SEVERITY ASSESSMENT FOR AERONAUTICAL RISK ANALYSIS

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Scopul acestui articol este de a descrie şi a analiza activităţile aeroportuare din punct de vedere al siguranţei aeronautice. Procesele de evaluare şi de control al riscurilor au fost întotdeauna considerate ca având un grad maxim de importanţă în industria aeronautică. Acestea au fost influenţate puternic datorită creşterii exponenţiale a traficului aerian în ultimii ani şi a evoluţiei lente a infrastructurii şi capacităţii aeroportuare. Ţinându-se cont de aceste aspecte, ***se propune metoda 6-4-3-5****, o metodă originală, capabilă să ia in consideraţie un număr mai mare de parametri; ea a fost aplicată cu scopul de a reduce severitatea posibilelor riscuri. În general, în comunităţile aeroportuare o atenţie mărită se acordă îmbunătăţirii permanente a nivelului de siguranţă. Prin utilizarea metodei 6-4-3-5 în acest cadru, măsurile necesare pentru diminuarea şi controlul riscurilor ce pot apărea la sol legat de aterizare, decolare, deservire la sol, mediu şi mentenanţă pot fi uşor identificate.*

The purpose of this paper is to describe and analyze the airports' safety aspects. Assessment processes and risk control have always been considered as having the highest degree of importance for the aviation industry. These have been highly impacted due to the exponential growth of the global air traffic and the slow development of the airport's infrastructure and capacity. From these reasons, ***the 6-4-3-5 method is proposed****, an original one, able to take in consideration an increased number of parameters. Usually, innovation in the airports is not an important service issue, the focus being on safety. Using this 6-4-3-5 method, solutions for management aspects like landing, take-off, ground handling, environment and maintenance can be easily identified, while observing the acceptable level of safety.*

Keywords: accident, airport, aviation, event, probability, risk, risk mitigation, score, severity.

1. Introduction

For the past years, risk management process has seen an important evolution within the civil aviation industry. Unlike the risk management theory applied in the economic environment, within the civil aviation industry the risk is,

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in the majority of cases, associated with death followed by other economic losses. In the civil aviation industry, the main objectives followed by the aeronautical service provided through their safety policy are to reduce the risk and minimize the damages. Systematic risk assessment, setting targets through specific methods and strategies for risk mitigation, as well as ongoing monitoring of implementation of measures to further improve the acceptable level of safety play an increasingly important role in the development and implementation of the civil aviation safety policies [1].

Assessment processes and risk control have always been considered as having the highest degree of importance for the aviation industry. These have been highly impacted due to the exponential growth of the global air traffic in the past years and the slow development of the airport infrastructure and capacity. This has translated into a substantial deficit occurring between air traffic and its necessary infrastructure leading at the end to increased risk levels on airports with high traffic.

Establishing an acceptable safety level in the civil aviation industry requires an estimation of the risk exposure closely related to air traffic and, according to this, developing an acceptable and efficient safety policy with the purpose of identifying the objectives which offer a balance between challenge and public and political acceptability. The safety policy is implemented as a measure of control and risk reduction [2].

2. Risk environment analysis

An airport is a multifunctional small universe where multiple networks intersect:

- of transportation – passengers and goods;
- of maintenance of the employees or others who travel from/to the airport (aircraft crew);
- of services: hotels, rentals, banking, etc.;
- of communication.

Airports are centers of air traffic; therefore their surroundings are areas with Airports are centers of air traffic; therefore, their surroundings are areas with high air traffic so the risk level is high. Accidents are happening during take-off, approaching landing, and landing processes, affecting the airports or its surroundings. The degree of risk level increases direct proportional with the airport size. The results of aviation accidents are sometimes as high as the results of road traffic events even if the air transportation represents the safest way of transport.

Increasing airport's operational capacity implies changes in land side and air side infrastructure leading directly to changes in aerodrome maneuvering area and its serving routes. These impact directly the airport and its surrounding risk levels, [3].

For local and national authorities, for the population surrounding the airports, and for airports' managers it is important to determine with a high level of accuracy the correct risk level associated with the air transportation. For this reason, we propose several models of risk level calculation from an airport's aviation assessments taking into consideration real events.

3. Risk in the civil aviation industry

When speaking of quality risks, intuitively one can say that there is a risk if there is a potential danger/hazard. When there is a hazard, a set of measures to eliminate or minimize these conditions is developed. However, the existence of a hazard is not sufficient to define a state of risk. The second risk element is represented by the uncertainty of the event, so it can be said that the risk represents the sum between the uncertainty and its damages as well as their consequences. Based on these statements, we can define *risk* as the assessment of the danger consequences taking as reference the worst foreseeable circumstances being quantified two-dimensional by two factors: probability and severity. There are several types of risks: environmental, human, technologic, etc.

- *Probability* represents the likelihood of an event or condition to appear.
- *Severity* represents the possible effects of an event or condition considering the most disadvantageous case.

Risk mitigation can be done by individually reducing one of the two factors: probability or severity. A simultaneous decrease of the two factors would be more efficient, however, this is difficult and many times impossible to achieve because the nature of these factors is different; probability is subjective (human factor, technological factor or environmental conditions) and objective (number of similar events, airport size, number of land maneuvers); severity, on the other hand, is strictly objective (aircraft size, number of victims or financial costs) [4].

Probability decrease can be obtained, as an example, through implementation of procedures which diminish or even eliminate the risk producing factor. For example, the probability of high risks due to low visibility is highly minimized by utilization of high performance ground radar (A-SMGCS, ILS), high performance radio communication and by different flying tools such as the automated system to avoid another aircraft (Traffic Collision Avoidance System TCAS). Another example would be to reduce the environmental risk due to the large number of aircrafts performing ground maneuvers, in case of a large airport, by implementing of an aviation service management system. In general, in the civil aviation industry, the principle applied is “lessons learned” [5]. This principle states that, after conducting the evaluation of an accident and determine its cause, the findings and the knowledge applied through the procedures will result in mitigation, control and possible elimination of the accident causes so it will not repeat.

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4. Severity Analysis

In the civil aviation industry, in conformity with the ICAO [7] definitions which are used also by the Romanian aviation, every type of event has a severity motive grade for which the following terms have been defined:

- accident - an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:
  a) a person is fatally or seriously injured as a result of: i) being in the aircraft; ii) or in direct contact with any part of the aircraft, including parts which have become detached from the aircraft; iii) or direct exposure to jet blast (except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers or crew);
  b) the aircraft sustains damage or structural failure which affects the structural strength, performance or flight characteristics of the aircraft would normally require major repair or replacement of the affected components (except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin);
  c) the aircraft is missing or is completely inaccessible;
- serious incident – an incident involving circumstances indicating that an accident nearly occurred; The difference between an accident and a serious incident lies only in the result;
- incident - an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation;
- aviation event – operational disruption, defect, error, or any other circumstance which has or might have influence over the flight safety and which doesn't have as a result an accident or a serious incident.

The accident, the serious incident, the incident, as well as the event can be called generically *events of civil aviation* with different severity and probability degrees.

Depending on the severity, the risk can be divided in three categories:

- acceptable risks – frequent risks whose consequences can be negligible;

- tolerable risks – occasional or frequent risks whose consequences have minor damage;
- unacceptable risks – rare risks whose consequences are catastrophic.

If an unacceptable risk is defined through the (1) relation, even if its value might be minimum due to its low probability, it cannot be considered a tolerable risk due to its high severity, respective its consequences. For these reasons a strategy for mitigating the consequences should be applied or, if this cannot be done, the event/action which generates the risk should be eliminated. If there is a requirement, and a strategy for mitigating the risk needs to be applied, the following should be analyzed:

- which are the consequences and what types of measures should be in place;
- which is the frequency of producing and what types of preventing programs should be started;
- the combing the above two methods.

In the following section of this paper two methods of analysis of an aviation event will be presented: ***the scenario analysis and morphological analysis based on 6-4-3-5 method.***

5. The scenario analysis of severity

Further, an example (see Table 1) of how to score the severity depending on the number of victims (deaths or wounded) and costs (material damages of the airport or its surroundings, airport size, aircraft type, aircraft damage) is presented. A score from 0 to 3 is attributed to each factor as following: 0 (no severity), 1 (low severity), 2 (medium severity), 3 (high severity). After scoring, an average is calculated [8] & [9]

Table 1

Aviation events around the globe

No.	ICAO Cod	Data/ Registration	Fly Phase	Country	Airport capacity	Dead	Injured	Damages	Causes	Score
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*[2+6+(7+8)+9+10]/5*
1	C (A320)	17.07.07 PR-MBK	Landing	Brazil	Big	187 + 12	0	Catastrophic	RWY excursion	*[3+3+(3+0)+3+3]/5=3*
2	C (A320)	26.10.07 RP-C3224	Landing	Philippines	Medium	0	19	Major	RWY excursion	*[3+2+(0+3)+2+2]/5=1,8*
3	C (A320)	15.01.09 N106US	Climb	USA	Big	0	0	Major	Birdstrike	*[3+3+(0+0)+2+3]/5=2,2*
4	C (A320)	04.05.09 N311US	Landing	USA	Big	0	0	Minor	Human factors	*[3+3+(0+0)+1+1]/5=1,6*
5	C (A320)	10.01.10 N816UA	Landing	USA	Big	0	0	Minor	Technical errors	*[3+3+(0+0)+1+1]/5=1,6*
6	C (B 737)	30.12.07 YR-BGC	Take-off	Bucharest RO	Big	0	0	Major	RWY excursion	*[3+3+(0+0)+2+2]/5=1,8*
7	C (B 737)	22.08.09 HA-LOG	Taxi	Bucharest RO	Big	0	0	Minor	Human factors	*[3+3+(0+0)+1+1]/5=1,6*
8	C (B 737)	04.04.10 OK-XGA	Handling	Bucharest RO	Big	0	0	Minor	Human factors	*[3+3+(0+0)+1+1]/5=1,6*
9	C (Bae 146)	22.04.08 YR-BEB	Landing	Bucharest RO	Big	0	0	Major	RWY excursion + Metrological Conditions	*[3+3+(0+0)+2+2]/5=1,8*
10	C (B 737)	20.12.08 N18611	Take-off	USA	Big	0	0	Major	Human factors + Metrological Conditions	*[3+3+(0+0)+2+2]/5=1,8*
11	C (A320)	11.08.04 3X-GCM	Take-off	Guinea	Medium	0	0	Major	Human factors	*[3+2+(0+0)+2+2]/5=1,8*
12	C (B 737)	05.05.07 5Y-KYA	Take-off	Kenya	Big	114	0	Catastrophic	Human factors + Metrological Conditions	*[3+3+(3+0)+3+3]/5=3*
13	C (B 737)	10.09.08 EI-DYG	Landing	Italia	Big	0	0	Major	Bird strike	*[3+3+(0+0)+2+3]/5=2,2*
14	C (B 737)	06.06.10 CN-RMF	Take-off	Oland	Big	0	0	Major	Bird strike + Human factors	*[3+3+(0+0)+2+3]/5=2,2*
15	C (Bae 146)	16.08.10 HK-4682	Landing	Columbia	Small	2	114	Catastrophic	RWY excursion + Metrological Conditions	*[3+1+(3+3)+3+3]/5=3*
16	D (A310)	31.03.1995 YR-LCC	Climb	Bucharest RO	Big	60	0	Catastrophic	Technological errors+ Human factors	*[3+3+(3+0)+3+3]/5=3*

17	D (A310)	07.03.2005 F-OJHH	Landing	Iran	Big	0	0	Minor	RWY excursion;	*[3+3+(0+0)+1+1]/5=1,6*
18	D (A310)	17.03.07 S2-ADE	Take-off	Dubai	Big	0	0	Minor	Technological errors + RWY excursion;	*[3+3+(0+0)+1+1]/5=1,6*
19	D (A310)	10.06.08 ST-ATN	Landing	Sudan	Medium	30/214	0	Catastrophic	Metrological Conditions	*[3+2+(3+0)+3+3]/5=3*
20	D (A310)	12.07.2000 D-AHLB	Landing	Austria	Big	0	0	Minor	Technological errors + Human factors	*[3+3+(0+0)+1+1]/5=1,6*
21	D (B 757)	14.09.2000 G-BYAG	Landing	Spain	Small-Medium	0	41	Catastrophic	RWY excursion + Metrological Conditions	*[3+2+(0+3)+3+3]/5=2,8*
22	D (B 767)	20.04.2009 CN-RNT	Landing	USA	Big	0	0	Minor	Human factors	*[3+3+(0+0)+1+1]/5=1,6*
23	D (B 757)	01.01.98 G-WJAN	Landing	Dominican	Small-Medium	0	0	Minor	Human factors	*[3+2+(0+0)+1+1]/5=1,4*
24	D (B 767)	31.10.99 SU-GAP	En Route	USA	Big	217	0	Catastrophic	Human factors	*[3+3+(3+0)+3+3]/5=3*
25	D (MD 11)	22.08.99 B-150	Landing	Hong Kong	Big	3/315	0	Catastrophic	Human factors + Metrological Conditions	*[3+3+(3+0)+3+3]/5=3*

6. Severity analysis based on 6-4-3-5 method

The 6-4-3-5 method is a combination between 6-4-3 method, method mainly applied in process developing, and 6-3-5 method which is characterized through minimization of the response time in realization of a process function. The method is based on the systematic study of the properties by combing them in an array of properties. This method is based on careful studies on the product functions and its risk. This analysis technique it is also known under the morphological analysis, ZWICHY analysis or morphological matrix [10].

There are opinions which state that this method is a variant of brainstorming, being a creative method which helps identifying all the variables of the problem, variables which are afterwards combined in different ways and result in a morphological table or ZWICHY diagram.

The morphological analysis is conducted in the following 6 steps, [11]:

1) establish all the possible events and their conditions under which they must be fulfilled;
2) record all possible variations or ways for the risk appearance; record all possible ways in which every condition of occurrence can be fulfilled;
3) describe all possible combinations transforming all possible variants into a morphological table;
4) describe in „clear” all variants obtained by numerical combinations in the table;
5) carry out an initial elimination of possible solutions: the solutions which are deleted are considered as known;
6) carry out the second elimination of possible solutions: the solutions which are deleted are absurd, incompatible, disadvantageous or dangerous.

The 6-4-3-5 method involves organizing a team of 6 people, which materializes every function in 3 constructive variants (or 3 ideas) in 5 minutes and score each variant from 1 to 4, where 4 represent catastrophic severity. In the most optimistic solution, the target is to obtain 18 materialization functions for each member. Often, in the defined period of time when each team member is working, he or she cannot find only new solutions different from those proposed by others. Every risk assessment is conducted in the same way [12] & [13]. To shorten the service materialization time while a team member materializes for example the *„i”* sub-function, another materializes the *„i+1”* or *„i-1”* function.

Finally, materialization of the event conditions is obtained. An example is presented: equation (4) is shown as an example of materialization of the event risks of a runway excursion, respectively the materialization of the risk *i* matrix.

$$F_i = \begin{pmatrix} a_{11} & \cdots & a_{13} \\ \vdots & \ddots & \vdots \\ a_{61} & \cdots & a_{63} \end{pmatrix}; i \in \{a; b; c; d; e; f\}. \quad (4)$$

For obtaining different solutions in order to mitigate and eliminate the risk, different combinations are done between the solutions proposed to the team for each function. Not all these solutions are reliable. The selection of the possible solution it is done as showed in Fig.1

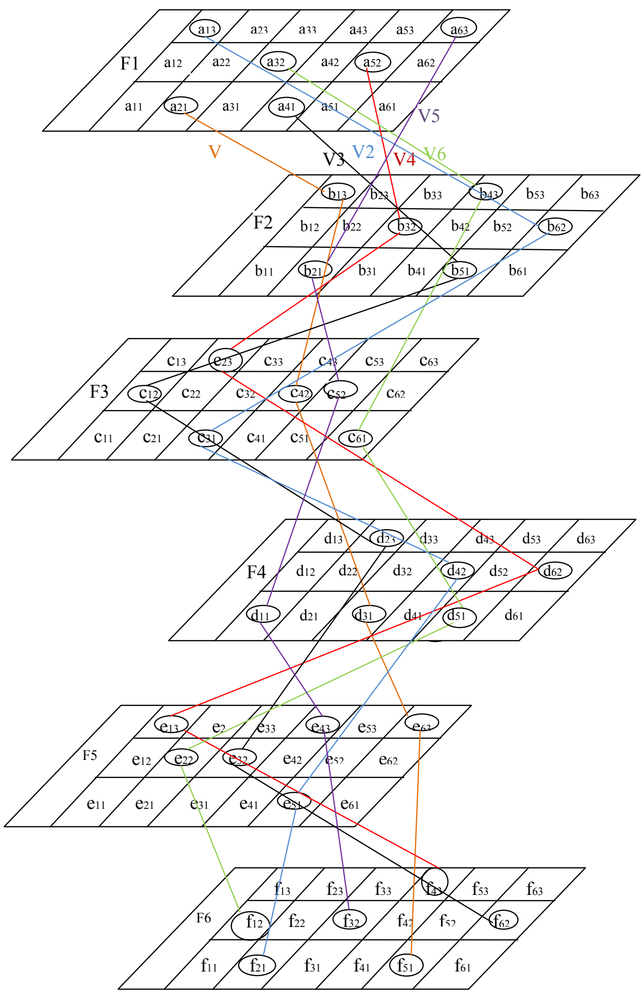

Fig.1: Risk solution selection and available variant selection

For example, a selected solution is: (a_{11}; b_{62}; c_{12}; d_{23}; e_{32}; f_{62}) the blue path, a combination of the 6 risks *a, b, c, d, e, f*. Six such paths were also selected as variants to be comparatively analyzed in the following. As major sources of risk can be considered, for example: pilot errors (risk a), engine failure (risk b), landing gear (risk c), LVO (risk d), rain (risk e) and handling (risk f).

These alternatives are explored by providing a score from 0 to 4 depending on the severity of the risk. In fig. 2 is presented a logical scheme for granting scores to quantify the risks and to determine the share of every characteristic.

For the unacceptable risks, a table is created in which the first column contains the conditions and the second column the share value allocated to each characteristic throughout the operations as presented in Table 2 and for each variant „i" a score from 1 to 4 is assigned depending on the influence. Every solution has 2 columns. In the first column the rating is given and in the second one the share, resulting from multiplying the weighting factor with the score given to the studied risk [14].

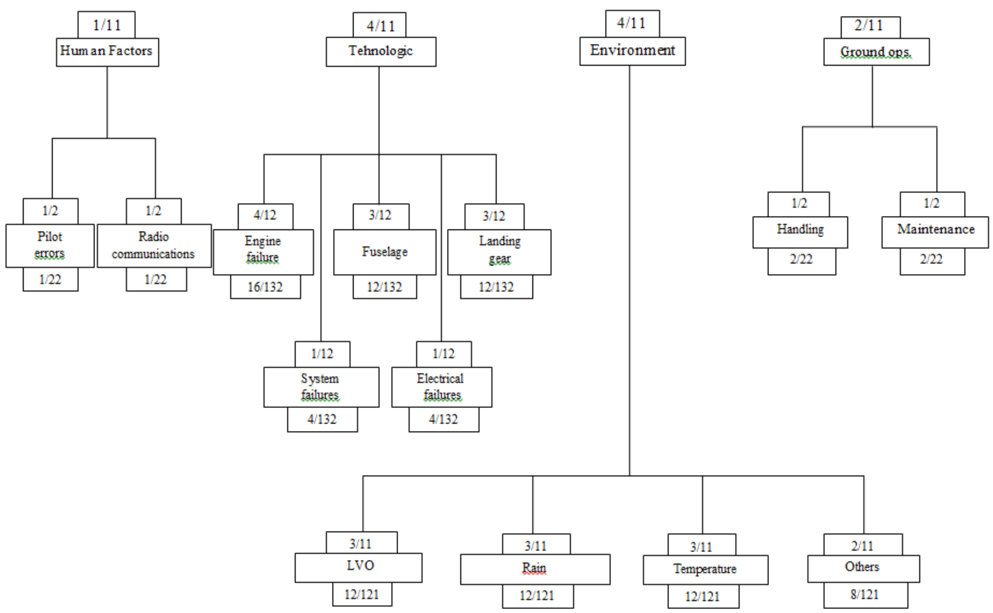

Fig. 2: Weights of every possible solution

By adding the weights of every possible solution, the total score of the accident severity will be obtained. The value considered the most realistic is the solution with the highest score. (**V1**-Table. 2)

Table 2

Risk factors using 6-4-3-5 method (See also Fig.2)

No.	Factors/ Hazards	x	V1		V 2		V 3		V 4		V5		V 6	
			y	xy	y	xy	y	xy	y	xy	y	xy	y	xy
1	Pilot errors	$\frac{1}{22}$	2	$\frac{2}{22}$	1	$\frac{1}{22}$	2	$\frac{2}{22}$	3	$\frac{3}{22}$	2	$\frac{2}{22}$	1	$\frac{1}{22}$
2	Radio communications	$\frac{1}{22}$	1	$\frac{1}{22}$	1	$\frac{1}{22}$	2	$\frac{2}{22}$	2	$\frac{2}{22}$	2	$\frac{2}{22}$	2	$\frac{2}{22}$
3	Engine failure	$\frac{16}{132}$	3	$\frac{48}{132}$	4	$\frac{64}{132}$	3	$\frac{48}{132}$	2	$\frac{32}{132}$	4	$\frac{64}{132}$	4	$\frac{64}{132}$
4	System failure	$\frac{12}{132}$	4	$\frac{48}{132}$	4	$\frac{48}{132}$	2	$\frac{24}{132}$	2	$\frac{24}{132}$	3	$\frac{36}{132}$	3	$\frac{36}{132}$
5	Fuselage	$\frac{12}{132}$	3	$\frac{36}{132}$	3	$\frac{36}{132}$	2	$\frac{24}{132}$	2	$\frac{24}{132}$	2	$\frac{24}{132}$	2	$\frac{24}{132}$
6	Electrical failure	$\frac{4}{132}$	2	$\frac{8}{132}$	1	$\frac{4}{132}$	2	$\frac{8}{132}$	1	$\frac{4}{132}$	2	$\frac{8}{132}$	1	$\frac{4}{132}$
7	Landing gear	$\frac{4}{132}$	2	$\frac{8}{132}$	2	$\frac{8}{132}$	3	$\frac{12}{132}$	2	$\frac{8}{132}$	2	$\frac{8}{132}$	1	$\frac{4}{132}$
8	LVO (low visibility operation)	$\frac{12}{121}$	3	$\frac{36}{121}$	3	$\frac{36}{121}$	2	$\frac{24}{121}$	3	$\frac{36}{121}$	2	$\frac{24}{121}$	2	$\frac{24}{121}$
9	Rain	$\frac{12}{121}$	4	$\frac{48}{121}$	2	$\frac{24}{121}$	3	$\frac{36}{121}$	3	$\frac{36}{121}$	3	$\frac{36}{121}$	2	$\frac{24}{121}$
10	Temperature	$\frac{12}{121}$	3	$\frac{36}{121}$	3	$\frac{36}{121}$	4	$\frac{48}{121}$	3	$\frac{36}{121}$	2	$\frac{24}{121}$	2	$\frac{24}{121}$
11	Others	$\frac{8}{121}$	4	$\frac{32}{121}$	3	$\frac{24}{121}$	3	$\frac{24}{121}$	3	$\frac{24}{121}$	3	$\frac{24}{121}$	3	$\frac{24}{121}$
12	Handling	$\frac{2}{22}$	4	$\frac{8}{22}$	2	$\frac{4}{22}$	1	$\frac{2}{22}$	1	$\frac{2}{22}$	2	$\frac{4}{22}$	3	$\frac{6}{22}$
13	Maintenance	$\frac{2}{22}$	2	$\frac{4}{22}$	1	$\frac{1}{22}$	2	$\frac{4}{22}$	3	$\frac{6}{22}$	2	$\frac{4}{22}$	3	$\frac{6}{22}$
14	**TOTAL**		**Σ xy = 3.059**		**Σ xy = 2.787**		**Σ xy = 2.425**		**Σ xy = 2.379**		**Σ xy = 2.499**		**Σ xy = 2.475**	

6. Conclusions

This paper has considered risk assessment applied to airports. The risk was defined as the assessment of the danger consequences taking as reference the worst foreseeable circumstances being quantified two-dimensional by two factors: ***probability and severity.*** Mathematically the risk was expressed as the product between ***p***, the probability of these damages to appear after applying the necessary actions and ***x,*** the severity expressed through the damages resulted from the hazard's consequences.

Two methods of analysis of an aviation event are presented: *the scenario analysis and morphological analysis based on 6-4-3-5 method.*

As regards the *scenario analysis*, an example was given of how to score the severity depending on the number of victims and costs of 25 aviation events that took place around the world in the past 15 years (Table 1).

In the second part of the paper, ***the 6-4-3-5 method was used, which is an original one.*** Usually, innovation in the airports is not an important service issue, the focus being on safety. Using this risk analysis method however, solutions for management aspects like landing, take-off, ground handling, environment and maintenance can be easily identified, while observing the acceptable level of safety. The method provides advantages like a large number of solutions, a good compliance regarding the safety standards and regulations, and a reduced time to develop solutions in order to mitigate and control the risks. The value considered the most realistic is the solution with the highest score (Table 2).

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