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Full Length Research Paper

An approach to Safety Management System (SMS) implementation in aircraft operations

Olja Čokorilo*, Petar Mirosavljević, Slobodan Gvozdenović

Department of Air Transport, Faculty of Traffic and Transport Engineering, University of Belgrade, Serbia.

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Each year a large number of approach and landing accidents occur worldwide. Safety statistics of commercial airline operators show that on average there is almost one occurrence every week. Each year there is also a number of approaches and landing accidents that resulted in third party damage and injuries on the ground. To operators it is therefore interesting to know how big their risk is and what possible actions could be taken to reduce this risk. The paper defines analytical tool intended to provide a sound, technically justifiable and consistent approach to analyzing the risk posed by an aircraft crash into a facility of importance during the approach and landing phase. This analytical approach is applicable to passenger terminals, Air Traffic Control (ATC) control towers, all facilities containing dangerous goods, etc. Presented methodology takes into consideration items determined to be important to understanding the risk from aircraft crash into certain facilities: number of aircraft operations/flights; crash probabilities; aircraft characteristics; facility characteristics; crash impact and facility damage. The simple case for airport with one runway was chosen. The result gives two risk roses (contours) for each threshold where each of them determines different risk zones on airport vicinity.

Key words: Safety management system, risk, aircraft, landing.

INTRODUCTION

The paper defines analytical tool intended to provide a sound, technically justifiable, and consistent approach to analyzing the risk posed by an aircraft crash into a facility of importance. This analytical approach is applicable to passenger terminals, ATC control towers, all facilities containing significant quantities of radioactive or hazardous chemical materials, gasoline, etc. It could be used through Safety Management System (SMS) implementation process as a risk measurement tool for new investments at the airport according to building location planning. Safety issues were first investigated in the transportation management literature (Foreman, 1993; Males, 2007; McLeod and Vingilis, 2008; Min et al., 2010; Wagenaar et al., 2007). This article attempts to go further than the above reviewed research by analyzing major events during the approach and landing phase, which is the most critical flight phase in aircraft operations. Figure 1 presents statistical information regarding the flight phases (FSF, 2010). The number of fatal hull-loss accidents per year is given. The figure includes corporate jet and military transport accidents.

SAFETY MANAGEMENT SYSTEM (SMS) IN AVIATION

To improve on existing levels of aviation safety in the light of the continuing growth of the industry, additional measures are needed. One such measure is to encourage individual operators to introduce their own SMS. Such a system is as important to business survival as a financial management system and the implementation

*Corresponding author. E-mail: oljav@sf.bg.ac.rs. Tel: 381 63 37 87 55.

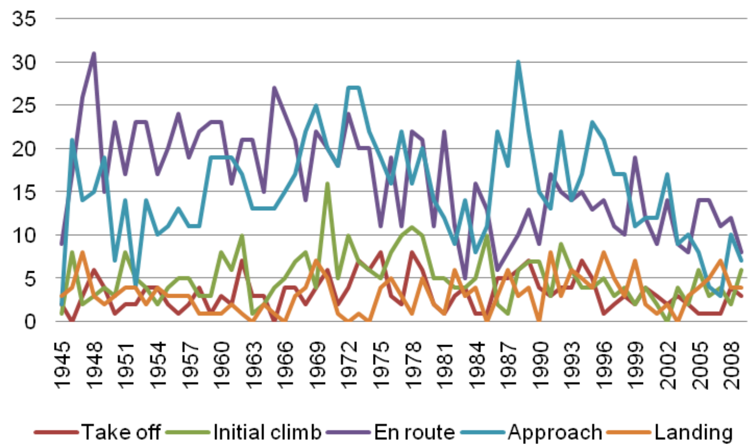

Figure 1. Aircraft accidents per flight phase.

of a SMS should lead to achievement of one of civil aviation's key business goals: enhanced safety performance aiming at best practice and moving beyond mere compliance with regulatory requirements (ICAO, 2009). According to CAA (2002), SMS is an explicit element of the corporate management responsibility which sets out a company's safety policy and defines how it intends to manage safety as an integral part of its overall business.

THE FUNDAMENTAL REQUIREMENT OF SAFETY MANAGEMENT

Success in a company's safety performance will be greatly strengthened by the existence of a positive safety culture. Safety culture in an organization can be described as the way in which it conducts its business and particularly in the way it manages safety. It emanates from the communicated principles of top management and results in all staff exhibiting a safety ethos which transcends departmental boundaries. It can be measured by informal or formal staff surveys, or by observations conducted in safety-related work areas. Safety must be actively managed from the very top of a company. Safety management must be seen as an integral strategic aspect of business management, recognizing the high priority attached by the company to safety. To that end, a demonstrable board-level commitment to an effective formal SMS must exist. Equally, every level of management must be given safety accountability. The contribution of the staff at and below supervisor level must be emphasized.

LANDING PHASE

Approach and Landing Accident Reduction (ALAR) has long been among the primary goals in aviation. A normal approach and landing involves the use of procedures for what is considered a normal situation; that is, when engine power is available, the wind is light or the final approach is made directly into the wind, the final approach path has no obstacles, and the landing surface is firm and of ample length to gradually bring the airplane to a stop (AIRBUS, 2002). The selected landing point should be beyond the runway's approach threshold but within the first one-third portion of the runway. The last part of the approach pattern and the actual landing could be divided into five phases: the base leg, the final approach, the round-out, the touchdown, and the after-landing roll.

The manufacturer's recommended procedures, including airplane configuration and airspeeds, and other information relevant to approaches and landings in a specific make and model airplane are contained in the Airplane Flight Manual and/or Pilot's Operating Handbook for that airplane. According to statistical data, take off and landing phase have been the most probable situations for initiating accident (Ranter, 2006). Causes for accidents during the landing phase are different: weight and balance problems, contaminated runway, weather conditions, aircraft system failures, reduced pilot capabilities, etc. According to pilot errors, contemporary accident investigations show that accidents often occur when flying task requirements exceed pilot capabilities. The difference between these two factors is called the margin of safety. Figure 2 presents that the margin of safety is minimal during the approach and landing. At this point, an emergency or distraction could overtax pilot capabilities, causing an accident.

From the airport point of view, an existing facilities, operations, vehicles, etc. could cause an accident. Particularly at large aerodromes the apron is a busy place of work. People and aircraft face many potential hazards, particularly from the movement and operation of

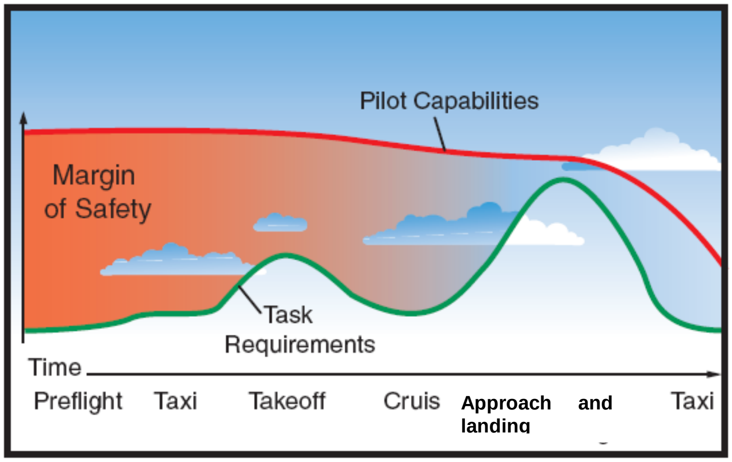

Figure 2. Margin of safety.

Table 1. Accident type and severity.

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

aircraft and ground vehicles. Failure to eliminate or control such hazards may lead to accidents of aircraft and/or people or cases of ill health. Common hazards at aerodromes include: vehicles striking aircraft and/or people; hazards to passengers on the apron; moving aircraft (including aircraft on pushback or being towed); live aircraft engines (including helicopters); falls and falling objects; operation of air-bridges; manual handling; noise; work equipment (including machinery); hazardous substances and dangerous goods (including radioactive substances); inadequate lighting, glare or confusing lights; adverse weather conditions (including winter operations); slips and trips; electrical hazards; faults and defects. The type of accident is directly linked to the accident severity. Accident severity classification (FAA, 2000) is shown in Table 1.

Main accident types are: departure from runway, loss of control, fatal accident, under-carriage related event, general disintegration, collision of aircraft and collision with terrain.

THEORETICAL REVIEW

This paper focuses on the method used for the assessment of risk for individual transport aircraft. The analysed problem belongs into the group of collision risk models or third party risk models. Collision risk models analyse collision of aircraft with other aircraft or terrain, which might happen after failure of aircraft systems. Those collisions are very rare events that are contributed by large number of fatalities and complete destruction of aircraft. An early example of this type of model was developed by (Siddiqee, 1973; Geisinger, 1985). Nowadays, this type of modelling has been based on Monte Carlo simulation (Rouvroroye et al., 2002; Bloom et al., 2006). Third-part risk modelling is based on defining risk contours according to aircraft crash location. Risk tolerability and cost benefit analysis for this type of risk assessment modelling should be the key factor (Ale et al., 2000). Nowadays, zoning around airports based on individual risk contours is undertaken in many countries (Hale, 2002) and present the most used third-part risk modelling tool.

RISK ROSE MODELLING - CASE STUDY: SINGLE RUNWAY AIRPORT

Four-factor formula

In recent years, the aviation industry has gradually begun to make use of flight safety analysis (GAIN, 2003). The following

Table 2. Aircraft crash rates by category and landing phase.

Aircraft	Crash rate (P)-per landing
General aviation	
Representative fixed wing	2.0×10^{-5}
Commercial	
Air Carrier	2.8×10^{-7}
Air Taxi	2.3×10^{-6}

methodology provides methods for calculating and analyzing the impact frequency of aircraft crashes into a facility. Aircraft crash frequencies are estimated using a "four-factor formula" (DOE, 2006) which considers: (a) the number of operations, (b) the probability that an aircraft will crash, (c) given a crash, the probability that the aircraft crashes into a one-square-mile area where the facility is located and (d) the size of the facility. Mathematically, the four-factor formula is in Equation1:

$$F = \sum_{i,j,k} N_{ijk} \cdot P_{ijk} \cdot f_{ijk}(x,y) \cdot A_{ij} \qquad (1)$$

where:
F = estimated annual aircraft crash impact frequency for the facility of interest (no. /year); N_{ijk} = estimated annual number of site-specific aircraft operations (that is, takeoffs, landings, and in-flights) for each applicable summation parameter (no. /year);
P = aircraft crash rate (per takeoff or landing for near-airport phases and ijk per flight for the in-flight (non-airport) phase of operation for each applicable summation parameter; provided in Table 2.
$f_{ijk}(x,y)$ = aircraft crash location conditional probability (per square mile) given a crash evaluated at the facility location for each applicable summation parameter;
A = the site-specific effective area for the facility of interest that includes ij skid and fly-in effective areas (square miles) for each applicable summation parameter, aircraft category or subcategory;
i = (index for flight phases): i=1, 2, and 3 (takeoff, in-flight, and landing);
j = (index for aircraft category or subcategory): j=1, 2,…;
k = (index for flight source): k=1, 2,..., K (there could be multiple runways, and non-airport operations);
ijk = site-specific summation over flight phase, i; aircraft category or subcategory, j; and flight source, k.

Determination of number of operations

The first factor in determining the aircraft impact frequency (F) is the number of annual aircraft flight activities
(N) near the site under consideration. Because of the different ways in which flight operations are conducted, aircraft flight activities are tabulated differently for the airport environment and the non-airport environment. In the airport environment, aircraft flight activities may be tabulated in terms of aircraft operations or airport operations. Aircraft operations include the arrivals at and departures from an airport at which an airport traffic control tower is located.

Aircraft crash rates

Generic crash rates for each aircraft category and sub-category were calculated based on a review of official accident reports for civilian aircraft.

Crash location probability

Crash location probabilities per square mile in the vicinity of a runway were calculated based on a review of historical data. Table 3 presents the probability values for commercial aircraft landing. The probability values are a function of distance from an intended runway. Each probability value reflects the conditional probability that, given a crash, the crash will occur within a specific one-square-mile bin in the vicinity of an airport.

Coordinate Convention

To define aircraft crash locations relative to airfield run-ways and facilities, it is necessary to establish a location coordinate system. This standard uses the Cartesian coordinate convention with the following characteristics: the origin of the coordinate system is at the centre of the relevant runway; the x axis coincides with the extended runway centreline; the positive direction is the direction of flight; the y axis is perpendicular to the x axis with the positive direction created by a 90°counter-clockwise rotation of the positive x axis. Often, the location of a facility is expressed in terms of the distance, R, and bearing, from the facility to the airfield. For purposes of this paper, it is appropriate to assume that these measurements represent the distance and bearing from the corner of the facility closest to the runway to the centre of the relevant runway. To determine the x, y values of the facility in the specified coordinate system, Equations (2) were applied.

$$\begin{aligned} x &= -R\cos(\theta - \varphi) \\ y &= R\sin(\theta - \varphi) \end{aligned} \qquad (2)$$

Where:
R = distance from the facility (miles);
θ= bearing from the facility to the airport;
φ= runway bearing as an angle with respect to magnetic north (this equals the runway number times ten).

Effective area calculations

The effective area represents the ground surface area surrounding a facility such that if an unobstructed aircraft were to crash within the area, it would impact the facility, either by direct fly-in or skid into the facility. The effective area depends on the length, width

Table 3. Crash location probability for commercial aircraft landing phase.

		Y											
		5,6	**4,5**	**3,4**	**2,3**	**1,2**	**0,1**	**-1,0**	**-2,-1**	**-3,-2**	**-4,-3**	**-5,-4**	**-6,-5**
	-16,-15						0.000014	0.000014					
	-15,-14				0.000012	0.000016	0.000029	0.000029	0.000016	0.000012			
	-14,-13		0.00001	0.000014	0.00002	0.000031	0.000059	0.000059	0.000031	0.00002	0.000014	0.00001	
	-13,-12		0.000014	0.000022	0.000034	0.000056	0.00012	0.00012	0.000056	0.000034	0.000022	0.000014	
	-12,-11	0.000012	0.000019	0.000031	0.000054	0.0001	0.00025	0.00025	0.0001	0.000054	0.000031	0.000019	0.000012
	-11,-10	0.000012	0.000021	0.00004	0.000079	0.00017	0.0005	0.0005	0.00017	0.000079	0.00004	0.000021	0.000012
	-10.-9		0.000021	0.000046	0.00011	0.00028	0.001	0.001	0.00028	0.00011	0.000046	0.000021	
	-9,-8		0.000016	0.000044	0.00013	0.00042	0.0021	0.0021	0.00042	0.00013	0.000044	0.000016	
X	-8,-7			0.000034	0.00013	0.00058	0.0043	0.0043	0.00058	0.00013	0.000034		
	-7,-6			0.00002	0.00011	0.00071	0.0086	0.0086	0.00071	0.00011	0.00002		
	-6,-5				0.000071	0.00075	0.017	0.017	0.00075	0.000071			
	-5,-4				0.000033	0.00065	0.034	0.034	0.00065	0.000033			
	-4,-3					0.00043	0.063	0.063	0.00043				
	-3,-2					0.00019	0.11	0.11	0.00019				
	-2,-1					0.000051	0.15	0.15	0.000051				
	-1,0						0.099	0.099					
	0.1						0.0069	0.0069					

and height of the facility, as well as on the aircraft's wingspan, flight path angle, heading angle relative to the heading of the facility, and the length of its skid. The effective area consists of two parts, the fly-in area and the skid area. The former represents the area corresponding to a direct fly-in impact and consists of two parts, the footprint area and the shadow area. The footprint is the facility area that an aircraft would hit on its descent even if the facility height were zero. The shadow area is the facility area that an aircraft hits on its descent, but which it would have missed if the facility height were zero. For this paper, the facility is repre-sented by a bounding rectangle, and the heading of the crashing aircraft with respect to the facility is assumed to be perpendicular to the diagonal of the bounding rectangle (Figure 3). These assumptions provide a conservative approximation to the true effective area.

$$A_{eff} = A_f + A_s \quad (3)$$

$$A_f = (WS + R)H\cot\Phi + \frac{2 \cdot L \cdot W \cdot WS}{R} + L \cdot W \quad (4)$$

$$A_s = (WS + R)S \quad (5)$$

Where:
A_f = effective fly-in area;
A_s = effective skid area;
WS = aircraft wingspan;
R = length of the diagonal of the facility, = $(L^2 + W^2)^{0.5}$
H = facility height, facility-specific;
cotφ = mean of the cotangent of the aircraft impact angle, provided in Table 4;
L = length of facility, facility-specific;
W = width of facility, facility-specific;
S = aircraft skid distance (mean value), provided in Table 5.

Risk Rose case study - single runway

Risk rose presents 360°risk zone, for certain runway threshold, measured from the runway centre. Risk rose is based on flight phase and category of aircraft used for airport operations. Final shape of risk rose determines risk zones which could reduce flight safety or initiate aircraft

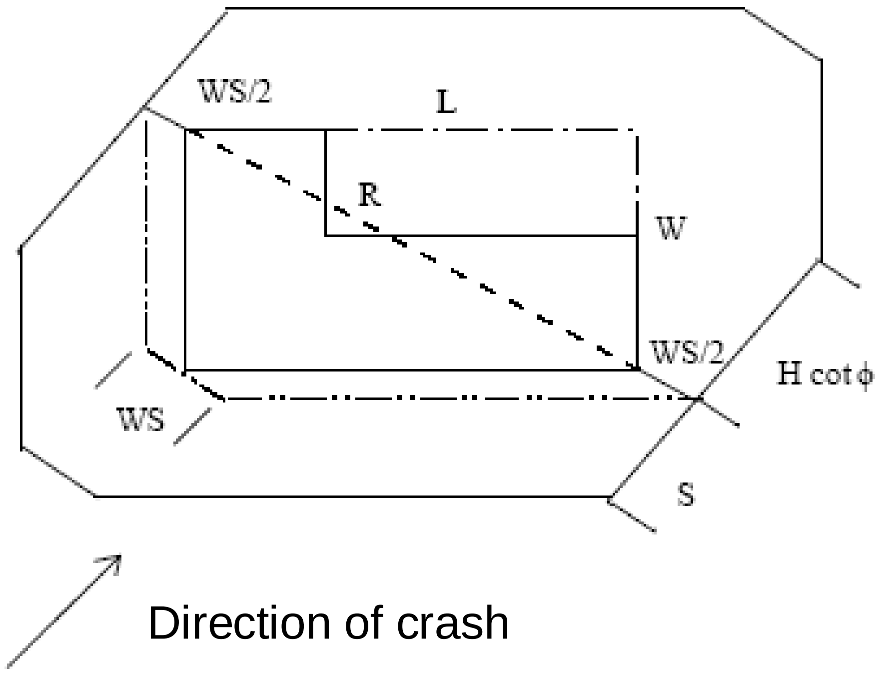

Figure 3. Rectangular facility effective target area elements.

Table 4. Values of the mean of the cotangent of the impact angle (cotΦ).

Aircraft category	Commercial aviation	General aviation	Helicopters
Mean (cot Φ)	10.2	8.2	0.58

Table 5. Mean skid distances (S) for each aircraft category.

Aircraft category	Commercial aviation	General aviation	Helicopters
Mean skid distance, ft	1440	60	0

collision with terrain or facilities. Therefore, through airport master planning process, risk rose should be used for determining new locations for certain objects: passenger terminal, fuel tanks, control tower, etc. The presented methodology was implemented on airport "Nikola Tesla" Belgrade (Čokorilo, 2010a). This airport presents typical international airport with single runway. Realized analysis considers risk zones for passenger terminal location according to distance of 500 m, 1000 m, 2000 m and 3000 m around runway for the landing phase. An investigation should present the safest location for the passenger terminal building (even if the airport already has one). Assumptions for airport Belgrade:

1. Belgrade Airport is the largest airport in Serbia handling more than 90% of the domestic passenger and 90% of the cargo traffic.
2.Runway 1: 3,400 m (11,154 ft) × 45 m; Direction 12/30; ICAO Cat. 1; 75 mvmnts/h; Parallel Taxiway; Aircraft size max: B747; Lighting: CAT III b.
3. RWY 12 - Commercial aviation air carrier landings per year 13863 (base year 2007).
4. RWY 30 - Commercial aviation air carrier landings per year 4621 (base year 2007).
5.Effective area calculation assumptions: (a) wing span (A320) 50 ft; (b) R-diagonal of terminal building 820.23 ft; (c) H-height of terminal building 32.81ft; (d) L-length of terminal building 321.52 ft; (e) Mean cot φ 10.20; (f) S-aircraft skid distance 1440 ft; (g) A_f=0.02 sq miles; (h) A_s=0.045 sq miles; (i) A=0.065 sq miles; Based on presented methodology and mentioned assumptions for certain single runway airport, two risk roses were defined, for RWY12 and RWY30.

The given results show that impact frequency for landing phase has flat distribution for distances less than 1000 m. Over than distance, get risk roses could be used for certain terminal location in a manner which could avoid impact frequency (see Figures 4 and 5 for 2000 m and 3000 m). Even if an analyst decides to locate terminal or other facility of interest in some of presented hazardous zones, further financial impact could be calculated based on total accident related costs presented below.

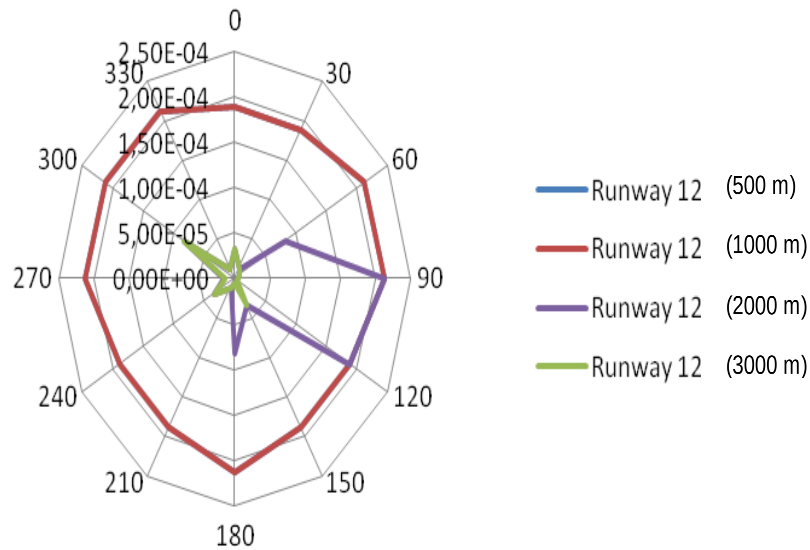

Figure 4. Risk rose RWY 12 – Total impact frequency per year (landing).

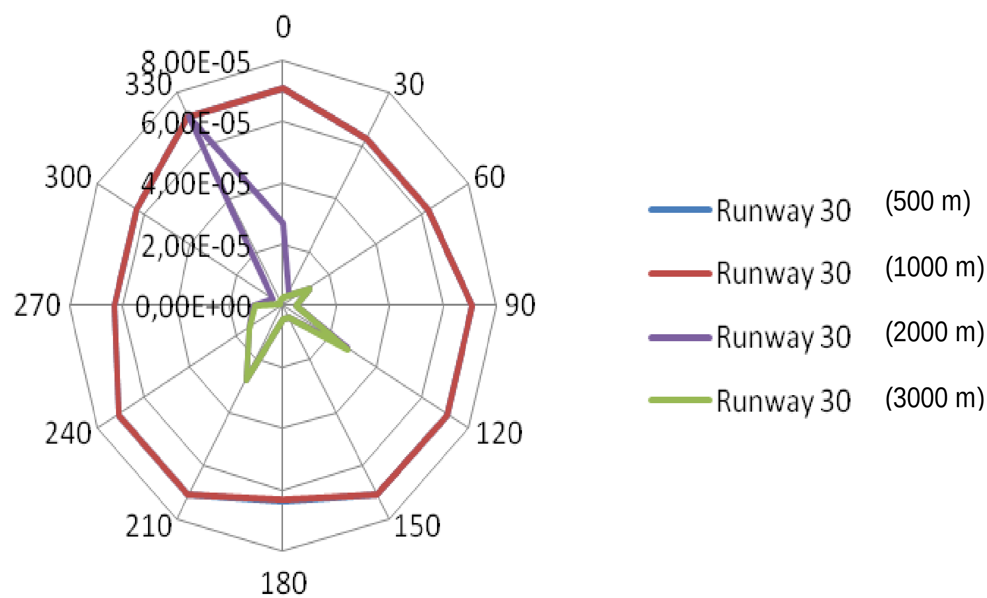

Figure 5. Risk rose RWY 30 – Total impact frequency per year (landing).

ACCIDENT COSTS CONSIDERATION

Total safety related benefits

Total benefits are estimated by multiplying the expected number of accidents with the (average) cost of a single accident (Roelen et al., 2001). This should be done for each year of the reference period. 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.

Total accident related costs - sample A320

The majority in total number of operations at Serbian

Table 6. 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

airports is realized by Airbus A320. Total accident related costs estimation is provided by data (Čokorilo et al., 2010b; Piers et al., 2006), 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. Following data presents total accident related costs according to accident severity[1]: decreasing rate of accident related costs is a function of aircraft age and accident severity. The realized study (Čokorilo, 2008) defined minimum total accident related costs scope that vary from 34M€ (case: aircraft age 12 years; severity: minor) to 211M€ (case: aircraft age 0 years; severity: catastrophic). Maximum total accident related costs scope is also defined from 414 to 591M€ (this calculation is gotten from the minimum costs plus 380M€ (maximum loss of reputation costs). Table 6 presents linear function of accident related cost.

x – Aircraft age (x = 0,1..12)[2]
y_{min} – min accident related costs for A320
y_{max} – max accident related costs for A320 with added max loss of reputation costs.

CONCLUSIONS

The methodology presented in this paper takes into consideration items determined to be important to understanding the risk from aircraft crash into certain facilities. These items include number of aircraft operations/flights; crash probabilities; aircraft characteristics; facility characteristics; crash impact and facility damage. Presented case study is based on aircraft landing phase that is determined as the most dangerous flight phase according to analyzed aircraft accident historical data. The simple case for airport with one runway was chosen. The result gives two risk roses for each threshold where each of them determines different risk zones at airport vicinity. Further cost consideration is presented on a sample of the most operated airplane, Airbus A320, at the certain airport.

[1] All analyzed costs are based on year 1999. For further analyzes, 5% of average annual increasing rate of costs is recommended by EU.
[2] A320 is in production 12 years until 1999 that is used as a referent year for the accident related cost calculation in this paper.

REFERENCES

AIRBUS (2002). Getting to grips with aircraft performance. France, p. 216.

Ale B, Smith E, Pitblado R (2000). Safety around airport – developments in 1990s and future directions, Det Norske Veritas, United Kingdom.

CAA (2002). CAP 712 - Safety Management Systems for Commercial Air Transport Operations. UK. p. 41.

Čokorilo O (2008). Risk management implementation in aircraft accident cost analysis. In: Proceedings of the 12th Air Transport Research Society (ATRS) World Conference. Athens, p.16.

Čokorilo O (2010a). Risk Management Implementation in Safety Management System (SMS). Published PhD, Belgrade University, p.149.

Čokorilo O, Gvozdenović S, Vasov L, Mirosavljević P (2010b). Costs of unsafety in aviation. Techn. Econ. Dev. Econ., 16(2): 188–201.

DOE (2006). Accident analysis for aircraft crash into hazardous facilities. U.S. Department of energy. Washington, p. 215.

FAA (2000). System Safety Handbook. Federal Aviation Administration. Washington, 15: 23.

Foreman SE (1993). An application of Box-Jenkins ARIMA techniques to airline safety data. Logist Transp. Rev., 29(3): 221-240.

FSF (2010). Flight Safety Foundation. USA. http://flightsafety.org/.

GAIN (2003). Guide to methods & tools for airline flight safety analysis. Global Aviation Information Network. USA. p. 198.

Geisinger K (1985). Airspace Conflict Equations. Trans. Sci. 19(2): 139-153.

Hale A (2002). Risk Contours and Risk Management Criteria for Safety at Major Airports with Particular Reference to the Case of Schiphol. Saf. Sci., 40(1-4): 299–323.

ICAO (2009). Doc 9859 - Safety Management Manual. Montreal. p. 264.

Males M (2007). California's graduated driver license law: effect on teenage drivers' deaths through 2005. J. Saf. Res., 38(6): 651-659.

McLeod I, Vingilis ER (2008). Power computations in time series analyses for traffic safety interventions. Accident Anal Prev., 40(3): 1244-1248.

Min JCH, Kung HH, Liu HH (2010). Interventions affecting air transport passenger demand in Taiwan. Afr. J. Bus. Manag., 4(10): 2121-2131.

Piers R, Lebouille R, Roelen A, Smeltinik J (2006). Safety has value! An approach for the assessment of the costs and benefits of safety measures. In: Proceedings of the 2nd International Conference on Research in Air Transportation (ICRAT). Belgrade. pp. 351-355.

Ranter H (2006). Airliner accident statistics 2005. Statistical summary of fatal multi-engine airliner accidents in 2005. Aviation Safety Network. http://aviation-safety.net/pubs/. p.25.

Roelen ALC, Piers R, Molemaker RJ, Hayes P (2001). Handbook for conducting cost benefit analysis of safety measures in air transport.

National Aerospace Laboratory (Report NLR-CR-2001-609). Amsterdam.
Siddiqee W (1973). A mathematical model for predicting the number of potential conflict situations at intersecting air routes. Trans. Sci., 7(2): 158-167.
Wagenaar AC, Maldonado-Molina MM, Ma L, Tobler AL, Komro KA (2007). Effects of legal BAC limits on fatal crash involvement: analyses of 28 States from 1976 through 2002. J. Saf. Res.,, 38(5): 493-499.