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EASY RISK ASSESSMENT FOR UNMANNED AIRCRAFT SYSTEMS: OUTLINE OF THE METHOD

Wiktor Wyszywacz
Aero Club of Poland, Board Member, Warsaw, Poland

Abstract

The key element of safety systems in air transport is risk management. The rules for the safety of unmanned aircraft system (UAS) operations are established by the Commission Implementing Regulations (European Union [EU]) and national regulations. Risk assessment is the foundation of all activities. The broadest scope is covered by the special category of flights for which the Joint Authorities for Rulemaking on Unmanned Systems (JARUS) developed the Specific Operations Risk Assessment (SORA) analysis. The primary purpose of the SORA analysis is to create a comprehensive safety portfolio, which is attached to the National Aviation Authority (NAA) application for permission to perform specific category flights. Aviation authorities may accept the use of other risk analysis methods to demonstrate risk reduced to a safe level. Easy Risk Assessment (ERA) for UASs is an attempt to determine the risk for UAS flights in a simple way by considering a range of factors influencing risk management in a similar way to the SORA. It is an uncomplicated method, which determines threats and their sources, provides risk management, and allows the determination of the level of risk tolerance. The ERA is intended to be an alternative to the SORA methodology for those looking to carry out risk assessment.

Keywords: easy risk assessment, UAS, safety, threats, risk analysis
Type of the work: original article

ABBREVIATIONS AND ACRONYMS

ADS-B, automatic dependent surveillance–broadcast; AGL, above ground level (height above ground level); ATC, air traffic control; BVLOS, beyond visual line-of-sight operation (operations beyond the visual range of the pilot); CONOPS, the concept of the operation; DAA, detect and avoid ('see and avoid')—the ability to see or detect threats and take appropriate action to meet acceptable flight rules; EASA, European Union Aviation Safety Agency; ERA, easy risk assessment—proprietary risk analysis method dedicated to unmanned aircraft system (UAS); FLARM (combination of 'flight' and 'alarm'), an electronic system used to selectively warn pilots of potential collisions between light aircraft; GA, general aviation; HF, the human factor; ICAO, International Civil Aviation Organization; JARUS, Joint Authorities for Rulemaking on Unmanned Systems; MTOM, maximum takeoff mass—the maximum mass of the unmanned aircraft specified by the manufacturer or constructor, including payload and fuel, at which the unmanned aircraft can be operated; NAA, National Aviation Authority; Pilot, a pilot of an unmanned aircraft; SORA, Specific Operations Risk Assessment—risk assessment for operations of a specific category; UAS operator—any legal or natural person operating or intending to operate one or more UAS; UAV, unmanned aerial vehicle; UAVO, unmanned aerial vehicle operator; ULC, Poland's Civil Aviation Authority; VLOS, visual line-of-sight operation—operations within the pilot's visual range.

* Corresponding Author: 600316413@wp.pl
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1. INTRODUCTION

Hazard risk management aims to ensure an adequate level of safety of unmanned aerial vehicle (UAV) operations. The level of risk depends on the sum of factors characterising a given operation. Risk analysis methods are in most cases based on statistical data. They refer to the occurrence of similar events in the past, under similar conditions, with the use of similar equipment, similar reactions of aviation personnel and regulations and the organisation of the tasks performed. With regard to UAVs, there is a small amount of analytical information or specifics about air incidents or accidents over a longer period of time. Statistics and the resulting figures form the basis for the use of quantitative methods. The lack of statistical data precludes the use of such methods. Therefore, qualitative analyses of a proactive and predictive nature are widely used. Hence, an intrinsic element of the risk assessment, regardless of the method, is its subjective component. Therefore, a subjective assessment may lead to differences between the verifying office issuing the consent to perform the operation and the applicant or the performer of the analysis. Regardless of the point of view of threats and possible materialised consequences, conducting a risk analysis builds the awareness and safety culture of unmanned aircraft system (UAS) operations.

In this proprietary risk analysis method, the elements of qualitative methods have been adopted. Appropriately prepared matrices were used to quantify the levels of probability of materialisation of threats and the severity of their effects and other elements. To build the matrices, data contained in official documents of aviation organisations and authorities [1–5], partial data available in the literature [1, 6–11] and opinions of experts, pilots and UAV operators were used. The following methods were also used: interview and questionnaire, the opinions and experience of air traffic controllers and general aviation pilots were taken into account.

The presented original easy risk assessment (ERA) method has features similar to other methods and the Specific Operations Risk Assessment (SORA) method (suggested by the European Union Aviation Safety Agency [EASA]) [12]. The basis for the risk analysis is data from the assumptions developed (the concept of the operation [CONOPS], context) related to the UAS operation. Risk management of the identified threats to UAV flights was based on a risk assessment procedure, which was carried out as follows. The study took into consideration two groups of activities, for which corresponding indicators were established. The basic indicators belong to the first group and the complementary indicators to the second group. The first group concerns the level of probability and severity of the effects of real threats. The risk of this group is related to the sources of hazards and threats, most of which relate to fixed elements of the operations performed. These include the human, technical, environmental and organisational factors. The group of basic indicators includes the P index (probability level index) and the D index (severity level index).

The second group covers the risk of UAV collision, the safety of people on the ground and the possibility of a UAV collision in the air. The indicators of this group concern the most severe effects of real threats to human health and life. The risk of this group is related to the assumptions that specify the conditions, type, place and airspace of the planned air operation. Therefore, the indicators of the second group require taking into account the details contained in the assumptions of the operation, despite the general risk assessment in the first stage of the analysis. The group of complementary indicators of the second group includes the F (fall) indicator, an indicator of the probability level of losses in relation to people after an UAV falls to the ground, and the C (collision) indicator, an indicator of the probability level of a UAV collision in the air with another aircraft (not only manned).

The risk analysis process takes place in four steps:
1. Defining the assumptions of the operation;
2. Determination of the core indicators, indexes^{PD} (the degree of risk relates jointly to the P and D indicators) and risk tolerance levels;
3. Determination of complementary indicators, index^{FC} (the degree of risk relates jointly to the F and C indicators) and risk tolerance level for the operation;
4. Defining how to deal with the risk (optional).

2. STEP I

The purpose of determining the assumptions of the operation is to collect basic information about the nature of the operation, the equipment used, pilots and the operator. The assumptions should contain the following important data allowing for rational risk analysis:
1. Visual line-of-sight/beyond visual line-of-sight (VLOS/BVLOS) operation;
2. Maximum flight altitude;
3. Operational area in terms of population:
   - controlled ground area,
   - rural sparsely populated areas,
   - populated urban areas and
   - assemblies of people
4. Class of airspace
5. Type of airspace
6. Operator (a brief description of activities, personnel and standard operations)
7. Type and model of UAS
8. Maximum takeoff mass (MTOM)
9. Equipment (standard and additional)

3. STEP II

In Step II, the basic indicators, indexes^{PD} and risk tolerance levels for individual threats are determined. The area of analysis is divided into three parts concerning the following issues:
- Human
- Environment and and situational determinants
- Procedures and organisation

The threats are related to their various sources. It has been established that one source may generate several different threats. One threat can come from several different sources at the same time. Knowing the sources of threats allows you to understand the dependencies and conduct a more precise risk assessment.

The ERA method associates the specified threats with the corresponding sources of threats. The system is not closed and other sources of threats may be added to a particular UAS operation or those that are not of significance may be omitted. Table 1 presents examples of several threats and their corresponding sources.

Table 1. Sources of threats in relation to the identified threats (sample part of the table).

Threat and possible sources of its origin		
Threats	**Sources of threats**	
Mistakes in the pilotage	Pilot's mistake while performing aviation activities	1
	Intended deviations from procedures	2
	Ignorance of the procedures to avoid collision courses with other aircraft	3
	Ignorance of emergency procedures	4
	Fall of the UAV	5
	Leaving the engines working after landing of the UAV	6
	Leaving the drive system power on after stopping the engines	7
	Takeoff/landing of the UAV in too strong wind	8
	Improper handling of collisions with birds	9
No flight parameter control	No continuous control of flight parameters	10
Possible mistakes in the pilotage	Poor psychophysical condition of the pilot	11
	Failure to specify the time and range of flights	12
	Performing aviation activities under the influence of alcohol or psychotropic substances	13
	Dangerous attitudes of the pilot related to personality traits	14
	Loss of orientation in the terrain	15
	No continuous control of the position and movement of the UAV in VLOS and BVLOS flights	16
	Insufficient level of knowledge of current regulations	17
	Loss of UAV control in flight	18
	Bad cooperation with observers in BVLOS flights	19
	Misunderstanding of the task to be performed	20
	Lack of continuous control of meteorological conditions	21
	Inadequate selection of personnel in relation to the difficulty of the mission	22
	A sudden change in meteorological conditions	23
	Occurrence of electromagnetic disturbances	24
	No valid medical certificate (if required)	25
Possibility of a mid-air collision	Ignorance of the procedures to avoid collision courses with other aircraft	26

Source: own study

BVLOS, beyond visual line-of-sight; UAV, unmanned aerial vehicle; VLOS, visual line-of-sight.

For each threat, the basic indicator of the probability level of the occurrence of the effects of a real threat is determined. Table 2 is used to calculate the probability indicator.

Table 2. Table specifying the probability index P.

Probability table of an event occurring		
Designation of the P indicator	Characteristics, description of the probability	Probability
A	very likely, frequent, certain	0,5
B	likely, quite frequent	0,1
C	practically possible, sometime will occur	0,01
D	unlikely though possible	10^{-3}
E	only occasionally possible	10^{-4}
F	unlikely	10^{-5}
G	theoretically possible	10^{-6}

Source: own study.

The ERA analysis method takes into account 19 types of threats together with their sources. The list of the specified threats can be extended with additional ones, related to the specificity of the operation. Under certain conditions, the analysed threats may become real, causing various damages and losses.

Table 3 lists the most significant threats for most standard UAS operations. Examples of the values of the basic probability level indicator P were assigned to all threats based on Table 2.

Table 3. Table of threats with probability level indicator P.

Threats table with probability level indicator P		
Threats		
	Human	Indicator P
1	Mistakes in the Pilotage	C
2	No Flight Parameters Control	D
3	Possible Mistakes In The Pilotage	C
4	Possibility of a Mid-Air Collision	E
5	Possible Loss of Control of UAV	D
6	Ignorance of Regulations and Procedures	C
7	Low Level of Safety Awareness	C
8	Poor Psychophysical Condition of the Personnel	D
9	Inadequate Qualifications of Personnel	C
	Environment-Conditions	
10	Incorrect Meteorogical Preparation	C
11	Incorrect Navigation Preparation	C

12	Incorrect Operating Preparation	E
13	Incorrect Technical Preparation	C
14	The Hidden Failure of the UAS from the Manufacturer's Fault	G
	Organization, procedures	
15	Maladjustment of Personnel Qualifications to Tasks	C
16	Incorrect Training Programs and Processes	C
17	Mismanagement	C
18	Improper Supervision	C
19	Inadequate Insurance	D

Source: own study.

Then, after determining the P indicator, the D severity level indicator should be determined, which relates to the effects of real threats. Table 4 was developed, which contains a systematic breakdown of the effects of materialised threats. It covers a wide spectrum of unwanted events, i.e., negative effects, from a mission not completed, to large material losses and loss of health or life of people. These effects are ranked in ascending order from the least severe to the most serious. They describe unwanted events in a general and broad manner but refer to possible cases related to UAV flights. These events are divided into five categories, from V to Z, each of which has three types. Table 4 summarises the effects of real threats.

Table 4. The effects of real threats.

Effects of realised threats				
Category		Type of consequence (effect)		
		1	2	3
Direct operator damage	V	V1: partially completed or not completed mission	V2: breach of credibility and brand image	V3: operator's costs increase
Material damage/loss	W	W1: small damage/material losses on the ground	W2: harm/material losses on the ground	W3: major damage/material losses on the ground
Aviation incidents	X	X1: aviation incident	X2: air accident, damage/ destruction of own UAV	X3: air accident, damage/ destruction to another aircraft
Health	Y	Y1: loss of health of the UAS pilot/personnel	Y2: loss of third-party health on the ground	Y3: loss of health of the pilot/ passenger of another aircraft
Life	Z	Z1: loss of life of the UAS pilot/staff	Z2: loss of third-party life on the ground	Z3: loss of life of the pilot/ passenger of another aircraft

Source: own study.

Each event in Table 4 has a value of one. In categories V, W and X, the more-severe event occurs together with the less-severe event. In categories Y and Z, events can occur independently. The value of the D indicator is determined by the sum of all events. The threats were divided according to the segmentation of the analysis area (the same as for the probability level index P), into three groups:

human, environmental conditions, and organisation and procedures. Table 5 presents examples of D indicators as an exemplification of the application of the division of the effects of real threats and the principles of calculating the basic indicator D.

Table 5. Table describing the severity indicator D.

Table Defining The Severity Level Indicator D																	
Threats		Categories V-Z and a type of effects 1 to 3 (D indicators)															Indicator **D**
		V			W			X			Y			Z			
	Human	V1	V2	V3	W1	W2	W2	X1	X2	X3	Y1	Y2	Y3	Z1	Z2	Z3	
1	Mistakes in the Pilotage	1	1	1	1	1	1	1	1	1		1	1		1	1	13
2	No Flight Parameter Control	1	1	1	1	1											5
3	Possible Mistakes in the Pilotage	1	1	1	1	1	1	1	1	1		1	1		1	1	13
4	Possibility of a Mid-Air Collision	1	1	1	1	1	1	1	1	1	1	1	1		1	1	14
5	Possible Loss of Control of UAV	1	1	1	1	1	1	1	1	1		1			1		11
6	Ignorance of Regulations and Procedures	1	1	1	1	1	1	1	1	1		1					10
7	Low Level of Safety Awareness	1	1	1	1	1	1	1	1								8
8	Poor Psychophysical Condition of the Personnel	1	1	1	1	1	1	1									7
9	Inadequate Qualifications of Personnel	1	1	1	1	1	1	1	1								8
	Environment-Conditions	V			W			X			Y			Z			
10	Incorrect Meteorological Preparation	1	1	1	1			1	1								6
11	Incorrect Navigation Preparation	1	1	1	1			1	1								6
12	Incorrect Operating Preparation	1	1	1	1	1		1	1	1		1					9
13	Incorrect Technical Preparation	1	1	1	1	1	1	1	1			1					9
14	The Hidden Failure of the BSP from the Manufacturer's Fault	1	1	1	1	1		1	1	1	1	1	1				11
	Organization, Procedures	V			W			X			Y			Z			
15	Maladjustment of Personnel Qualifications to Tasks	1	1	1	1			1	1		1						7
16	Incorrect Training Programs and Processes	1	1	1	1			1	1			1					7
17	Mismanagement	1	1	1	1												4
18	Improper Supervision	1	1	1	1	1	1	1	1								8
19	Inadequate Insurance				1	1		1	1								4

Source: own study.

After the P and D indicators are determined, the indexes^{PD} are determined. They define the risk of the analysed threats for a given operation. The indexes^{PD} are summarised in Table 6.

Table 6. Table of indexesPD for specific threats.

Table of indexes PD			
Threats		**Index PD**	
	Man	Indicator P	Indicator D
1	Mistakes in the Pilotage	C	13
2	No Flight Parameters Control	D	5
3	Possible Mistakes In The Pilotage	C	13
4	Possibility of a Mid-Air Collision	E	14
5	Possible Loss of Control of UAV	D	11
6	Ignorance of Regulations and Procedures	C	10
7	Low Level of Safety Awareness	C	8
8	Poor Psychophysical Condition of the Personnel	D	7
9	Inadequate Qualifications of Personnel	C	8
	Environment-Conditions		
10	Incorrect Meteorological Preparation	C	6
11	Incorrect Navigation Preparation	C	6
12	Incorrect Operating Preparation	E	9
13	Incorrect Technical Preparation	C	9
14	The Hidden Failure of the UAS from the Manufacturer's Fault	G	11
	Organization, procedures		
15	Maladjustment of Personnel Qualifications to Tasks	C	7
16	Incorrect Training Programs and Processes	C	7
17	Mismanagement	C	4
18	Improper Supervision	C	8
19	Inadequate Insurance	D	4

Source: own study.

Knowing the indexes^{PD}, the risk tolerance level is determined from the developed tolerance matrix for indexes^{PD} (Table 7). The matrix includes the values of the designated risk indexes^{PD} for the P and D indicators.

Table 7. Tolerance matrix for indexes PD.

Tolerance matrix for indexes PD																
Probability indicator P from A to G	Indicator D – severity (A1-E3) from 1 to 15															
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	
A	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*A11*	*A12*	*A13*	*A14*	*A15*	EXTREME INTOLERABLE
B	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*B8*	*B9*	*B10*	*B11*	*B12*	*B13*	*B14*	*B15*	
C	*C1*	*C2*	*C3*	*C4*	***C5***	***C6***	***C7***	***C8***	***C9***	***C10***	*C11*	***C12***	***C13***	*C14*	*C15*	
D	*D1*	*D2*	*D3*	***D4***	***D5***	*D6*	***D7***	*D8*	*D9*	*D10*	***D11***	*D12*	*D13*	*D14*	*D15*	
E	*E1*	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	*E8*	*E9*	*E10*	*E11*	*E12*	*E13*	***E14***	*E15*	
F	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*	*F11*	*F12*	*F13*	*F14*	*F15*	
G	*G1*	*G2*	*G3*	*G4*	*G5*	*G6*	*G7*	*G8*	*G9*	*G10*	***G11***	*G12*	*G13*	*G14*	*G15*	
RISK	ACCEPTABLE INSIGNIFICANT					LOW CONTROLLED			TOLERATED MODERATE					HIGH		

Source: own study.

The risk tolerance matrix for the PD indexes indicates which threats have an acceptable risk and which require risk reduction.

4. STEP III

If the level of risk determined in Step II is too high, reduce the risk and repeat Step II. Step III can be commenced after achieving an acceptable risk level in Step II. Step III verifies the credibility of the results of Step II of the risk analysis. In Step III, the complementary indicators F (fall, defining the ground risk) and C (collision, determining the airborne risk), indexFC and the level of risk tolerance for the operation are determined as a complement to Step II. In the ERA method, a maximum flight altitude of 250 m above ground level (AGL) was used to quantify the fall indicator level F. Most UAV flights are performed in the VLOS category at altitudes up to 120 AGL. This restriction is included in the EU regulations on VLOS flights in the open category, effective from Jan. 1, 2021 [4,13]. Flights beyond >120 m AGL are performed much less frequently. The following criteria were also used in Step III:
(a) UAV MTOM up to 5 kg and up to 25 kg (largest UAV dimension <3 m)
(b) Categories of operations VLOS and BVLOS;
(c) Population density of the flying area.

The operational ground area is divided into the following:
- Controlled ground area;
- Sparsely populated land area (up to 53 people/km^2—rural areas in Poland);
- Populated area (up to 4,000 people/km^2—urban areas in Poland);
- Area with a high density of people (>4,000 people/km^2).

The application of a buffer taking into account the adjacent area and the adjacent airspace may allow for the reduction of the F indicator. The presented criteria have been included in the matrix of F indicator values presented in Table 8.

Table 8. Table of F (fall) indicator.

Table of F fall indicator				
MTOM/type of operations	Controlled ground area	Number of people/km²		
		Sparsely populated area (up to 53 people)	Populated area (up to 4,000 people/km²)	Area with a high density of people (over 4,000 people/km²).
up to 5 kg / VLOS	F1	F5	F9	F13
up to 5 kg / BVLOS	F2	F6	F10	F14
5 to 25 kg / VLOS	F3	F7	F11	F15
5 to 25 kg / BVLOS	F4	F8	F12	F16

Source: own study.

BVLOS, beyond visual line-of-sight; VLOS, visual line-of-sight.

The following criteria were adopted to quantify the level of the C collision indicator:

(a) flight altitude below and above 120 m AGL;
(b) instrumentation;
(c) airspace category C/D and G.

Flights >150 m AGL are burdened with a significantly increased probability of a collision due to the much greater possibility of meeting a manned aircraft. The term 'instrumentation' means equipping the UAS with devices and the possibility of using systems to reduce the risk of collisions. These are devices such as Detect and Avoid (DAA), FLARM (combination of 'flight' and 'alarm'), or automatic dependent surveillance–broadcast (ADS-B) integrated with air traffic control (ATC) systems. Flights in controlled airspace, in permanent or flexible airspace structures >150 m AGL, performed under the obtained conditions and permits, are also exposed to an increased likelihood of collisions. Based on the above criteria, Table 9 was developed to quantify the level of the C collision indicator.

Table 9. Table of C collision indicator.

Table of C collision indicator		
Airspace category C, D and G/ instrumentation	Flight altitude	
	up to 120 m	over 120 m
G / with instrumentation	C1	C5
G / no instrumentation	C2	C6
C, D / with instrumentation	C3	C7
C, D / no instrumentation	C4	C8

Source: own study.

Having designated the indicators F and C, the index FC is determined to establish the level of risk tolerance. The sum of the values of the F and C indicators, for the operating conditions specified in the analysis, forms a complementary index^{FC} (e.g., the F10 fall indicator and the C2 collision indicator; hence, index^{FC} is 12). Then, from the matrix for determining the tolerance for the index^{FC} (Table 10), the level of risk associated with falling to the ground and a midair collision is determined.

Table 10. Tolerance matrix for index FC.

Tolerance matrix for index FC																
C collision indicator	F fall indicator															
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
C1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
C2	3	4	5	6	7	8	9	10	11	**12**	13	14	15	16	17	18
C3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
C5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
C6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
C7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
C8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
RISK	ACCEPTABLE INSIGNIFICANT															
	LOW CONTROLLED															
	TOLERATED MODERATE															
	HIGH															
	EXTREME INTOLERABLE															

Source: own study.

The matrix (Table 10) shows that if the risk tolerance for the complementary index^{FC} is in the intolerable area, i.e., index^{FC} ≥20, the operation should not be performed. It is necessary to return to the concept of the operation and introduce appropriate changes to mitigate the risk. If the tolerance level is defined as acceptable or tolerable, i.e., index^{FC} ≤15, one can proceed with the operation as the risk has been reduced to a tolerable level. For index^{FC} with values in the range of 16–19, actions should be taken to reduce the index^{FC} to the range of tolerable or acceptable risk. The index^{FC} assigned for the example operation is 12 (marked in bold) and falls within the acceptable risk area. The index^{FC} relates mainly to the collision and fall of UAV and verifies the result of the risk tolerance of the index^{PD}. If the index^{PD} and index^{FC} indicate the same level of risk tolerance, the operation can be safely performed. In case of negative differences, the risk should be treated by lowering its level.

Each of the methods of qualitative risk analysis, by its nature, is characterised by a descriptive, discretionary and thus subjective component. The operator (applicant) estimates the level of risk for individual threats taking into account their sources. It was assumed that the operator, i.e., the risk analysis contractor, makes the best use of his/her knowledge and the will to carry it out reliably to adjust the requirements of the operation to the assumed risk level. Such actions are in the interest of the operator.

The level of credibility of the results of the risk analysis for UAS operations depends on many factors. The most important are as follows:

- Including significant elements of threats in the assumptions of operations;
- The effectiveness of the methods used to reduce the risk and their reliability;
- The level of subject knowledge of the analysis contractor.

In the preparation of the assumptions of the UAS operation, in addition to setting the mission goal, a very important element in risk management is a clear definition of the potential risk and the proposed measures to reduce it. The use of appropriate methods, systems, or devices allows for appropriate risk mitigation. The level of mitigation depends on the effectiveness of the method used, which increases the 'safety gain'. The credibility of the obtained safety may be a subjective assessment of the operator.

The credibility assessment may also be:

- confirmed by appropriate tests or experiments performed by the operator—the first degree of credibility,

and

- documented by an independent, specialised, recognised entity—the second degree of credibility.

The ERA method allows taking into account the credibility of the first and second degrees when determining the probability level indicator P (forming the indexes^{PD}) and the complementary collision indicator C (forming the index^{FC}). When determining these indicators, the methods, systems, or devices used may—to a small or large extent—mitigate the risk. When using the first degree, the P indicator can be changed by one level (with the second degree by two levels) in the direction of decreasing probability. Similarly, the C indicator can be reduced by one point for credibility of the first degree and by two points for the second degree, which lowers the value of the index^{FC} by two points. If an appropriate safety buffer for adjacent areas is justified, the F indicator can be reduced by one point. An important factor influencing the credibility of the performed analysis is the level of subject knowledge of the analysis contractor.

5. STEP IV

Risk management to reduce or mitigate it depends on many factors related to the nature of the operation and the kind of operator. Most often, the operator can take effective safety measures because of the best understanding of the details of the operation. Therefore, the ERA method provides only the tools useful for efficient operator actions and not arbitrary solutions.

The method explains the basic issues related to risk management. The risk management strategy depends on many factors. The main factors are as follows:

- risk perception;
- robustness/vulnerability;

and

- planned risk responses.

An active approach to safety problems determines appropriate risk management [6,11]. The use of specific actions is considered effective if they reduce the risk to an acceptable level. The acceptable level of risk can be defined as a contractual value agreed by the stakeholders. It determines the degree (level) of risk (called risk appetite) that the stakeholders are ready to accept and the extent to which they will tolerate the possible effects of the threats becoming real. This level corresponds to the value of risk balanced between benefit and loss (taking into account the capital expenditure). The essence of actions is included in the risk management diagram and the ways of reducing its level—risk reduction, avoidance, or transfer, as represented in Fig. 1.

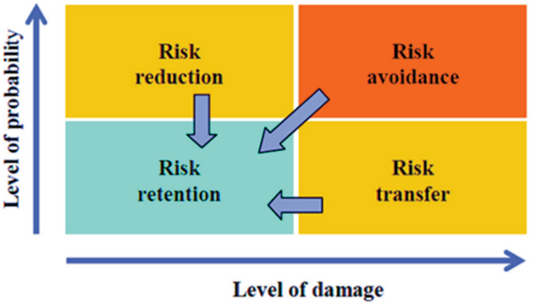

Figure 1. Scheme of risk management activities.
Source: Jamroz K., Kadziński A., Chruzik K., Szymanek A., Gucma L., Skorupski J., TRANS-RISK, Integrated risk management method in transport, Journal of KONBiN 1 (13) 2010 [11].

The ERA method presents the procedure for dealing with risk, which is presented in Table 11.

Table 11. Procedure for dealing with risk.

Procedure for dealing with risk	
Sequence of actions	A description of the action
1	Determining the threats with the highest PD indexes
2	Determining the sources of threats for which the basic indicators P and D have the highest index for threats from point 2
3	Defining the type of action: risk reduction, avoidance and/or transfer, or a mixed-method
4	Identification of operational and/or strategic measures
5	A detailed description of the procedure taking into account the assumptions of the operation
6	Risk evaluation after applying the actions, and in the case of no improvement, repetition the actions from point 4 to 7
7	Deciding on further actions for the third stage of the risk assessment
8	For the FC index ≥20 (intolerable risk) or the FC index with values in the range 16–19 (high risk, tolerable), the actions from point 4 to 7
9	Lowering the risk level in steps II and III of the risk assessment to the assumed level allows for safe performance of UAV operations
10	Lowering the risk level in steps II and III of the risk assessment to the assumed level allows for safe performance of UAV operations

Source: own study.

The ERA method indicates that to choose the appropriate method of operation, it is necessary to move from threats of high-value indexes^{PD} to the sources of these threats. This narrows down the search area for the causes of a high level of risk. Actions to reduce the indexes^{PD} values have been catalogued and divided into two groups: one group consists of human factors, procedures and organisation; and the second group concerning operational, meteorological, navigational, environmental and technical conditions. The exemplary catalogue of risk management is presented in Table 12.

Table 12. Catalogue of operations dealing with risk related to humans, procedures and organisation.

Catalogue of operations dealing with risk – humans, procedures, organization		
1	Qualifications, training	High-quality staff training
2		Improvement training
3		Training sessions on simulators
4		Updating knowledge of regulations
5		Implementation of correct procedures
7		Training in dangerous, contingency and emergencies
6	Organization, procedures	Adaptation of safety and emergency procedures
8		Using and customizing the checklist
9		Shaping safety awareness
13		Maintaining a proper working atmosphere
15		Careful flight planning
16		Precise setting the goals of operations and their implementation methods
22		Proper insurance
10	Management, supervision	Eliminating wrong attitudes
11		Implementation of conscious elimination of stimulants and psychotropic substances
12		Implementation of the principle of working in good psychophysical condition
14		Not allowing personnel to work outside the normative time
17		Adequate selection of personnel to the level of difficulty of the operation
18		Application of effective management
19		Applying effective supervision
20		Periodic verification of personnel qualifications
21		Conducting periodic control of medical examinations
23	Others	Other activities adequate to the needs

Source: own study.

The ERA method recommends technical activities related to equipping UAV with devices and instrumentation, which increase the level of safety of performed operations. Concerning the FC index, the method compiles a catalogue of actions that effectively reduce the value of this index.

The checklist routinely used in aviation also provides answers to questions about what measures should be implemented to reduce the level of risk. The checklist is an effective risk modification tool that indicates specific actions to be performed. The ERA method provides a checklist with preflight, in-flight and postflight routines and activities.

6. SUMMARY AND CONCLUSIONS

The presented ERA risk analysis method is an alternative to other qualitative risk assessment methods and is dedicated to UAS operations. It allows for a detailed analysis of threats and takes into account their sources. This enables an in-depth assessment of the risk and the level of its tolerance. The risk assessment procedure has two components: the first is a risk analysis that takes into account the extremely important human factor, and the second component concerns the measurable parameters of the operation. The risk tolerance level of the second component verifies the correctness of the results of the first component. If the results (tolerance levels) do not match, the risk must be dealt with, which should equalise the risk tolerance levels. This conservative approach increases the accuracy of the method and the level of safety. The ERA is not a normative method, but it enables an in-depth assessment of the risk level intuitively in constant contact with operational reality. The part devoted to dealing with the risk helps find the causes of the threats and the ways of reducing the risk without imposing obligatory solutions.

The ERA has two important limitations. The first refers to the maximum flight altitude up to 250 m AGL and the second, the MTOM up to 25 kg. Apart from that, the ERA method can be compared to the SORA method, which was developed for the risk assessment of special category operations. The advantage of the ERA method is that it takes into account the sources of threats and their identification. The ERA considers the effects of materialised threats to a greater extent with a similar level of risk analysis on the ground and in the air.

In the process of analysis, SORA imposes certain requirements (criteria for the level of integrity, certainty and robustness), while the ERA allows for the selection of risk reduction methods more freely. The ERA takes into account the human factor (HF) to a greater extent, is much less complex, and does not require high competencies from the person performing the analysis.

The proprietary method of the ERA within its scope of use (limitation) has all the features of an effective alternative method of risk analysis for UAS operations.

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