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COSTS OF UNSAFETY IN AVIATION

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Abstract. The purpose of this paper is to define an analytical tool intended to provide a sound, technically justifiable, and consistent approach to analyzing the risk posed by aircraft accidents. The methodology presented in this paper takes into consideration items determined to be important to understanding the risk of aircraft accident and safety appraisal. These items include a number of aircraft operations/flights; crash probabilities; aircraft characteristics; costs, revenues, socio-economic benefits, value statistical life, etc. The presented case study gives various cost assessments for an A320 crash depending on accident severity and aircraft age. It could be used as a risk assessment tool for implementing safety management system (SMS) process.

Keywords: risk management, safety, aircraft accident costs.

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1. Introduction

The term "risk management" has been defined best by ICAO as "the identification, analysis and elimination (and/or mitigation to an acceptable or tolerable level) of those hazards, as well as the subsequent risks, that threaten the viability of an organization" (ICAO Doc 9859 … 2009).

Other authors (Wells and Rodrigues 2003) also define "risk management as "the overall process of identifying, evaluating, controlling or reducing, and accepting risk. It is the general term given to the process of making management decisions about risk that have been identified and analyzed".

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The term "safety risk management (SRM)" has been defined by FAA as "a formal process within the SMS composed of describing the system, identifying the hazards, assessing the risk, analyzing the risk, and controlling the risk. The SRM process is embedded in the processes used to provide the product/service; it is not a separate/distinct process" (FAA AC120-92).

The complete elimination of risk in aviation operations obviously is an unachievable and impractical goal (being perfectly safe means to stop all aviation activities and to ground all aircraft). As not all risks can be removed, nor are all possible risk mitigation measures economically practical. In other words, it is accepted that there will be some residual risk of harm to people, property or environment, but this is considered to be acceptable or tolerable by the responsible authority and the society.

Risk management, being a central component of the SMS, plays vital role in addressing the risk in practical terms. It requires a coherent and consistent process of objective analysis, in particular for evaluating the operational risks. In general, risk management is a structured approach and systematic actions aimed to achieve the balance between the identified and assessed risk and practicable risk mitigation.

The flow chart below (Fig. 1) depicting the risk management process is extracted from ICAO Doc 9859 – Safety Management Manual.

Today the risk conception penetrates practically into all human activities and existence areas (Bounchet *et al.* 2003). Most aviation organizations are (or will soon be) required by their National Aviation Authority to implement a Safety Management System (SMS). The International Civil Aviation Organization (ICAO) has published a framework for a typical SMS with risk management as the core component. Risk Management is split into two elements,

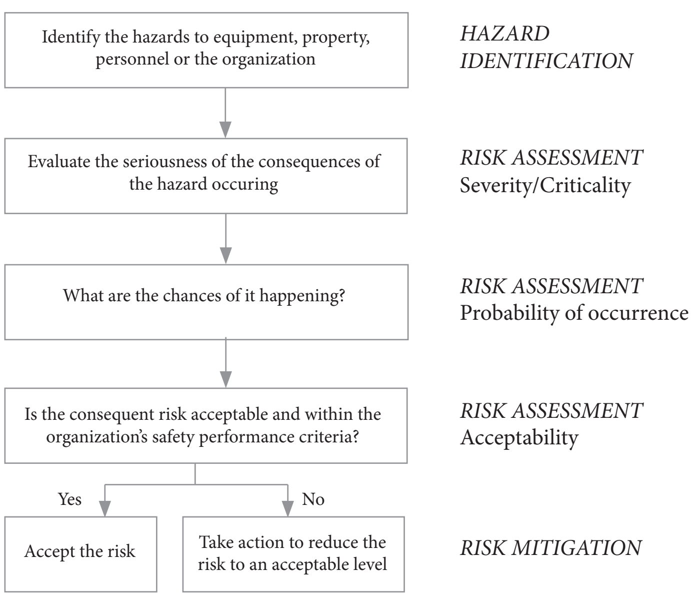

Fig. 1. Risk management process

(a) hazard identification and (b) risk assessment and mitigation. According to (Rutkauskas 2008) every risk corresponds to its own system of the risk management methods.

The authors believe that this methodology will not only enhance the quality of risk assessment in individual aviation organizations but also stimulate increased cooperation between them. This is because the approach introduced is partly built on the idea of "global" risk, i.e. the total risk produced by all involved organizations for certain country.

The methodology is delivered at two levels: the conceptual framework, which should be universal; and a practical application of the methodology which can be customized to meet local specificities of certain country.

The aim of this paper is to produce useful and cohesive operational risk assessment method for certain country. The method is based on (GAIN 2003) which provides information on 57 existing analytical methods and tools that can help the airline community turn their data into valuable information to improve safety.

The produced method needs to match the needs of users across the aviation domain in terms of integrity of results and simplicity of use; and thereby effectively support the important role that risk management has in aviation Safety Management Systems.

2. An approach to risk assessment in aviation

The presented research is based on a cost benefit analysis due to safety related benefits connected to aircraft accident. The sample presented in this paper provides data according to Serbia. The actual safety level for a particular country is based on the total number of realized operations, accidents and incidents while the targeted safety level is based on forecasted data and is assessed according to criteria such are cost, revenues, socio-economic benefits, value statistical life and risk.

The physical safety effects in this paper are expressed as an increase or reduction of accident probability relative to the accident probability in the base case. The associated accident severity and the operational context determine the costs per accident. Multiplication of accident probability by the number of flights results in the physical safety effect: an increase or decrease in the number of accidents. Multiplying the physical safety effects by the accident cost provides the overall safety-related costs. Similar to the other costs and benefits, the safety related costs for each of the alternatives must be compared to the accident related costs of the base case. It is important to realize that a reduction of accident probability (usually the purpose of safety improvement measures), and hence a reduction of the safety related costs constitute a benefit of the project rather than a cost. Calculating the cost associated with the safety effects requires various steps for each of the project cases. The steps can be put into two categories:

- Determining the physical safety effect: calculate accident probability; determine accident type and severity; calculate accident frequency;
- Determining the safety-related benefits: determine aircraft market value and aircraft physical damage cost; determine number of people on-board, number of fatalities and associated costs; determine other heads of cost; calculate total safety-related benefits.

3. Determining the physical safety effect

This paper considers physical safety effects through several issues: accident probability/frequency, type and severity.

Accident probability: determining accident probability is a multifunctional process that should be based on historical data or mathematical models related to event prediction.

Determining accident type and severity: the type of accident is directly linked to the accident severity. Accident severity classification (FAA 2000).

Main accident types: departure from runway, loss of control, fatal accident, weight and balance related event, general disintegration, collision of aircraft, and collision with terrain.

Accident frequency: the accident frequency is calculated by multiplying the accident probability by the (forecasted) number of flights (IFR) for the evaluation period.

4. Determining the safety related benefits

4.1. Determining aircraft market value and aircraft physical damage costs

Accident type and aircraft damage (expressed as a percentage, 100% represents a hull loss) are linked according to Table 1. Translating this damage percentage into monetary terms requires an estimate of the aircraft market value, which largely depends on aircraft size and aircraft age, as demonstrated by (Thomas and Richards 1998). In most cases an average aircraft size and age will have to be estimated. The following tables show data for the aircraft market value (Table 2 and 3) and aircraft physical damage costs appraisal (Table 4) for the A320 that is one of the most commonly operated regional aircraft (Airclaims… 1999).

Table 1. Accident type and severity

Level	Damage, %	Death, %
Catastrophic	100	80
Disaster	100	30
Major	80	0
Moderate	50	0
Minor	15	0

Table 2. Unit value of new aircraft (1999) based on average published list prices

Type	Unit Cost [million €]
A320	44.7

Table 3. Used aircraft, average loss of value with age

Age (yr)	0	1	2	3	4	5	6	7	8	9	10	11	12
Value (%)	100	92	86	81	76	71	66	62	58	54	52	49	46

Table 4. Estimated monthly lease rates expressed as % of current market value

Age (yr)	Narrow-bodied	Wide-bodied
0	1.8	1.6
1	1.8	1.6
2	1.9	1.7
3	1.9	1.7
4	2.0	1.8
5	2.1	1.9
6	2.1	1.9
7	2.2	2.0
8	2.3	2.1
9	2.3	2.2
10	2.4	2.3
11	2.5	2.3
12	2.6	2.5

Table 5. Estimated airport closure relative to accident severity

Catastrophic	5 days
Disaster	5 days
Major	4 days
Moderate	2 days
Minor	2 days

The costs of delay due to aircraft accident presented in Table 6, for example cause by runway decontamination, are specified by (IATA … 1997).

Table 6. Cost per minute of delay per aircraft

	€/min
Ground cost of delay	22.0
Cost of additional flight time/delay in the air	33.0

4.2. Number of fatalities and associated costs

The number of passengers on-board the aircraft equals the number of seats multiplied by the load factor. Table 7 provides average load factors determined by (Piers *et al.* 2006) that can be used when no specific data is available. The number of crew (flight crew and cabin crew) should be added to obtain the total number of occupants. Keep in mind that this number may change during the evaluation period.

Costs associated with fatalities are usually expressed as a Value of a Statistical Life (VOSL) where this 'value' generally includes an element of indemnity together with society's 'willingness to pay' to avoid a statistical fatality (Roelen *et al.* 2001). It is felt that no one 'cost of life' should be 'recommended' but that, rather, it should be left to the user to decide which approach should be adopted and what monetary value should be used. Based on UNITE (UNIfication of accounts and marginal costs for Transport Efficiency, project funded by 5th Framework RTD Programme) the value of statistical life (VOSL) by country, compared to official values in the state concerned (adjusted from 1998 prices), the average VOSL data for different European States is in range 0.65–2.64 million €.

Table 7. Average passenger load per flight

Manufac-turer	Type	Passenger load	Manufac-turer	Type	Passenger load
Airbus	A300	138	Boeing	747 (Classic)	165
Airbus	A310	91	Boeing	747–400	248
Airbus	A319	73	Boeing	757	203
Airbus	A320	96	Boeing	767	236
Airbus	A321	124	Canadair	RJ	30
Airbus	A330	294	Embraer	145	27
Airbus	A340	161	Fokker	F28	54
Avro	RJ	60	Fokker	70	44

4.3. Accident related costs appraisal

Cost estimation is the process of identifying elements of cost and then quantifying (or estimating) them. Cost identification is the first step in the cost estimation process. Cost quantification is the second step in the cost estimating process where cost values are assigned to the cost elements identified in step 1, cost identification (Report No. WP-43-FA92F-99-1, 1998).

Table 8 presents data according to aircraft accident cost estimation due to aircraft type demonstrated by (Čokorilo 2006).

Table 8. Total accident related costs

Cost category	Costs
Aircraft physical damage	Minor, 15% damage Moderate, 50% damage Major, 80% damage Disaster, 100 % damage Catastrophic, 100% damage
Possible loss of resale value	5–10 % of aircraft market value for partial losses
Aircraft loss of use	Monthly lease cost x assumed months to replace = cost of "loss of use" (Table 4)
Site contamination and clearance	Wide body 1.2–2.8 million € Narrow body 0.7–1.3 million € Smaller aircraft 0.13–0.2 million €
Airline costs for delay	Wide body: 22 € per seat per hour Narrow body: 20 € per seat per hour
Airport closure	Airport disruption depends on severity of the accident, estimates provided in Table 5
Deaths and injuries	Value of Statistical Life (VOSL) 1–2.64 million € (Value of injury is 13% of VOSL)
Loss of staff investment	Replacement cost per pilot 45,000 € (Only for catastrophic and disaster events)

Continuation of **Table 8**

Cost category	Costs
Loss of baggage	Underfloor cargo carried on passenger flights 110,000 € Personal baggage on passenger flights 45,000 € (Only for catastrophic and disaster events)
Search and rescue costs	Average SAR cost claim 0.6 million €
Airline immediate response	Average costs per accident 0.5–3 million €
Cost of accident investigation	State 0.1–100 million € Airline 1 million € Manufacturer 1 million € (Only for catastrophic and disaster events)
Third party damage	Third party death and injury: use similar VOSL as in passenger death and injury. Third party physical damage
Increased cost of insurance	Loss of 20% insurance discount for airline involved
Loss of reputation	Airline loss of turnover 0–380 million € Huge range. Loss to society is far less than to airline, since major part of reduced demand will shift to other airline.
	Manufacturer Likely that airline will buy aircraft from other manufacturers.
Other costs	They are part of those listed before

4.4. Total safety related benefits

The total benefits are estimated by multiplying the expected number of accidents by the (average) cost of a single accident. This should be done for each year of the reference period. As indicated before, it is only considered a benefit if the number of accidents is expected to decrease. However, with respect to safety-improving measures this is usually the case.

5. Air traffic forecast for determining air safety profile

This paper presents the forecast of annual numbers of IFR (Instrument Flight Rules) flights from 2003 to 2010 for Republic of Serbia based on (EUROCONTROL 2004). Republic of Serbia is rated Category 2 in the FAA's International Aviation Safety Assessment Program (IASA). From 1947 to 2005, 9 fatal accidents and 12 incidents occurred in the Republic of Serbia with a total number of 164 fatalities.

The forecast is developed by growing a baseline (traffic for the whole of 2003). The forecast takes into account factors such as economic growth, past patterns of supply, the growth of low-cost carriers and the influence of high-speed trains. Three "scenarios" are used to capture the likely range of traffic growth.

Baseline air traffic growth: Gross domestic product (GDP) growth following recent estimates and in other respects lying between the following two scenarios. This is the "most likely" of the three scenarios.

High air traffic growth: This is an optimistic economic recovery scenario, with limited impact from HST, continuing strong growth of low-cost carriers and no increase in load factors.

Low air traffic growth: This is a pessimistic economic growth scenario, with more persistent and greater impact of HST, and some continuation in the increase of load factors.

Figure 2 summarizes the average annual growth of IFR flights for the Republic of Serbia. The main features of the forecast for the defined baseline scenario are slowly declining growth through the period, averaging 4.8% per year (total flight growth from 2003 to 2010 is 38.4%).

Improvement of actual safety level depends on accident frequency in the observed period (until 2010).

6. The proportion accident type model

This approach model involves statistical modeling of the occurrence of air accidents over time; a Poisson sequence or Poisson process is often deployed. Such a process is based on the following assumptions:

- an event can occur at random and at any time or point in space. Past aircraft accidents possess this characteristic. They occur in a random manner in different parts of the world;
- the occurrence of an event at a given time or space interval or segment is independent of what happened in any other non-overlapping intervals or segments. Air accidents, except very rare mid-air collisions, have occurred as a series of independent events in time and space;
- the probability of an event occurring in a small interval Δt is proportional to Δt and can be estimated by $\lambda \cdot \Delta t$ where λ is the mean rate of occurrence of the event. It is assumed constant and equal to $\lambda = 1/T_a$, where T_a is the average time interval between consecutive events. The probability of two or more occurrences in Δt is negligible (of higher order than Δt). From empirical evidence, as Δt is assumed to be a sufficiently short period, the probability of an occurrence of more than one aircraft accident will normally be negligible.

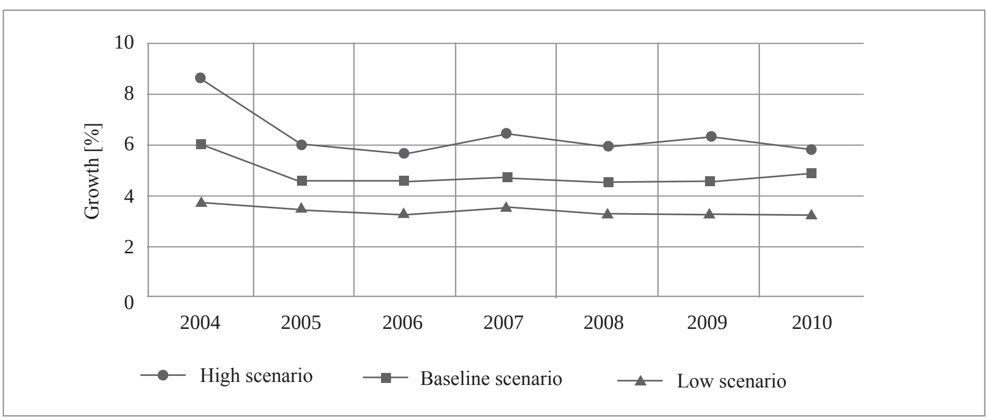

Fig. 2. Annual growth of IFR flights forecast

In Poisson processes, the time intervals between successive events are exponentially distributed, indicating the no-memory property of the process. This means that future events do not depend on the number or time of previous events. This would logically seem to be the case with air accidents. Mathematically, let T be the random variable representing the time between any two consecutive events. This variable is exponentially distributed.

The probability that no accident will occur in time period t is:

$$P(T > t) = P(X_t = 0) = e^{-\lambda \cdot t}, \quad (1)$$

where X_t is the number of air accidents in time t.

Similarly, the probability of the occurrence of at least one event in time t is:

$$P(T \leq t) = 1 - P(T > t) = P(X_t \neq 0) = 1 - e^{-\lambda \cdot t}. \quad (2)$$

The probabilistic assessment of accidents uses a sample of 21 accidents over the period 1947–2003 defined by (Ranter 2006). The distribution of time intervals between these events is shown in Table 9.

Table 9. Number of accidents distribution in 8 years intervals

Observing period (8 years)		
from	**until**	**number of accidents**
1947	1955	4
1955	1963	1
1963	1971	6
1971	1979	6
1979	1987	0
1987	1995	0
1995	2003	4

A simple calculation provides an estimate of the average accident rate of 0.78 accidents per observation period. An analysis of the time intervals between accidents, independent of aircraft type, indicates they have been independent and exponentially distributed. This offers confirmation that the observed pattern of accidents can be treated as a Poisson process. Using the exponential distribution seen in Table 10, it is possible to assess the probability of the occurrence of an air accident.

Table 10. Sample of accident frequency based on poisson distribution

Number of accidents x_i	Number of 8 years periods when x_i accidents were realized: f_i	Poisson $P_\lambda(x) = \frac{\lambda^x e^{-\lambda}}{x!}$	Theoretical frequencies	Probability, %
0	2	0.22	2	22
1	1	0.15	1	15
2	0	0.05	0	5
3	0	0.05	0	5
4	2	0.22	2	22
5	0	0.05	0	5
6	2	0.22	2	22

$$\sum_i f_i = 7. \tag{3}$$

$$\lambda \approx \frac{1}{7}(0\cdot 2+1\cdot 1+2\cdot 0+3\cdot 0+4\cdot 2+5\cdot 0+6\cdot 2)=3. \tag{4}$$

Analysis of the results achieved for the given variation of entered data enables us to determine two main conclusions:

- The probability of a minimum of one expected accident occurrence in Serbia during the period from 2003 to 2010 is 0.78 which is an alarmingly high score.
- Let us assume that during the period from 2003 to 2010 there will certainly be one accident. According to that fact, the probability of at least one expected accident occurrence per IFR flight is $3.5 \cdot 10^{-7}$.

From the airline point of view a probability of $3.5 \cdot 10^{-7}$ accident per single IFR flight is not a troubleshoot, but for medium-term forecasts, one serious accident per 8 year-period presents a risk investment in terms of resources and finance.

7. Total accident related costs A320

In order to ascertain total accident related costs, an estimation is provided on a sample of A320 in the data shown in Table 8: aircraft physical damage, possible loss of resale value, aircraft loss of use, site contamination and clearance, airline costs for delay, airport closure, deaths and injuries, loss of staff investment, loss of baggage, search and rescue costs, airline immediate response, cost of accident investigation, third party damage, increased cost of insurance, loss of reputation and other costs. In order to determine these costs it is necessary to make several assumptions as shown in (Čokorilo 2008):

- It is assumed that 6 months is the optimal period to repair damaged aircraft or to include new aircraft in a fleet after an accident. As a matter of fact this period lasts from 6 months to one year, which is necessary to complete the accident investigation and all procedures and reports.
- Compared to other accident related costs, airline delay related costs are negligible (4000€–20 000€).
- The assumed accident location is not close to the airport, so airport closure related costs are not considered in this study.
- The number of deaths is based on accident severity (Table 1) and average passenger load (Table 7). The number of injuries is calculated as the difference between total number of passengers and number of deaths on a certain flight. For the purpose of this study cabin crew are defined as: cabin crew (4), flight crew (2). The value of statistical life is determined as the average value of all European countries (1.82 million €).
- Accident investigation costs are defined from 0.1 to 100 million €. In this paper a value of 0.5 million € is accepted for the calculation.
- Third party damage is not considered.
- Airline loss of reputation costs are widely defined from 0 to 380 million € and are used in this study to determine limit values of the total accident related costs: min (loss of reputation 0) and max (loss of reputation 380 million €).

Based on previous considerations, results are shown in Fig. 3. All analyzed costs are based on the year 1999. For further analysis, a 5% average annual increase rate of costs is recommended by the EU.

For the observed data we can clearly conclude that a decreasing rate of accident related costs is a function of aircraft age and accident severity. The previously described approach defines a minimum total accident related costs scope (Fig. 4) that varies from 34 million € (case: aircraft age 12 years; severity: minor) to 211 million € (case: aircraft age 0 years; severity: catastrophic). Max total accident related costs scope is also defined from 414–591 million € (this calculation is obtained from the minimum costs increased by 380 million € (max loss of reputation costs).

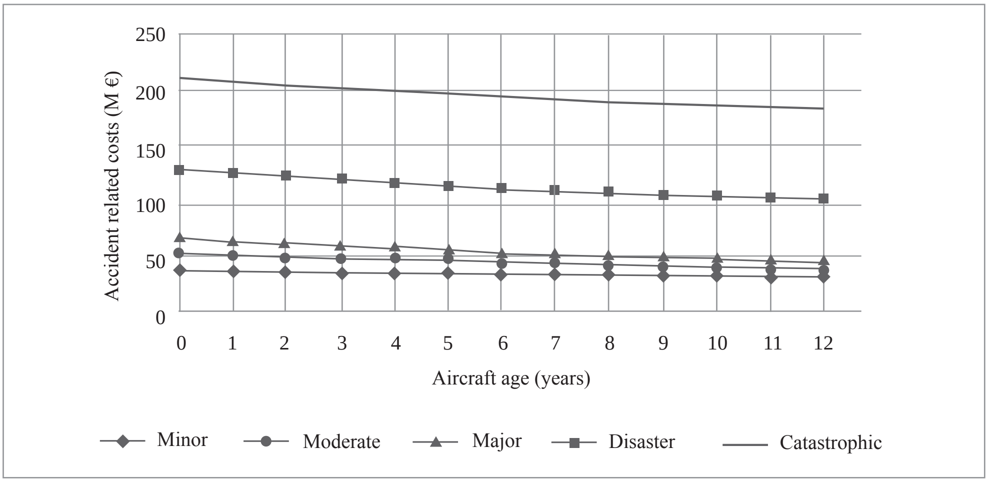

Fig. 3. Min total accident related costs as a function of aircraft age and accident severity (A320)

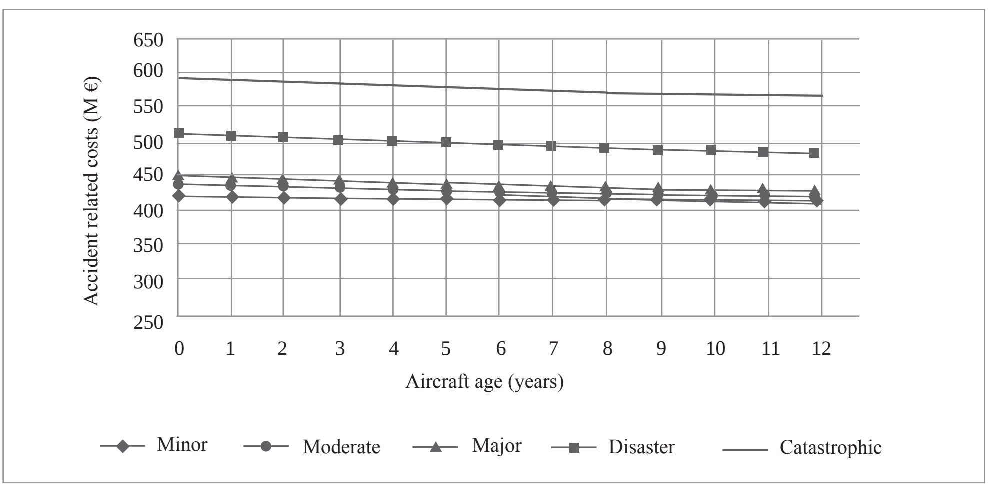

Fig. 4. Max total accident related costs as a function of aircraft age and accident severity (A320)

In the process of defining optimal function it is shown in Table 11 that accident related costs are a linear function of accident severity and aircraft age.

Table 11. Accident related costs as a function of accident severity and aircraft age

Accident severity	Min costs function	Max costs function
Catastrophic	$y_{min} = -2.2101x + 210.38$	$y_{max} = -2.2101x + 590.38$
Disaster	$y_{min} = -2.2101x + 129.62$	$y_{max} = -2.2101x + 509.62$
Major	$y_{min} = -1.8166x + 69.224$	$y_{max} = -1.8166x + 449.22$
Moderate	$y_{min} = -1.2265x + 55.882$	$y_{max} = -1.2265x + 435.88$
Minor	$y_{min} = -0.5379x + 40.315$	$y_{max} = -0.5379x + 420.31$

The A320 was in production for 12 years until 1999, which is used as a referent year for the accident related cost calculation in this paper.

x – Aircraft age (x = 0, 1...12),

y_{min} – min accident related costs for A320,

y_{max} – max accident related costs for A320 with added max loss of reputation costs.

8. Conclusions

This paper has considered risk assessment applied to the measurement of the costs of unsafety, caused by aircraft accident, which could have serious circumstances on human and technical resources.

This approach shows that if the expected accident frequency is high it is recommended that the whole air transport process be re-checked, and critical points improved under the financial resources of potential aircraft accidents with the aim of avoiding them. We determine the cost range based on aircraft (type and age) and accident severity to be min costs 34–211 million €; max costs 414–591million €).

The final product of this research will be a quantitative tool that can be utilized for implementing a safety management system (SMS) which has to be based on cost benefit analysis which balances accident probability and related costs against the costs of safety improvement measures.

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IŠLAIDOS, PATIRIAMOS AVIACIJOJE DĖL NESAUGUMO

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Santrauka

Šio straipsnio tikslas – aprašyti analizės priemonę, skirtą patikimai ir techniškai pagrįstai orlaivių avarijų rizikos analizei. Straipsnyje pateikta metodika gali įvertinti svarbiausius orlaivių avarijų rizikos ir saugos aspektus: tai orlaivių skrydžių skaičius; avarijų tikimybė; orlaivio charakteristikos; išlaidos; pajamos; socialinė ir ekonominė nauda; statistinė eksploatavimo trukmė ir pan. Pavyzdyje pateikiamas įvairių orlaivio A320 avarijos sąnaudų vertinimas priklausomai nuo įvykio sunkumo ir orlaivio amžiaus. Vertinimo metodika galėtų būti taikoma kaip rizikos vertinimo priemonė, diegiant saugos valdymo sistemą (SVS).

Reikšminiai žodžiai: rizikos valdymas, saugumas, orlaivių avarijų išlaidos.

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