are rarely used.

References

1. Allan, J. (2006). A heuristic risk assessment technique for birdstrike management at airports. Risk analysis, 26(3), 723-729.
2. Annual Safety Review 2021, EASA, DOI: 10.2822/071257, pp. 154.
3. *Bow tie diagrams*, Available at: https://www.ulc.gov.pl/pl/zarzadzanie-bezpieczenstwem/analizy-bezpieczenstwa/4429-diagramy-bow-tie.
4. Chang YH, Yang HH, Hsiao YJ. Human risk factors associated with pilots in runway excursions. Accid Anal Prev. 2016;94, pp. 227–37.
5. Commission Delegated Regulation (EU) 2020/2034 of 6 October 2020 supplementing Regulation (EU) No 376/2014 of the European Parliament and of the Council as regards the common European risk classification scheme, Annex, pp. 4.
6. De Vivo, C., Ellena, M., Capozzi, V., Budillon, G., & Mercogliano, P. (2021). Risk assessment framework for Mediterranean airports: a focus on extreme temperatures and precipitations and sea level rise. *Natural Hazards*, 1-20.
7. Annex to Decision 2014/012/R Of The Executive Director Of The Agency of 27 February 2014 adopting Acceptable Means of Compliance and Guidance Material to Regulation (EU) No 139/2014, Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Authority, Organisation and Operations Requirements.
8. Decision 2014/012/R Of The Executive Director Of The Agency of 27 February 2014 adopting Acceptable Means of Compliance and Guidance Material to Regulation (EU) No 139/2014 https://www.easa.europa.eu/downloads/16802/en
9. Dollard, P., Griffin, I., Berro, A., Cohen, N. J., Singler, K., Haber, Y., ... & COVID, C. (2020). Risk assessment and management of COVID-19 among travelers arriving at designated US airports, January 17–September 13, 2020. Morbidity and Mortality Weekly Report, 69(45), 1681.
10. Easy Access Rules for Aerodromes (Regulation (EU) No 139/2014, revision from April 2022, EASA, pp. 130-132.
11. Falavigna, G. P., Iescheck, A. L., & Souza, S. F. D. (2021). Obstacles risk classification model in aerodromes protection zones using the multi-criteria decision analysis ahp. Boletim de Ciências Geodésicas, 27.
12. Gordon, R., Kirwan, B., & Perrin, E. (2007). Measuring safety culture in a research and development centre: A comparison of two methods in the Air Traffic Management domain. *Safety Science*, *45*(6), pp. 669-670.
13. GUIDANCE ON HAZARDS IDENTIFICATION, ECAST Safety Management System and Safety Culture Working Group (SMS WG), 2009, pp. 2.
14. Hales, B.M. and Pronovost, P.J. (2006) The Checklist—A Tool for Error Management and Performance Improvement. Journal of Critical Care, 21, pp. 231-235.
15. *How does bow tie work,* Available at: https://www.caa.co.uk/safety-initiatives-and-resources/working-with-industry/bowtie/about-bowtie/how-does-bowtie-work/The Mind Map Book: How to Use Radiant Thinking to Maximize Your Brain's Untapped Potential, Penguin Publishing Group, 1996.
16. ICAO Doc 10152 Manual on Testing and Cross-border Risk Management Measures, Second Edition, 2021, pp. 4-2.
17. ICAO: Safety Management Manual - Doc 9859-AN/474. 4th ed. International Civil Aviation Organisation. (2018).
18. IEC 31010:2019. Risk management — Risk assessment techniques. Geneva: International Organization for Standardization, pp. 32-39.
19. IEC 61882, Hazard and operability studies (HAZOP studies) – Application Guide

20. Inan, T. T. (2020). Application of High Reliability Organizations (HRO) in Civil Aviation Related With Civil Aviation Business Models as an Overview. *J Aeronaut Aerospace Eng*, *9*, 222.
21. Ishikawa K. Guide to Quality Control. Revised, Subsequent edition. Tokyo: Asian Productivity Organisation; 1986. Pp. 225.
22. Janik, P., Zawistowski, M., Fellner, R., & Zawistowski, G. (2021). Unmanned Aircraft Systems Risk Assessment Based on SORA for First Responders and Disaster Management. Applied Sciences, 11(12), 5364, pp. 2.
23. Kirkland, I. D. L., Caves, R. E., Humphreys, I. M., & Pitfield, D. E. (2004). An improved methodology for assessing risk in aircraft operations at airports, applied to runway overruns. Safety Science, 42(10), 891-905.
24. Kirwan, B. (1998). Human error identification techniques for risk assessment of high risk systems—Part 1: review and evaluation of techniques. Applied ergonomics, 29(3), pp. 157-177.
25. Lewis, P. (2013, April). Comparison of High Reliability Organizations (HROs). In *2013 Integrated Communications, Navigation and Surveillance Conference (ICNS*). IEEE. pp. 1.
26. Martinez, C., Sanchez-Cuevas, P. J., Gerasimou, S., Bera, A., & Olivares-Mendez, M. A. (2021). SORA Methodology for Multi-UAS Airframe Inspections in an Airport. Drones, 5(4), 141.
27. Martínez-Córcoles, M., & Vogus, T. J. (2020). Mindful organizing for safety. *Safety science*, *124*(January), pp. 1.
28. Marzec, D. (2021). Safety First or Safety Sometimes? In: Kwasiborska, A., Skorupski, J., Yatskiv, I. (eds) Advances in Air Traffic Engineering. ATE 2020. Lecture Notes in Intelligent Transportation and Infrastructure. Springer, Cham. https://doi.org/10.1007/978-3-030-70924-2_7
29. Marzec, D.: The management of change as part of the safety management system of selected civil aviation organisations. War Studies University Scientific Quarterly 2(115), 60-76 (2019).
30. O'Neil, P. D., & Kriz, K. A. (2013). Do High-Reliability Systems Have Lower Error Rates? Evidence from Commercial Aircraft Accidents. *Public Administration Review*, *73*(4), pp. 604.
31. Polish State Commission on Aircraft Accidents Investigation (PKBWL). Final Report, Bombardier DHC-8-402, SP-EQG, 10 January 2018, EPWA. 2018, pp. 62.
32. Porte, T. L., & Consolini, P. (1998). Theoretical and operational challenges of "high-reliability organizations": air-traffic control and aircraft carriers. *International Journal of Public Administration*, *21*(6-8), pp. 848.
33. Spriggs, J. (2002). Airport Risk Assessment: examples, models and mitigations. In Components of System Safety (pp. 183-195). Springer, London.
34. Wilhelmsen, C. A., Ostrom, L. T.: Risk assessment: tools, techniques, and their applications. 2nd ed. John Wiley & Sons.(2019).
35. Yousefi, Y., Karballaeezadeh, N., Moazami, D., Sanaei Zahed, A., Mohammadzadeh S, D., & Mosavi, A. (2020). Improving aviation safety through modeling accident risk assessment of runway. International journal of environmental research and public health, 17(17), 6085.
36. Aven, T. (2022). A risk science perspective on the discussion concerning Safety I, Safety II and Safety III. Reliability Engineering & System Safety, 217, 108077.
37. FAA_Order_8040.4B Safety Risk Management Policy.
38. UK CAA Safety Management Systems (SMS) guidance for organisations CAP 795.
39. Buzan T., The Mind Map Book: How to Use Radiant Thinking to Maximize Your Brain's Untapped Potential, Penguin Publishing Group, 1996.
40. EASA, Easy Access Rules for Unmanned Aircraft Systems, September 2021.