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Risk Assessment Around Airport

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Abstract

In Europe, risk analysis has been detailed in several countries in order to define Public Safety Zones around airports that are implemented on all the planning instruments of the territory. This article deals with the study conducted within a collaboration between "Sapienza" University of Rome and ENAC for the detection of a standard individual risk calculation method for the definition of Public Safety Zones around airports. The article also describes the regulation that ENAC has issued for the establishment of the protection measures of the surroundings in terms of land use planning.

Keywords: Airport, risk assessment, public safety zone.

1. Introduction

The airport is the place where the operations of aircraft take-off, landing and ground handling occur. In the overall airplane mission, these phases cover a very small percentage of time: both take-off and landing last just 1%, but, according to statistical studies, a high proportion of accidents (32%) is concentrated in these phases (Table 1). This percentage reaches 53% including the stages of final approach and initial climb [1].

Accidents occurring in these phases of flight involve not only passengers and crew of the flight, but also a vast territory around airport with a large number of residents that, in some cases, have paid a high toll in terms of lives. Some examples: in 1986 in Cerritos, California, an air cargo crashed on some houses after a collision with a general aviation aircraft, causing 15 deaths; October 4, 1992 in Amsterdam, an El Al Boeing crashed into a building killing 43 people; July 25, 2000 Concorde just taken off from Paris fell on a hotel, killing 109 people.

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Table 1. Fatal Accidents by Phase of Flight -Worldwide Commercial Jet Fleet – 1999 Through 2010 [1]

Phase of Flight	Exposure (Percentage of flight time estimated for a 1.5 hour flight) %	Fatal accidents
Taxi, load/upload parked, tow	< 1	15
Take-off	1	10
Initial climb	1	7
Climb (flaps up)	14	5
Cruise	57	11
Descent	11	3
Initial approach	12	13
Final approach	3	14
Landing	1	22

2. European methods of third party individual risk calculation

In Europe, the Third Party Individual Risk analysis was examined in England by the National Air Traffic Service (NATS) [2], Ireland by Environmental Resources Management (ERM) [3] and the Netherlands by National Aerospace Laboratory (NAL) [4].

All three models have been developed for medium and large airports, with traffic more than 150,000 movements per year. The three models assumed that: the airport is equipped with systems for precision instrument flight; there are at least 70% of precision approaches; at least 90% of flights belongs to companies in North America and Western Europe (to have homogeneous analysis conditions); at the airport there are an air traffic control system and a meteorological information; no obstacle higher than 600 m is present within a zone within 6 NM and no barrier in excess of 1800 m within a radius of 25NM; only incidents occurring between 1980 and 1997 were analysed, to consider only events occurring to aircrafts supplied to airlines yet; accidents involving general aviation have been excluded; the minimum aircraft take-off weight is 5.7 tonnes (small aircraft produces no significant damage in the territory and 5.7 t is the threshold weight division between commercial aircrafts and general aviation); accidents due to sabotage, terrorism or military action have been excluded; only accidents during take-off, initial climb, the initial approach, final approach and landing have been considered.

An important difference among the three methods exist in the accident localization model. The British and Irish ones assume a distribution of accidents on the extended runway centreline. The Dutch methodology instead locates the point of impact on trace of the flight route. A correct approach should consider the dispersion of traffic routes to the axis by analysing the airport radar tracks. If they 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 as a function of destroyed area, that depends both on the size and the weight of the aircraft. Considering the level of calculated individual risk, every models define the Public Safety Zones (PSZs) which regulate the destination of use of territory. Synthetically *Inner PSZ* are the areas at greatest risk ($>10^{-5}$) and *Outer PSZ* are the areas at lower risk ($10^{-5} \div 10^{-6}$). In the first ones, all methods provide only for aeronautical activities, in the *Outer PSZ* also industrial activities are allowed. For these risk levels, Ireland accepts also housing, but should not ever be built vulnerable buildings, while UK accepts all kind of buildings.

Recently in Italy, ENAC has issued the implementation policy of risk assessment [5] that must be applied in areas around the airports. The Italian Safety Zones are:

- High Protection Zone: included inside 10^{-4} iso-risk curve.
- Inner Zone: included between 10^{-4} and 10^{-5} iso-risk curves.
- Intermediate Zone : included between 10^{-5} and 10^{-6} iso-risk curves.
- Outer Zone: included outside 10^{-6} iso-risk curve.

Usually, the *High Protection Zone* lies inside the airport; but if it is located outside the airport fence, the constant presence of people must be avoided in this area. In this context, the opportunity to develop plans containing programs of demolition and/or measures regression with respect to existing works must be evaluated.

In the *Inner Zone* the control of human presence is ensured by freezing the existing situation. If considerable anthropogenic load is already evident in the area, containment measures should be assessed and planning instruments should not allow new projects involving the increase of anthropogenic load.

In the *Intermediate Zone*, the existing buildings are not subject to intervention and containment measures can be provided. New non-residential activities must be characterized by the presence of a small number of people.

The *Outer Zone* has not influenced by the aeronautic activity.

In addition, in the *High Protection*, *Inner and Intermediate Zones*, the following conditions should be avoided:

- activities which, if involved by an air crash, may amplify the consequences of an accident and create damage to the environment (aboveground fuel depots, chemical plants, etc.);
- buildings like schools, hospitals, high crowding centre, etc.;
- operating conditions on the roads that may generate traffic congestion and significant increase in the anthropogenic load (such as toll booths).

3. Third party individual risk calculation method adopted in Italy

In 2005, in Italy, the Law to review the Aviation Code of navigation [6] introduces the concept of individual risk assessment. The decree stipulates that ENAC identifies those airports that should be subject to risk analysis. Sapienza - University of Rome has developed a computer program to assess the third party risk by calculation model derived from the Irish [3] and Dutch [3, 7, 8] models, Probability Distribution Functions (PDF) has been assumed from the first model, while the calculation of the Individual Risk (IR) is referred to the Dutch model.

The airplane crash risk assessment in the areas surrounding an airport, involves the following steps:

- analysis of risk exposure and traffic at the airport; at this stage present and future traffic volumes (in terms of number of movements) in the airport are calculated;
- determining accidents frequency; the study is based on gathering information from international databases using those more adaptable to case study;
- identification of the geographic distribution of accidents around the airport;
- definition of the probability curve that best fit the accident location identified in the previous step;
- assessment of the consequences of air accident; aircraft crash in an uninhabited area has minor consequences than an accident in a high density residential area;
- definition of the factors combination causing an accident.

The calculation model needs to know the overall length of runway, the position of the threshold (if it is penalized or not) and the distribution of traffic on runways and thresholds.

The probability of impact at a point beyond *End2* (Fig. 1) must be calculated considering the movements that occur annually on the runway.

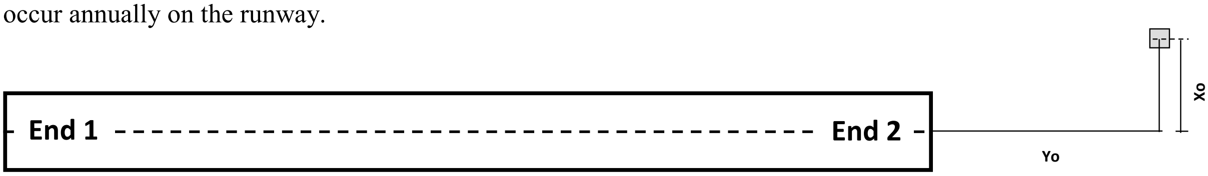

Fig. 1. Reference, point calculating IR and runway.

Takeoffs and landings are divided into two types:

- (A) movements (take-off or landing) for which the aircraft meets the runway before a point on the territory;
- (B) movements (take-off or landing) for which the aircraft meets a point on the territory before the runway.

Referring to Fig. 1, in the point x_0, y_0, take-offs and landings in direction 1 are type (A).

The accidents are also classified into overrun and non-overrun. Overrun is considered only type (A), i.e. when aircraft runs beyond the runway.

4. PSZ Definition Model

The model developed for the assessment of the Public Safety Zone (PSZ) around airports consists of three sub-models, in line with the guidelines of ICAO Airport Planning Manual [9]:

- a probabilistic model of accidents;
- a probabilistic model of accidents dispersion around the airport;
- a model of accident consequences.

The first model defines the accident probability for each aircraft type and flight phases, starting from available data-bases. Data set must be chosen and adapted to each airport under evaluation and is closely related with the traffic mix. All accidents within airport fenced area should also be discarded. ICAO, FAA, Airsafe, ANSV (Italian Agency of Flight Safety) database were analyzed. Depending on these data, it is possible to evaluate the Probability Density Function (PDF) of an accident in every point of a specific area.

The localization model defines the geographical distribution of accidents in relation to runways and routes. Again the data are derived from databases of ICAO, FAA, Airsafe, ANSV. The dispersion of traffic routes in the runway fixed reference can play an important role in the calculation of individual risk. The data is arranged on a grid whose main axis is the extended centreline (Fig. 2). Each type of accident has a different distribution both as a function of the accident feature and the longitudinal and transverse distance from the runway. For example, the accident probability during a landing is highest close to the threshold, while the maximum for a take-off will be moved a few dozen meters. Instead in the case of veer-off and overrun the peaks of probability will be very close to the runway.

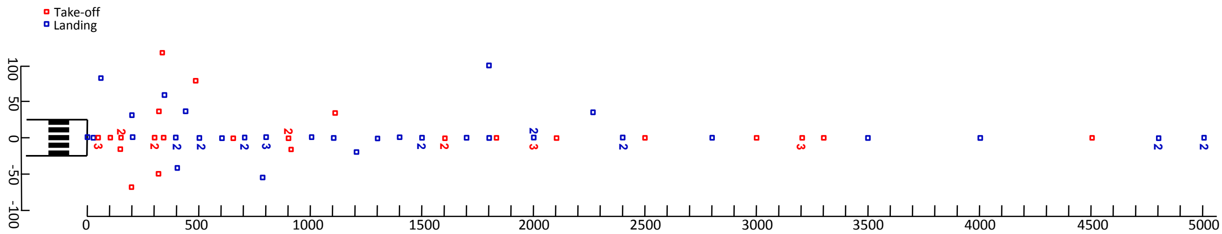

Fig. 2. Location of the accidents.

Fig. 3 shows the curves of probability density distribution: the number 1 is related to overruns, the number 2 is the probability density curve for take-off and the number 3 for landing. They are Weibull distribution, related to the Gaussian distribution (curve 1 and 3) and Gamma distribution (curve 2).

The model that studies the consequences of an accident only takes injured people on the ground, not the passengers or the crew and sets out the consequences of a plane crash in terms of extension of the destroyed area. The accident severity is thus expressed in units of surface and it is related to aircraft weight and wingspan.

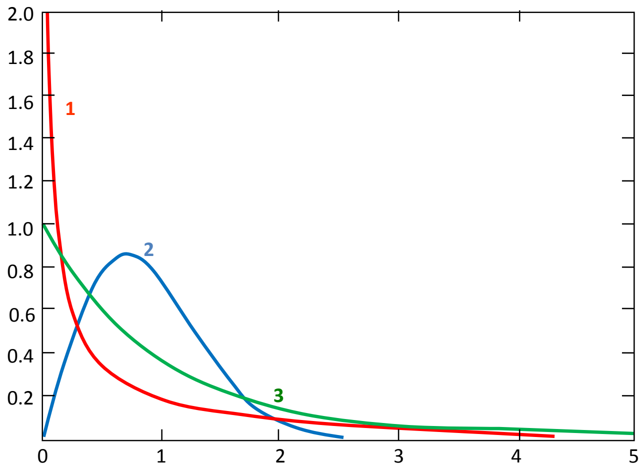

Fig. 3 Curves of probability density distribution.

The accident rate, the maximum takeoff weight, and the destroyed area are associate to each aircraft. The destroyed area is calculated for each aircraft as a function of MTWA (Maximum Takeoff weight Authorized) and it is weighted according to the number of movements and the crash rate for each aircraft type, with Eq. (1):

$$A = \frac{N_1 A_1 + \ldots + N_n A_n}{N_1 R_1 + \ldots + N_n R_n} = \frac{\sum_{i=1}^{n} N_i A_i}{\sum_{i=1}^{n} N_i R_i} \tag{1}$$

where:
N_i is the number of aircraft movements i;
R_i is aircraft crash rate i;
A_i is the destroyed area from aircraft i;
n is the number of aircraft in the traffic mix.
The destroyed area is represented by a square, the length of whose sides are $a = (A)^{0.5}$.
The distribution of accidents, on the base of data from cited international data-bases, is shown in Table 2.

Table 1. Distribution of accidents adopted in the model.

P	**Crash rate per million movements**		
	Crashes	**Overruns**	**Total**
Landings	0.52 R	0.2 R	0.72 R
Take-offs	0.2 R	0.08 R	0.28 R

The weighted average crash rate (per movement) R is calculated by Eq. (2):

$$R = \frac{R_1 N_1 + \ldots + R_n N_n}{N} = \frac{\sum_{i=1}^{n} R_i N_i}{N} \tag{2}$$

The next step is the study on the accident location near the airport and the definition of the probability distribution curve that best fit the accidents location on the surrounding area at the airport.

For the first point, two reference systems are set: they have the axes in the same directions but the origins are different depending on the aircraft operation. The point on the centerline at the runway end is the origin for take-off and the runway threshold is that one for landing. After localizing accidents in these reference systems, the Probability Density Function (PDF) that best fit the accident distribution has found.

This analysis produces two distributions: the first has the ordinate y as independent variable, which coincides with the trajectory of the aircraft, the second has the abscissa x as independent variable defined on an orthogonal axis to the trajectory. The two distributions are respectively the Gamma and Weibull PDF, defined by (3) and (4):

$$g(y) = p\frac{1}{\beta^{\alpha}\Gamma(\alpha)}y^{\alpha-1}\exp\left[-\left(\frac{y}{\beta}\right)^{\alpha}\right] \tag{3}$$

$$h(x,y) = \frac{1}{2}\frac{\alpha}{\beta^{\alpha}}|y|^{\alpha c}|x|^{\alpha-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\alpha}|y|^{\alpha c}\right] \tag{4}$$

The functions have different forms depending on the aircraft movement (takeoff or landing, overrun or overrun). The product of the two functions *g(y)* and *h(x,y)* gives a function *f(x,y)* (5) that expresses the probability surface density of accident:

$$f(x,y) = g(y)\cdot h(x,y) \tag{5}$$

The value of Individual Risk *IR* is given from Eq.(6):

$$IR_r = \sum_{i=1}^{t}\int_{X_0-\frac{a_i}{2}}^{X_0+\frac{a_i}{2}}\int_{Y_0-\frac{a_i}{2}}^{Y_0+\frac{a_i}{2}}\left[2\cdot p\cdot R_i\cdot m_{i,r}\cdot f(x,y)\right]dx\,dy \tag{6}$$

where:

p: accident percentage per million of movements (whose value depends on the accident type, see Table 3);

$m_{i,r}$: number of movements of aircraft i on the route r;

R_i: aircraft accident rate;

$f(x, y)$: probability distribution function of different types depending on the operation performed by the aircraft.

a: side of the square that identifies the destroyed area.

The integral is calculated numerically in the points of a mesh, generally with not constant step, to clustering these points in areas closer to the runway. The individual risk at each point is the sum of the values obtained for each route of each airplane.

5. Development of a VBA software

The model described in the previous paragraphs has been implemented in Microsoft Visual Basic for Applications® (VBA) integrated development environment (IDE) in MS Excel® spreadsheet. The program named **SARAS** (*Sapienza Airport Risk Analysis Software*) can be used for any airport with a number of runways up to four, however skewed and any length. The runways are identified by the threshold coordinates, under which a mesh is created to calculate the Individual Risk. Fig. 4 shows the main screenshot of SARAS spreadsheet program. The aircraft routes can be numerically input or points can be read on an Autodesk AutoCAD2010® drawing and reported in coordinates in the referring mesh calculation, pointing the threshold at which the routes are related. Traffic mix in the airport is inputted on an MS Excel® spreadsheet by means of the following data:

name of the aircraft, related route, average number of movements, maximum takeoff weight (MTOW), accident rate. The first outputs are: destroyed area, accident rate for overrun and not overrun landing and take-off.

Elapsed time		05:30:33
Grid data		
P0=grid reference	x0	0
	y0	0
Width grid (m)		5000
Grid lenght (m)		20000
px(m)		100
py(m)		100
incl. grid (0-180 gradi)		0
number of rows "nr"		201
number of columns "nc"		51
Total Number of grid points		10251
Global coordinate	TOTAL INDIVIDUAL RISK	START
X Y	IR TOT	

RWY1			RWY2			RWY3			RWY4		
THRESHOLD P1 e P2	xp1	800	THRESHOLD P3 e P4	xp3	0	THRESHOLD P5 e P6	xp5	-1200	THRESHOLD P7 e P8	xp7	0
	xp2	800		xp4	0		xp6	-1200		xp8	0
	yp1	6600		yp3	6200		yp5	2550		yp7	0
	yp2	2680		yp4	2280		yp6	150		yp8	0
Pm1	xm1	800	Pm2	xm2	0	Pm3	xm3	0	Pm4	xm4	0
	ym1	4640		ym2	0		ym3	0		ym4	0
LRWY1	3920.000		LRWY2	3920.000		LRWY3	2400.000		LRWY4	0.000	
m1	0.000		m2	0.000		m3	0.000		m4	0.000	
incl1	0.000		incl2	0.000		incl3	0.000		incl4	0.000	
azimut1	0		azimut3	0		azimut5	0		azimut7	0	
azimut2	0		azimut4	0		azimut6	0		azimut8	0	
LandingDA1	3920.000		LandingDA3	3920.000		LandingDA5	2400.000		LandingDA7	0.000	
LandingDA2	3920.000		LandingDA4	3740.000		LandingDA6	2400.000		LandingDA8	0.000	

Fig. 4 Main screenshot of SARAS spreadsheet program.

The software calculates the IR at all points of the mesh related to all aircrafts along all routes "r" adding contributions, from overruns and overruns both take-offs and landing. The IR values and the coordinates of the corresponding point are written to an Excel spreadsheet and highlighted with different colors so an immediate graphical display of PSZ is available even on the Excel sheet (Fig. 5).

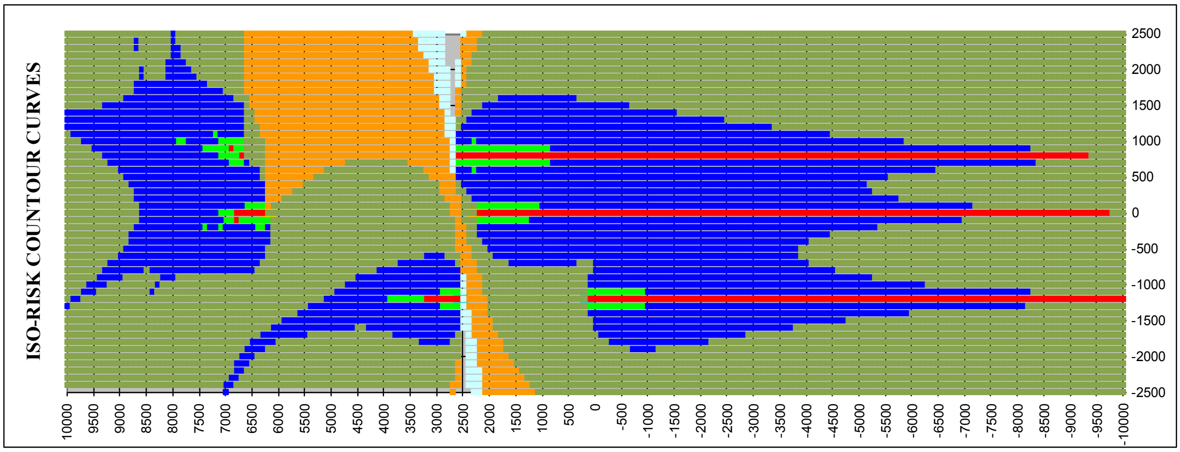

Fig. 5 Graphical display of PSZ on Excel sheet.

To get the perimeter of areas at the same risk, the set of points subject to the same value of risk index is determined by the Surfer® 8 software which also allows to export the results as Autocad DXF file. This operation allows to join the iso-risk curves with the map and territorial master plan of the area close to the airport.

The result can also be displayed, modified and plotted in Autocad using an adequate cartographic base of area around the airport.

6. Case study: Milan Malpensa Airport

Actually Milan Malpensa airport has two runways, 17L/35R and 17R/35L, both paved with asphalt concrete and the thresholds in cement concrete. They are both 3920 m long and 60 m wide, with strips of 4040x300 m. The runways are equipped with I.L.S. in Category III and II at RWY 35R and 35L. Runway 17L is equipped with ILS in class I; instead the approaching procedures for RWY 17R are controlled by VOR / DME and NDB.

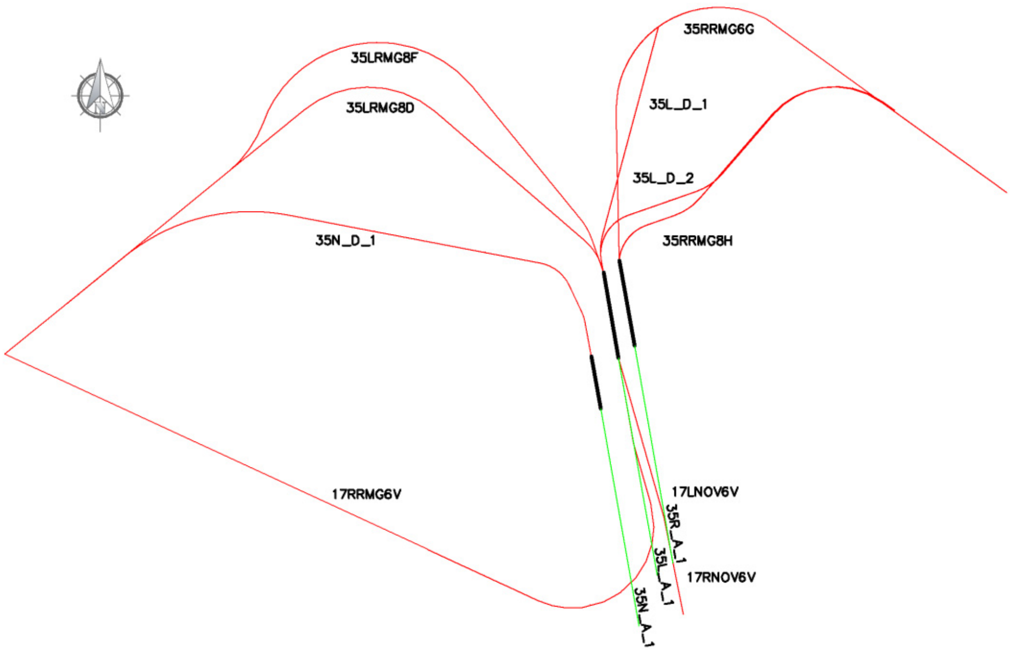

Fig. 6 Future development of Milan Malpensa Airport: three runways with 12 routes (3 routes for landing and 9 for take-off).

The future development of Milan Malpensa airport includes a third runway parallel to those existing at about 1200 m west of runway 17R-35L, 2400 m long and 60 m wide. In this study, it has been conventionally called 17N-35N. In 2007, Milan Malpensa Airport recorded 248,960 movements (landings and takeoffs) for commercial air traffic, while in future status 469,383 are expected, distributed on the routes shown in Fig. 6, as reported in Table 3. The types of aircraft for every route, their weight and their accident rates are also defined.

Table 3: Future development of Milan Malpensa Airport: number of movements on different routes.

OPERATION	GATE	ROUTES	N° MOVEMENTS	% ROUTE USE
TAKE-OFF	35L	35L_D_1	15300	6,42
		35L_D_2	25154	10,56
		35LRMG8D	10750	4,51
		35LRMG8F	30423	12,77
TAKE-OFF	17R	17RNOV6V	3877	1,63
		17RRMG6V	1920	0,81
TAKE-OFF	35R	35RRMG6G	43207	18,14
		35RRMG8H	23892	10,03
TAKE-OFF	35N	35N_D_1	83660	35,12
LANDING	35R	35R_A_1	93703	40,56
LANDING	35N	35N_A_1	83226	36,03
LANDING	35L	35L_A_1	54272	23,41

The iso-risk curves have been calculated by varying the mesh discretization step in both directions x and y, from 10 m to 50 m, depending on the distance from the runway, optimizing the mesh size. The three iso-risk curves 10^{-4}, 10^{-5} and 10^{-6} shown in Fig. 7 have been defined.

In addition, in Fig. 7, the takeoff and landing routes are reported to show how their direction and shape have defined the PSZ form.

10^{-6} iso-risk curves form a unique very large area including 35L, 35R and 35N thresholds. Instead, two rather limited surfaces are defined at Threshold 17: one affects the Thresholds 17R and 17L globally and the other grows only on the Threshold 17N.

10^{-5} and 10^{-4} iso-risk don’t overlap among the runways and are very concentrated in each threshold area.

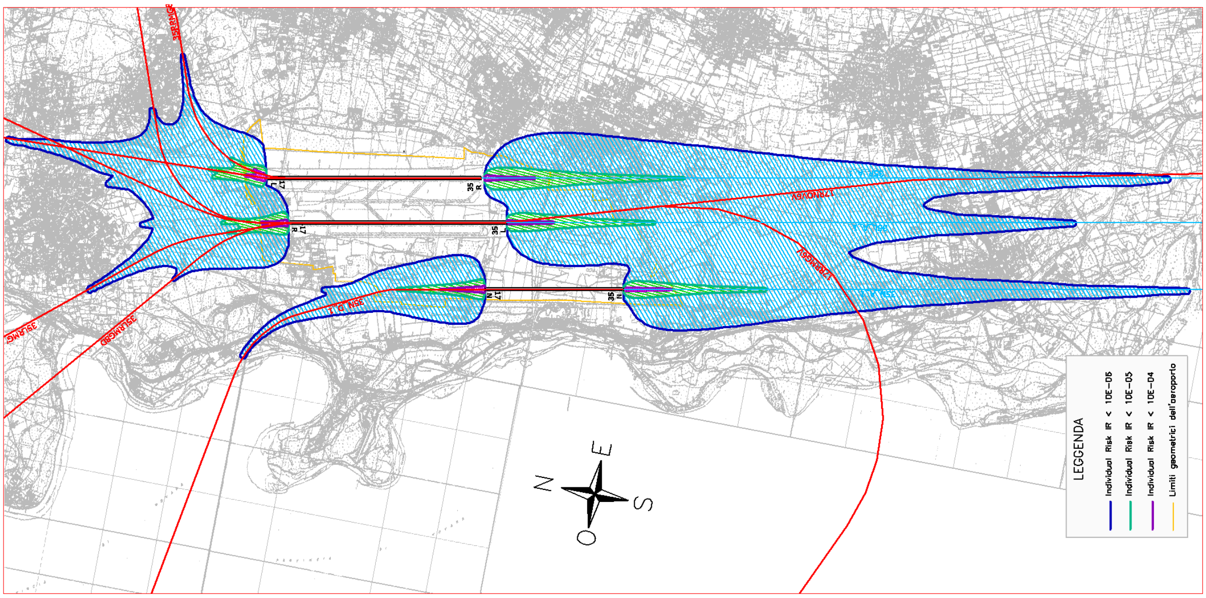

Fig. 7 The iso-risk curves for Milan Malpensa airport (future scenario).

7. Conclusions

The risk of accident in takeoff and landing operations involve, as well as passengers and crew of the flight, a vast territory near the airport and a great number of people living there.

Following a series of accidents around the world, the need to develop legislation to protect people living in neighbouring areas to airports has born in many countries. In Italy, the recent Legislative Decree n.96 dated 9 May 2005 [5] introduces the duty of risk assessment coming from plane crash for identifying areas to subject to any protective measures.

The purpose of risk assessment in areas near airports must be sought in several aspects:

- its implementation in the plans of the municipalities in the territory near the airport in terms of intended use of land;
- the development planning of an airport in the medium-long term, taking into account the risk assessment into development choices;
- the operational level, for mitigation of social risks, trying to optimize the use of runway directions for approach and takeoff operations.

This paper has presented a model of risk assessment for Italian airports with automated calculation software in VBA language in Excel environment. This model has been applied to different configurations and Italian airports and the study carried out at the Italian airport of Milan Malpensa has been presented in this article.

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