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RISK ANALYSIS IN THE SURROUNDING AREAS OF ONE-RUNWAY AIRPORTS: A METHODOLOGY TO PRELIMINARY CALCULUS OF PSZs DIMENSIONS

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ABSTRACT

The risk analysis of aeronautical accidents has been faced in several countries in order to plan the territory around airports. In the past, many accidents have had serious consequences in the surrounding of airports. To protect the dwellers in these zones, Sapienza University of Rome has studied a risk assessment model of air crash accident during take-off or landing. In force of an agreement with the National Aviation Authority, the major Italian airports have been analysed. These studies have highlighted the opportunity to know the influence on the territory of the variation of the traffic volume. This knowledge can be particularly useful for forecasting the impact on the territory in a preliminary phase of the master planning activity of the airport. The influence of the traffic volume and the types of aircraft on the sizes of safety areas around airports has been studied with a computer program developed by the authors. As a result of this first analysis, a simplified approach to study the extension of the Public Safety Zones around an airport is presented. This method calculates the area and the main dimensions of PSZs for a number of representative cases of one-runway airports with more than 30000 operations per year. In Europe, there are a large number of one-runway airports and they have similar operational and traffic conditions. Therefore, the results here presented can be applied for a preliminary study to all the one-runway airports, having the same level of traffic of the airports considered in this paper.

Keyword: airport, risk assessment, public safety zone, land use, crash accident.

INTRODUCTION

According to statistical studies (Boeing, 2014) a remarkable percentage of accidents (61%) occurs during the operations of take-off, initial climb, landing and final approach even if these phases last a small percentage of time in the overall airplane mission. The analysis of this kind of accidents shows that about half of them (49%) occurs outside the airport and they are concentrated in the areas close to the thresholds (Cardi *et al*. 2012).

Several methods have been developed for forecasting the impacts on the territory in a preliminary phase of the planning activities (Miccoli *et al*. 2014, Miccoli *et al*. 2015). In some countries, for example in the Netherland (Ale, 2002), the concern for safety in industrial activities, both inside the establishments and in the surroundings, has a long history. This attention was also turned to the risk analysis related to aircraft accidents near airports (Jonkman and Verhoeven, 2013), but in many cases it was referring only to a specific kind of accident (Kirkland *et al*., 2004, Moretti *et al*., 2017a, Moretti *et al*., 2017b,). Only few studies concern the total set of accidents occurring in the areas near the airports.

In USA Wong *et al.* have studied an interesting model based on their own data-base including 440 cases, of which 199 are landing overruns, 122 are landing undershoots, 52 are take-off overruns and 67 are crashes after take-off. (Wong *et al*. 2008a and b).

In Europe, the Third Party Individual Risk analysis was studied in England by the National Air Traffic Service (Smith, 2000), Ireland by the Environmental Resources Management (ERM, 2005) and the Netherlands by the National Aerospace Laboratory (NLR, 2000). All three models have been developed for great civil aviation airports (more than 150,000 movements per year), equipped with precision flight instruments. The statistical analysis performed for these methods excludes the accidents due to sabotage, terrorism or military action or involving general aviation.

The accident localization model in the three methods presents large differences. The British and Irish ones assume a distribution of accidents on the extended runway centreline. The Dutch methodology instead considers the distribution referring to the trajectory of the flight route.

A correct approach should consider the dispersion of traffic routes to the axis by analysing the airport radar tracks. If these latter are not available, the examination of flight procedure maps can lead to a good approximation of the accidents distribution law. In all the methods, the accident severity is defined by the destroyed area, calculated as a function both of the wingspan and the weight of the aircraft. To limit the risks in the area surrounding the airport some countries (Jonkman *et al.*, 2002) have set the limit of 10^{-6} as standard for populated areas. The Dutch Ministry of Housing, Spatial planning and Environment states that risks lower than 10^{-6} per year should always be reduced to a level as low as is reasonably achievable (ALARA) (Jonkman *et al.*, 2002)

In USA (Netjasov F., Janic M.; 2008) the probability of being killed by crashing aircraft around an airport is estimated as 1.3×10^{-8}. This probability decreases more than proportionally with increasing distance from the airport and increases with increasing volume of the airport traffic at distances up to about two miles.

English (Smith, 2000), Irish (ERM, 2005) and Dutch (NRL, 2000) models define two Public Safety

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Zones (PSZs) with a different level of individual risk: the *Inner PSZ* with a risk greater than 10^{-5} and the *Outer PSZ* included between 10^{-5} and 10^{-6} risk contours. In the first one, all methods provide only for aeronautical activities, in the second one also industrial activities are allowed. In this zone, Ireland accepts also housing, but excludes vulnerable buildings, while UK accepts all kind of buildings.

In Italy, the National Civil Aviation Authority (ENAC, 2010) has issued the policy of land use in the surrounding of the airports defining four Public Safety Zones. Each of them is defined by the 10^{-4},10^{-5} and 10^{-6} risk contours. The area outside 10^{-6} risk contour is considered not influenced by the aeronautic activity.

In addition, the Italian Authority requires the individual risk assessment for the airports with a traffic flow greater than 50000 operation/year. Sapienza - University of Rome in force of an agreement with ENAC has developed the model for these studies. It has been widely described in (Attaccalite *et al*., 2012) and it has been implemented in Microsoft Visual Basic for Applications® (VBA) Integrated Development Environment (IDE) in MS Excel® spreadsheet.

The program named SARA (*Sapienza Airport Risk Analysis*) calculates the risk contours for any airport with up to four runways and it calculates the individual risk at all points of a mesh drawn around the runway. Figure-1 shows an example of the program outcomes.

The results are plotted with contour map diagram that can be overlapped on the map to the territory surrounding the airport.

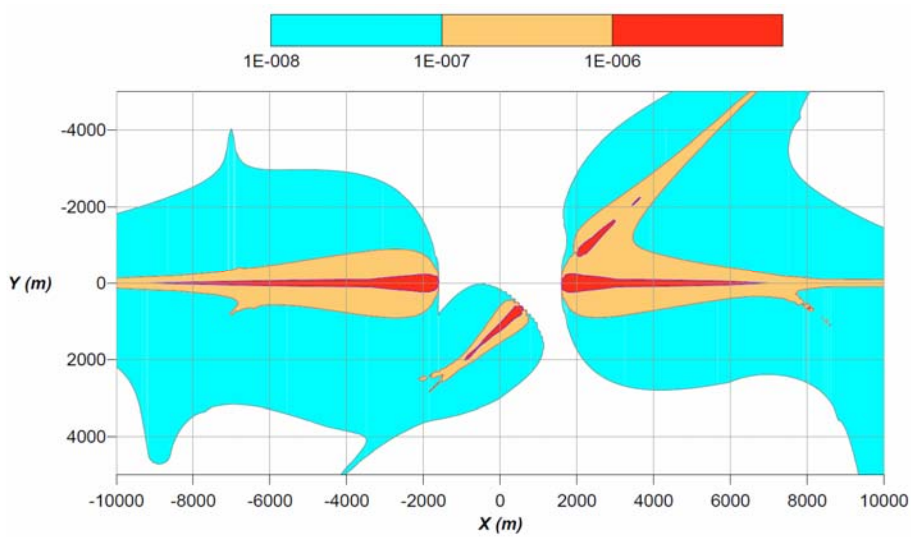

Figure-1. The Public Safety Zones plotted with contour map diagram by SARA program.

RISK ANALYSIS IN ONE-RUNWAY AIRPORTS

As part of an agreement with the Italian Civil Aviation Authority to define the PSZ in the areas surrounding the Italian airports, all the busiest airports have been analysed using SARA program described in (Attaccalite *et al*., 2012). Most of them have only one runway.

The shape of the risk contour depends on the traffic mix and volume, and on the routes. The take-off routes may have different trajectories due to the presence of obstacle near the airport or the noise limitations. Instead, the landing routes are always along the prolonged runway centreline. Indeed, the risk contours of the Italian one-runway airports have always the same shape, but the dimensions may be different depend on traffic (number of movements and mix) operating in the airport.

In addition, as aircrafts take off and land with opposite wind, usually the thresholds of most airports are specialized for these operations and in many cases only a threshold is equipped with precision landing systems (ILS). For these considerations, it can be assumed averagely that for each airport 95% of the operations take place on a threshold and 5% on the other.

As well as Italy, the most of European airports has only one runway and the statistics (ACI) show that the traffic on these airports is increasing. Therefore, this study has been conducted to investigate the effect of the increasing total number of movements and the type of operating aircrafts on the extent of the risk contours.

For each airport, the number of movements has been derived from the statistical directory of ENAC (ENAC, 2014), and the traffic mix has been inferred from the flight schedules published on the websites of the airports. The risk assessment of the Italian one-runway airports has been performed referring to straight take-off and landing routes. Considering straight take-off routes, instead of the actual ones, results in a minimal variation of the risk contours. Figure-2 shows the comparison between risk contours (actual take-off routes vs straight take-off routes) for three examined airports.

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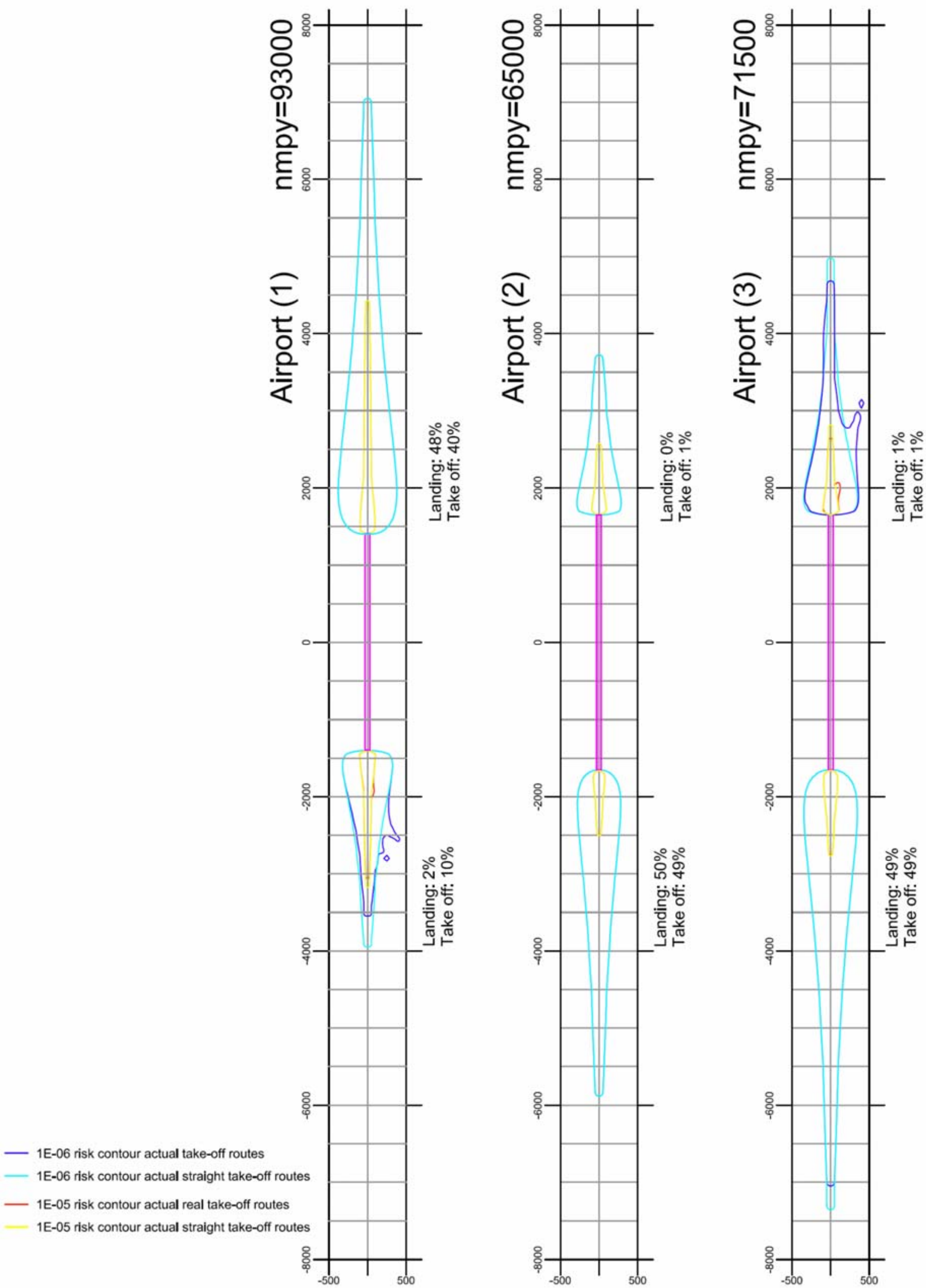

Figure-2. Comparison between risk contours for three airports.

ARPN Journal of Engineering and Applied Sciences

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Therefore, all the single runway airports have been divided into 3 categories according to the number of movements per year (*nmpy*):

- **Airport category I:** Number of annual movements less than 50000 (and up to 30000).
- **Airport category II:** Number of annual movements between 50000 and 75000.
- **Airport category III:** Number of annual movements exceeding 75000.

The aircrafts operating in all the airports have been grouped into the 6 ICAO classes, identified by the letters A through F, depending on the outer main gear wheel span and wing span and for each class a reference plane has been defined. The reference plane has a maximum take-off weight (MTOW) and a risk index (IR) weighted by the number of movements of all aircrafts belonging to the same class according to the expressions (1) and (2):

$$MTOW_W = \frac{\sum_{i=1}^{N} MTOW_i \; Mov_i}{\sum_{i=1}^{N} Mov_i} \quad (1)$$

$$IR_W = \frac{\sum_{i=1}^{N} IR_i \; Mov_i}{\sum_{i=1}^{N} Mov_i} \quad (2)$$

where

N = total number of aircrafts of code from A to F
Mov_i = number of movements of i[th] aircraft
$MTOW_W$= weighted maximum take-off weight of the reference aircraft
$MTOW_i$ = maximum take-off weight of the i[th] aircraft
IR_w = weighted accident rate of the reference aircraft
IR_i = accident rate of the i[th] aircraft

Table-1 lists the results. The percentage of each aircraft class for airport category is graphically shown in Figure-3.As we can see; a very high percentage of aircraft belonging to class C is present in all airport categories. A moderately greater allocation of aircrafts of different classes is only in category II airports.

Table-1. Traffic mix data for each airport category.

Percentage	A	B	C	D	E	F
Cat. I	0.01	0.44	98.96	0.54	0.04	0.01
Cat. II	1.00	5.22	88.70	4.98	0.09	0.01
Cat. III	0.50	1.92	93.90	2.43	1.24	0.01
MTOW [T]	A	B	C	D	E	F
Cat. I	9	16	68	172	270	405
Cat. II	9	17	57	111	212	405
Cat. III	9	15	59	133	175	405
IR	A	B	C	D	E	F
Cat. I	0.01	0.47	0.27	0.54	0.01	0.79
Cat. II	0.63	0.88	0.21	0.38	0.20	0.79
Cat. III	0.24	0.69	0.23	0.46	0.34	0.80

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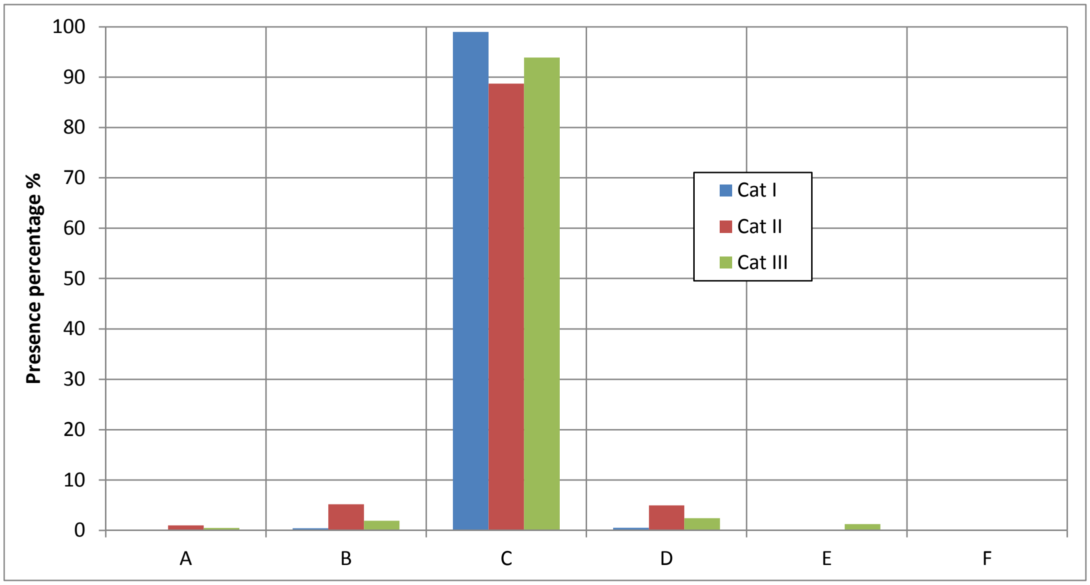

Figure-3. Percentage of presence of each aircraft class for each airport category.

With the data in Table-1 the aeronautical risk, referring to a runway 3000 m long, has been obtained. However, for the purposes of this study, the runway length is not essential because of the risk areas are related only to the runway threshold and not to the runway lateral areas. The results of this study can be therefore applied to any other length of runway. The routes have been considered straight both in landing and in take-off on both threshold of the reference runway. With SARA program, the values of the risk have been calculated on a square mesh of 50 m size. These values have been interpolated and plotted to obtain the risk contours (Figure-4).

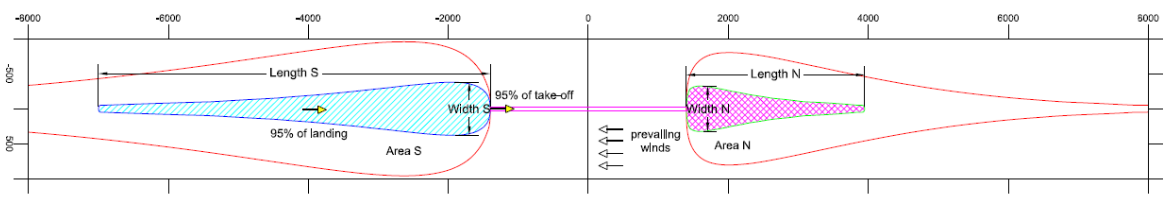

Figure-4. Scheme of risk contours related to a runway.

The analysis considers the following levels of traffic:

- I-30
- I-40
- I-50
- II-50
- II-65
- II-75
- III-75
- III-100

where the first Roman numeral corresponds to the airport category and the second number indicates the thousands of movements considered in the simulation; with the different levels of traffic on each airport category, the variations of the PSZs have been evaluated for increasing traffic.

In reference to Figure-4, the two runway thresholds are conventionally indicated as North and South and the values of the area, the length and the width of the areas enclosed by the 10^{-6} curve on the two runway thresholds are listed in Table-2.

The analysis considers only the 10^{-6} risk contours, because these curves generally define the zones where restrictions on land use are imposed.

ARPN Journal of Engineering and Applied Sciences

Table-2. Sizes of PSZs for each airport category and for different traffic volumes.

	Area N (m^2)**x1000**	**Width N** (m)	**Length N** (m)	**Area S** (m^2)**x1000**	**Width S** (m)	**Length S** (m)
III-100	1459	870	3250	2817	850	6650
III-75	1036	730	2700	2063	710	5550
II-75	996	720	2650	1992	700	5450
II-65	833	660	2350	1700	650	4950
II-50	605	570	1950	1261	550	4100
I-50	776	640	2250	1592	620	4750
I-40	594	560	1950	1234	550	4050
I-30	416	480	1550	880	460	3250

Table-2 shows that the PSZ on the South threshold (S) is greater than that in North threshold (N). This is due to the high percentage of landings assumed on this threshold (95%); andlanding crash rate is much higher than take-off one. The areas are variable as the level of traffic changes. For the same traffic volume, the areas change according to the airport category, since the traffic mix is different and therefore also the risk index and the influence of the take-off weight on the destroyed area.

MODEL VALIDATION

To validate the results in Table-2, a generic airport in Italy has been analysed with SARA program with the monitored traffic and the actual runway dimension. The airport will be conventionally named RWY 03/21. The airport has an asphalt concrete runway, about 2800 m long and 45 m wide. The threshold 03 is equipped with ILS (Instrumental Landing System) allowing category III precision instrument approaches. Approach procedures for RWY 21 include VOR/DME and NDB.

The annual traffic volume of this airport is 64,187, therefore it belongs to category II and it will be compared with the case II-65 in Table-2.

Table-3 shows the percentage of landings on each threshold: the values are very similar to 95% assumed in the study presented in the previous chapter.

The PSZs related to RWY 03/21 have been calculated with the traffic mix monitored in the airport and listed in Table-4.

The results are shown in Figure-5: the blue line represents the 10^{-6} risk contour calculated with the real traffic mix, the red one represents the same risk contour for a generic airport of category II-65: the curves are very close.

Table-3. Number and percentage of operations on each threshold of RWY 03/21.

Operation	**Threshold**	**N° of movements**	**% on each threshold**
Landing	***03***	30506	94.26
Landing	***21***	1858	5.74

Table-4. Traffic mix of RWY 03/21.

Aircraft ICAO Code	**n. Take-off**	**MTOW [t]**	**IR**	**Percentage** (actual)	**n. Take-off**	**MTOW** [t]	**IR**	**Percentage** (theoretical)
A	127	9	0.24	0.40	371	9	0.63	1.00
B	466	16	0.80	1.45	1745	17	0.88	5.22
C	30277	48	0.24	94.47	28902	57	0.21	88.70
D	873	101	0.31	2.72	1667	111	0.38	4.98
E	82	143	0.27	0.26	59	212	0.20	0.09
F	0	-	-	0.00	3	405	0.79	0.01

ARPN Journal of Engineering and Applied Sciences

Figure-5. Comparison between the real PSZs and those of an airport belonging to category II-65.

In addition, other three airports shown in Figure-5 have been compared in the actual and theoretical traffic conditions. They belong to the categories III 100, II 75 and II 65. The PSZ 10^{-6} risk contours have been calculated with SARA model in actual traffic conditions and compared with values in Table-2.

In all cases, the dimensions are comparable, as shown in Table-5.

The PSZ width resulting from theoretical traffic mixes is underestimated in all the examined examples, with a 15% variation as maximum. Instead, the lengths show variations in the range of +/– 25%.

The larger range of variation in lengths is due to the cut of the PSZ, which is conventionally made when the footprint width decreases to 100 m (for the 10^{-6} risk contour) and 50 m (for the 10^{-5} risk contour). This variation could be caused by the numerical approximation adopted by the interpolation contours program.

In any case the actual traffic conditions can significantly modify the theoretical PSZ dimensions (e.g. for airport nmpy=93000); therefore, a rigorous model is recommended when a detailed analysis is needed.

In conclusion, the results in Table-2 can be used for a preliminary study about the extension of the Public Safety Zones near every airport where the traffic mix is similar to those represented in Table-2.

Table-5. Dimensions comparison between theoretical and real PSZ.

	Airport nmpy=93000		**Airport nmpy=65000**		**Airport nmpy=71500**	
	Dimensions in actual traffic condition	**Dimensions from Table-2**	**Dimensions in actual traffic condition**	**Dimensions from Table-2**	**Dimensions in actual traffic condition**	**Dimensions from Table-2**
Length N (m)	2547	3250	2073	2350	3329	2650
Width N (m)	750	870	573	660	696	720
Area N (m^2) x 1000	1050	1459	624	833	971	996
Length S (m)	5650	6650	4230	4950	5702	5450
Width S (m)	756	850	560	650	691	700
Area S (m^2) x 1000	2170	2817	1317	1700	1985	1992
Airport class	III 100		II 65		II 75	

ARPN Journal of Engineering and Applied Sciences

CONCLUSIONS

The importance of the risk assessment of air crash during take-off or landing in the areas surrounding airports is evident for the land use planning. To safeguard people living near an airport, many European Countries have settled the Public Safety Zones (PSZ) where the planning is limited by national or local rules.

In this paper, the authors have studied the influence of the volume and the mix of traffic on the sizes of the PSZs, using the probability model of aircraft crash in the areas around the airport, developed by Sapienza - University of Rome.

The analyses carried out on the Italian airports have shown a substantial similarity among their operating conditions. The shape of the risk contours are very similar, in the case of rectilinear routes, unless the relative extension which depends on the number of movements. This has led to propose the present study with the aim of achieving a grid of possible cases applicable to all airports characterized by the same traffic conditions.

In order to validate the study, the risk contours of four airports have been calculated considering both the actual traffic mix and the simplified traffic mix typical of the category that the airport belongs to.

The comparison has shown that the two curves are close. Therefore, the proposed approach can be used for a preliminary study about the extension of the Public Safety Zones near every airport where the traffic mix is similar to those examined in this study.

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