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## **PROPOSAL OF A METHODOLOGY FOR AIRPORT PUBLIC SAFETY ZONES POLICY**

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*Distefano N.*

*Physical Doctor – University of Catania – [ndistefa@dica.unict.it](mailto:ndistefa@dica.unict.it)*

*Leonardi S.*

*Researcher – University of Catania – [s.leonardi@unict.it](mailto:s.leonardi@unict.it)*

*Buscema D.*

*Engineer – [daniebuscema@virgilio.it](mailto:daniebuscema@virgilio.it)*

### **ABSTRACT**

The Public Safety Zones are areas of land at the end of the runways at the busiest airports within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing.

The implementation of Public Safety Zone policy at civil airports is based on a model work carried out using appropriate aircraft accident data to determine the level of risk to people on the ground around airports.

The basis of the policy of new development or removal within Public Safety Zones is cost-benefit analysis.

In case of new development within Public Safety Zones, they will be inhibited if the benefits deriving from inhibition are greater of the relative costs. In case of existing activities, they will be able to remain within of the Public Safety Zones if the removal costs are greater of the relative benefits.

This work determines firstly the extent of be subjected to a particular level of risk of being killed as a result of an aircraft accident.

The second part of the work considers methods for setting tolerability criteria for airport third party risk. It conclude that cost benefit analysis (CBA) would be the most appropriate method for determining PSZ policy. In this regard, we will propose an original methodology in order to define Public Safety Zones policy.

The proposed methodology, finally, will be applied to the airport of Catania.

## 1. RESEARCH OBJECTIVES

The Public Safety Zones are areas at end of the runways at airports. People can live or work normally in a Public Safety Zone. Within Public Safety Zones there should be no increase in the number of people living, working or gathering.

In these areas, new development should be controlled to restrict the number of people who may be exposed to risk if there is an aircraft accident on take-off or landing.

Public Safety Zone policy has full effect only where any new development needs planning permission. In cases where there are residential, commercial or industrial properties within the higher risk contour close to the ends of the runway, it is necessary for those properties to be emptied.

This paper determines firstly the extent of individual risk contours, upon which a person remaining in the same location for a period of a year would be subjected to a particular level of risk of being killed as a result of an aircraft accident; secondly it propose an original methodology in order to define Public Safety Zones policy not only in regard to individual risk, but in the broadest sense, in relation to particular types of development such as transport infrastructure and in relation to other uses (residential, commercial or industrial).

## 2. AIRPORT PUBLIC SAFETY ZONE DETERMINATION

The Public Safety Zones are areas of land at the end of the runways at the busiest airports within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing. The implementation of Public Safety Zone policy at civil airports is based on a model work carried out using appropriate aircraft accident data to determine the level of individual risk to people on the ground around airports.

For definition, the individual risk is equal to the annual risk of death, as a result direct of an aircraft crash, of an individual that is assumed resides in a date location for 24 hours a day and for every day of the year.

This work determines the extent of individual risk contours, upon which a person remaining in the same location for a period of a year would be subjected to a particular level of risk of being killed as a result of an aircraft accident. The Public Safety Zones represent a simplified form of the risk contours, in order to make the Zones easier to understand and to represent on maps, and also in recognition of the imprecise nature of the model work.

The calculation of individual risk contours requires three basic quantities:

- 1) the annual probability of a crash occurring near a given airport (crash frequency);
- 2) the distribution of such crashes with respect to location (crash location model);
- 3) the size of the crash area and the proportion of people likely to be killed within this area (crash consequence model).

In this paper we propose a procedure to trace simply, but with good precision, the lines of equal individual risk.

It has been noted that the individual risk at any point is approximately proportional to the product of the *average crash rate*  $R$  (it is calculated as a movement weighted

average), movement numbers  $N$ , and average destroyed area  $A_{des}$ , (it is defined as destroyed area as it is a result of an aircraft accident and coincident with the area where the pieces of the aircraft wreckage are dispersed as a result of an aircraft accident) appropriate to the airport in question.

Through the statistical treatment of the data concerning some airports it was possible to define the linear regression that associate the product  $N \cdot R \cdot A_{des}$  with the areas ( $A$ ) relative to the three risk individual values ( $10^{-4}$ ,  $10^{-5}$ ,  $10^{-6}$ ):

$$A = 0,00015 \cdot N \cdot R \cdot A_{des} + 3,095 \quad (R^2=0.978) \text{ for individual risk} = 10^{-4} \quad (\text{Eq.1})$$

$$A = 0,00250 \cdot N \cdot R \cdot A_{des} + 60,52 \quad (R^2=0.999) \text{ for individual risk} = 10^{-5} \quad (\text{Eq.2})$$

$$A = 0,03380 \cdot N \cdot R \cdot A_{des} + 849,97 \quad (R^2=0.988) \text{ for individual risk} = 10^{-6} \quad (\text{Eq.3})$$

The total area  $A$  is expressed in hectares, the number of annual aircraft movements  $N$  is expressed in millions of movement, the average crash rates  $R$  is expressed in crashes per million of movements, the average destroyed area  $A_{dis}$  is expressed in hectares.

The resultant shape of the Public Safety Zones is an elongated isosceles triangle, with its base at the end of the runway and extending outwards beyond the airfield boundaries.

If an airport had more of one runway, the area  $A$  will divide proportionally among these in function of the respective utilization factor; while to divide the area  $A$  among the two runway ends it is necessary to employ the percentage of the accidents for the different typologies of accidents and the percentage of movements in the analyzed direction (Eq. 4).

$$A_{re} = \sum_{i=1}^n A \cdot P_{Lre} \cdot P_{ai} + \sum_{i=1}^n A \cdot P_{Tre} \cdot P_{ai} \quad (\text{Eq. 4})$$

Where:

- $A_{re}$  = PSZ's area relative to runway end ( $re$ )
- $n$ : number of typologies of accidents considerate;
- $P_{Lre}$ : percentage of landings in the direction  $re$ ;
- $P_{Tre}$ : percentage of take-offs in the direction  $re$ ;
- $P_{ai}$ : percentage of the accidents for typology  $i$ .

If we know the area of the triangle for the levels of individual risk  $10^{-4}$ ,  $10^{-5}$ ,  $10^{-6}$ , the average of the ratio  $\rho$  between the length ( $l$ ) and the width ( $w$ ) of the triangle, it will be possible to determine the dimensions of the triangle, for every level of risk, the following system:

$$\begin{cases} A = \frac{1}{2} \cdot l \cdot w \\ \rho = \frac{l}{w} \end{cases} \Rightarrow l, w \quad (\text{Eq. 5})$$

### 3. PROPOSAL OF CRITERIA FOR PSZs POLICY

In this paper the authors propose a methodology for the PSZ policy based on Cost-Benefit Analysis (CBA). The application of CBA to the policy of PSZs in principle requires the following steps:

1. identify the risk contour corresponding to the individual tolerability limit of a risk of death of  $10^{-4}$  (intolerable value),  $10^{-5}$ ,  $10^{-6}$  (negligible value) per year;
2. at each point included in zone between  $10^{-4}$  contour and  $10^{-5}$  contour, compare the benefits from reducing risk, using the appropriate valuation, with the costs of removing or prohibiting activities at that point;
3. designate the PSZ as the area within the contour between  $10^{-4}$  and  $10^{-5}$  together with the area in which the benefit in exceeds the cost.

The economic costs are the costs of removing in case of existing activity or a percentage of the value of development of the land in case of change of use (from building site to agricultural ). The benefits are relationship to the monetary value to the humans life interested of the activity and to the individual risk in the specific location taken by activity.

#### 3.1 Costs estimation

The costs to estimate are related to the followings hypotheses:

- the removal of a building of private ownership (residence, shop, industry, etc);
- the removal of a public building (school, cinema, swimming pool, etc);
- the change of use of land (from building site to agricultural).

To estimate the economic loss, relative to each of the three hypotheses, is based on the concept of opportunity cost, this is the consequential cost from the missed exploitation of a granted opportunity to the economic subject.

The economic costs relative at the first and at the second hypothesis are show in figure 1.

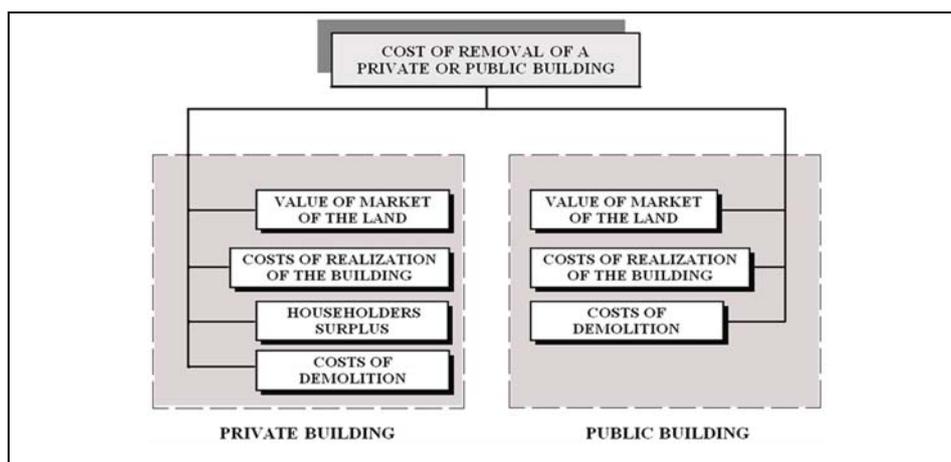
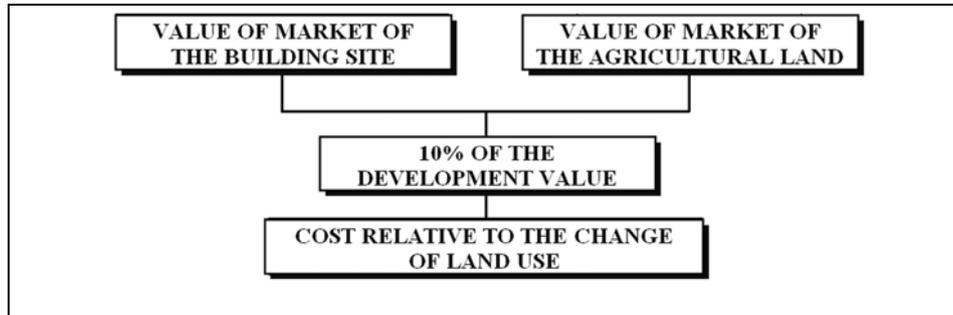


Figure 1 Opportunity cost related to the removal of private and public building

The figure 2 show the flow diagram for the valuation of the costs relative at the change of use of land from building site to agricultural land.



**Figure 2 Opportunity cost related at the change of use of land**

The difference between the value of building site and its value after the change of use is called “development value”.

It has been assumed that the opportunity cost of inhibiting of new development is a percentage of the land’s development value; the percentage has been taken as a representative value is 10%.

### 3.2 Benefits estimation

The benefits related to the removal or to the inhibition of a generic activity are considered in relationship to the costs related to the individuals' death interested by the activities and to the value of individual risk in the specific location taken by activity. Then the benefit is express as value of the risk.

If the value of statistical life doesn't vary with the absolute risk, the value of the risk at any location is proportional to the absolute individual risk level, said  $r$ . Let the average number of occupants per dwelling be  $n$ , and let the value of statistical life be  $v$  (taken as 1.000.000 €). Then the value of the statistical lives of the occupants of the average house is  $n \cdot v$ , and if the activity is located on risk contour  $r$ , the annual value of the risk is  $n \cdot v \cdot r$ . If this risk is maintained for  $m$  years (taken as 30 years), and the discount rate for future costs and benefits is  $d$  (taken as 3.5 per cent per year), the present value of the benefit from the risk is:

$$\text{Risk value: } n \cdot v \cdot r \cdot \left( \frac{1 - \frac{1}{(1+d)^m}}{1 - \frac{1}{1+d}} \right) \quad (\text{Eq.6})$$

But, it is not so much the number  $n$  of individuals statements to the risk to determine the value of the risk of the specific activity, how much the density with which the people occupy the territory and the hours in one day and the number of days in one year when the presence of the  $n$  individuals is verified inside the specific activity.

Therefore, in this paper the authors, in order to determine the value of the risk as the benefit consequential from the inhibition or removal of an activity, propose the following relationship:

$$\text{Risk value: } n \cdot \alpha \cdot \frac{t}{24} \cdot \frac{g}{365} \cdot v \cdot r \cdot u_d \cdot \left( \frac{1 - \frac{1}{(1+d)^m}}{1 - \frac{1}{1+d}} \right) \quad (\text{Eq.7})$$

It has been introduced the factors  $t/24$  and  $g/365$  in which  $t$  represents the average number of hours in one day and  $g$  the average number of days in one year when the  $n$  individuals are rally present inside the specific activity.

The table 1 show some of the typologies of structures on the territory and, for every of them, the values to assign at the parameters  $t$  and  $g$ .

**Table 1 Values of  $t$  and  $g$  related to the possible activities**

Activity	Structures	$t$	$g$
Residential	Residences. Hotels. Rest-homes	24	365
Working. Commercial	Industries. Offices. Shops. Restaurants	8-10	Working days
Sports - Free time	Gyms. Swimming pools	12	Working days
Educational	Schools. Colleges. Universities	6	Working days
Sanitary	Hospitals. Nursing homes	24	365
Prison	Jails. Barracks police	24	365

Moreover, it has been introduced the factor  $u_d$  through which wanted to attribute a greater value of the risk if this interests young men. For example in the schools, of every order and degree, it results opportune to assume  $u_d$  equal to 2, in order to do greater weight at a possible loss of the children's life.

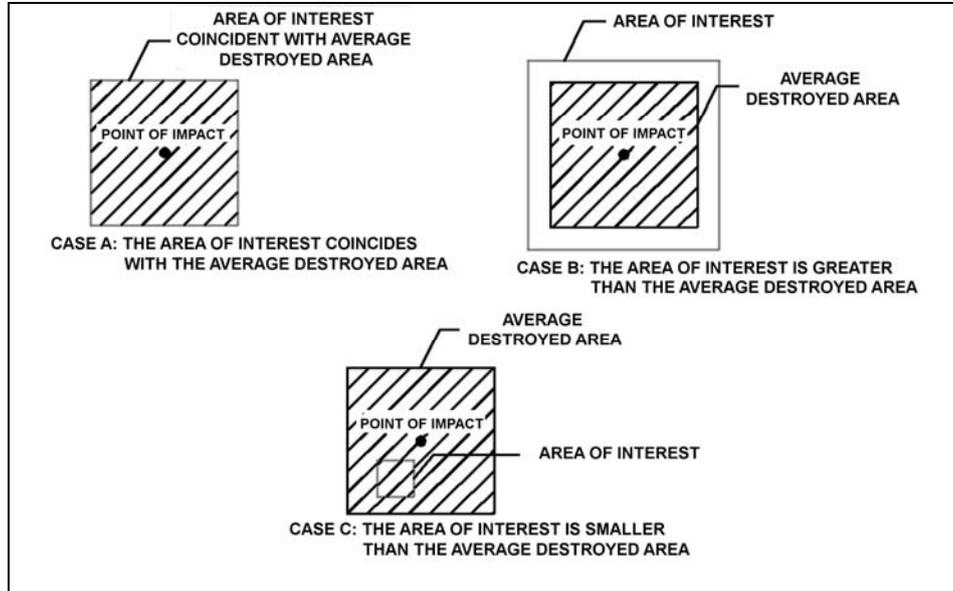
The  $\alpha$  coefficient is introduced in consideration of the relation between activity's area and average destroyed area.

The average destroyed area is definite as the area on the ground which was destroyed as a result of an aircraft accident and coincident with the area where the pieces of the aircraft wreckage are dispersed as a result of an aircraft accident. To simplify the treatment is assumed that such area has a squared form and that the point of impact of the aircraft coincides with the barycentre of the aforesaid square.

For the valuation of the  $\alpha$  coefficient it is necessary to differentiate three cases (Fig. 3):

- *Case A:* The  $n$  individuals occupies an area  $A$  wide as well as the average destroyed area. In this case is likely to conclude that, the wreckage due at the impact of an aircraft of this will interest the whole area, provoking the death of all the individuals that occupy the area, in the only case in which the point of impact of the aircraft coincides with the barycentre of the area  $A$ , therefore:

$$\alpha = 1$$



**Figure 3 Compare among area of interest and average destroyed area**

- *Case B:* the area A ( $A_{int}$ ) resulted to be wider of the average destroyed area ( $A_{des}$ ). In this case it would be permissible to consider the hypothesis that someone among the people that occupy the area would be able don't die because the wreckage of the airplane would interest an inferior area of A, it is therefore logical to assume a value of the risk inferior in comparison to that in which the area A coincides, as extension, with the average destroyed area, in this case:

$$\alpha = \frac{\bar{A}_{des}}{A_{int}} \quad (\text{Eq.8})$$

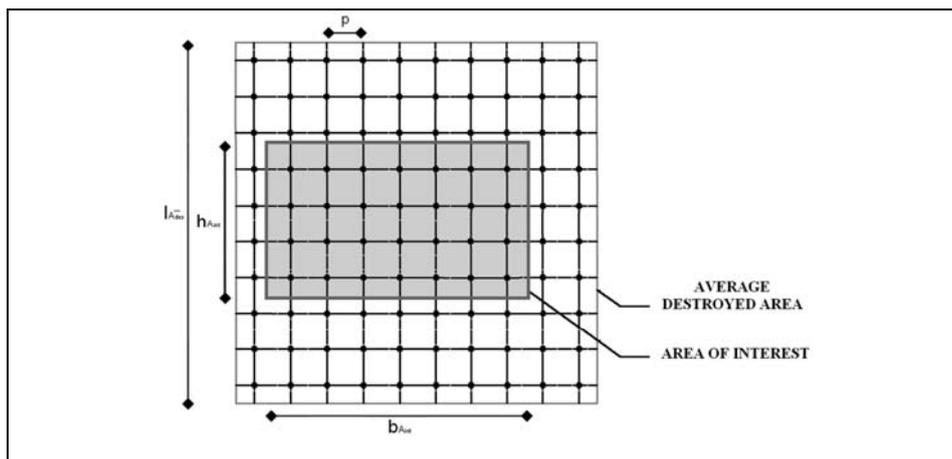
- *Case C:* the area A is smaller of the average destroyed area (Fig. 4). In this case all the people present in the area A would die, not only if the aircraft fell in the barycentre of A, but also if the impact happened in numerous near points. Considering all the positions of the point of impact that involve the total inclusion of the area of interest within of the relative average destroyed area it is possible define the  $\alpha$  coefficient through the following equation:

$$\alpha = \left( 1 + \frac{l_{\bar{A}_{des}} - b_{A_{int}}}{p} \right) * \left( 1 + \frac{l_{\bar{A}_{des}} - h_{A_{int}}}{p} \right) \quad (\text{Eq.9})$$

Where:

$l_{A_{des}}$  = side of the average destroyed area;

$b_{A_{int}}$  = base of area of interest;  
 $h_{A_{int}}$  = height of area of interest;  
 $p$  = step, distance of the point of impact, that determines a variation of the location of the average destroyed area that is significant (taken as  $l_{A_{des}}/10$ ).



**Figure 4 Relation between the dimensions of the Average destroyed area and area of interest**

### 3.2.1 Transport infrastructure within Public Safety Zones

Although transport infrastructure within Public Safety Zones is used typically by any one person for only a short period at a time, a large number of people can be using a particular facility at any particular time.

Transport infrastructure is therefore considered for Public Safety Zone policy purposes as if it is residential, commercial or industrial development. As with those forms of development, it is not considered necessary to remove existing transport infrastructure from within Public Safety Zones.

But new transport infrastructure such as railway stations, bus stations and park and ride schemes will not be permitted within Public Safety Zones, as they would result in a concentration of people for long periods of the day. Although people passing along a transport route are likely to be within the Public Safety Zone for only a very small part of the day, the average density of occupation within the Zone may be significant, and as high as that for fixed development.

Proposals for major roads and motorways will be carefully assessed in terms of the average density of people that might be expected to be exposed to risk. Low-intensity transport infrastructure, such as minor or local roads, can be permitted within Public Safety Zones.

Since the individuals transit on the infrastructures, the number of people  $n$  subject to the risk is a varying parameter in the time and in the space.

Also the value of the individual risk is a varying parameter from a point to another of the infrastructure.

The interest area ( $A_{int}$ ) is the area constituted by the portion of infrastructure included between the triangles of risk equal at  $10^{-4}$  and  $10^{-5}$  (fig 5).

For this area, it is necessary to determine the value of n individual that occupy the area  $A_{int}$ , utilizing the following equations:

$$V \cdot O_{cc} = p \text{ (indiv./h)} \quad (\text{Eq. 10})$$

Where:

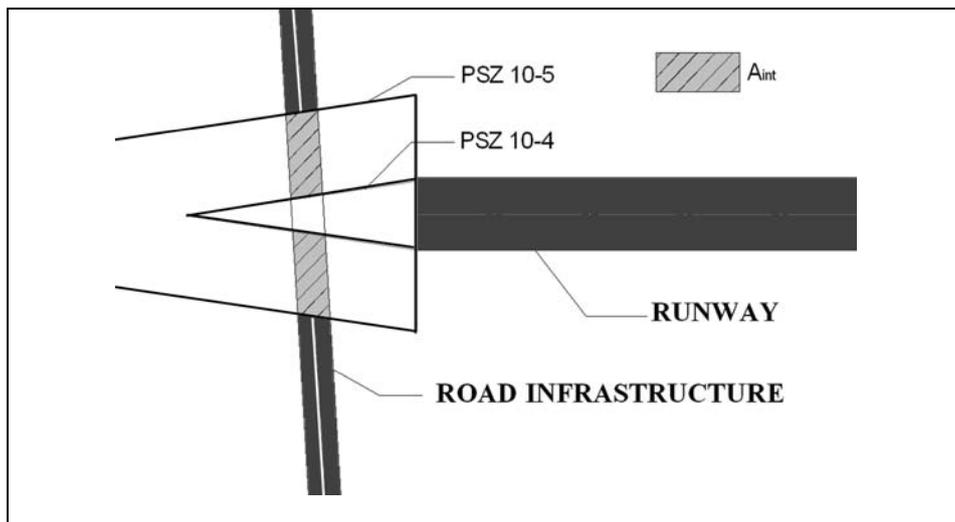
$p$  = number of individuals for hour in  $A_{int}$ ;

$V$  = Flow rate (veic/h);

$O_{cc}$  = number of occupants for vehicle (indiv./veic.) (taken as 1.5)

In a hour, they occupy a surface  $s$  equal to the product among the average travel speed  $S$  (km/h) and the width  $w$  (m) of the road section.

$$1000 \cdot S \cdot w = Z \text{ (m}^2\text{/h)} \quad (\text{Eq. 11})$$



**Figure 5 Area  $A_{int}$  of the road infrastructure**

Consequently, the number of people that occupy a square meter of the infrastructure is provide to:

$$\frac{p}{Z} = \bar{p} \text{ (indiv./m}^2\text{)} \quad (\text{Eq. 12})$$

In conclusion, the value n is provide of the equation 13:

$$\bar{p} \cdot A_{int} = n \text{ (indiv.)} \quad (\text{Eq. 13})$$

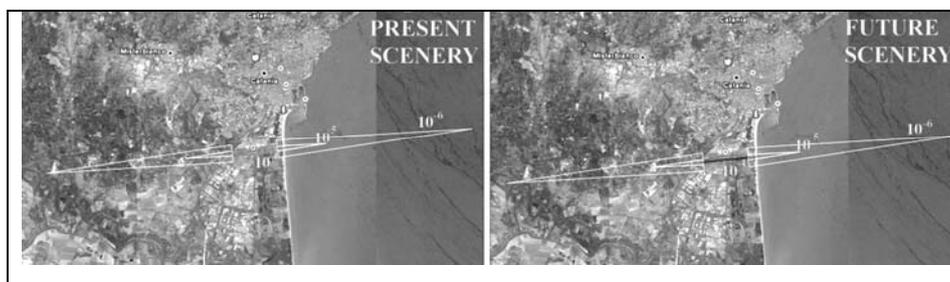
#### 4. APPLICATION OF THE METHODOLOGY PROPOSED TO CATANIA'S AIRPORT

The Catania's airport is one of the most important of Italy, and it is characterized, in terms of traffic, from a remarkable annual rate of growth.

We have effected the risk analysis for the determination of PSZs policy both in the present scenery and in future scenery (year 2012). The development plans of the Catania's airport, will bring in 2012 to the realization of the runway 08-26 South, in parallel position to the existing runway 08-26.

The individual risk calculations were performed using the methodology proposed in paragraph 3.

The results are plotted in the form of contours showing lines of equal risk in Figure 6. The contours shown correspond to third party individual risk values of one in  $10^{-4}$ , one in  $10^{-5}$ , and one in  $10^{-6}$ .



**Figure 6 Individual risk contours at Catania's airport**

The application of CBA methodology exposed in paragraph 3 for the determination of PSZs policy, has originated the following results: in the present scenery of Catania Airport and in that future, all the residential, scholastic and industrial activities are located outside the  $10^{-6}$  contour.

The table 2, therefore, show the risk bands relative to the inhibition of the activities and not for their removal.

**Table 2 Risk bands relative to the inhibition of the activities within Catania's airport PSZs**

Typology of activity	Risk bands relative to the inhibition of the activities	
	Present scenery	Future scenery
Residential (low density of people)	$10^{-4} \div 1,5 \cdot 10^{-5}$	$10^{-4} \div 10^{-5}$
Residential (high density of people)	$10^{-4} \div 5 \cdot 10^{-6}$	$10^{-4} \div 4,5 \cdot 10^{-6}$
Industrial	$10^{-4} \div 1,5 \cdot 10^{-5}$	$10^{-4} \div 10^{-5}$
Scholastic	$10^{-4} \div 5 \cdot 10^{-6}$	$10^{-4} \div 2 \cdot 10^{-6}$

The activities that are submitted to a level of individual risk  $>10^{-4}$  are exclusively represented by the road infrastructures. In the present scenery, the levels of intolerable risk interest the SP 53 (*Lungomare Presidente Kennedy*) and the *S. Giuseppe alla Rena street* in the territory adjacent to the 26 end runway, the railway and the SP 70 (*Asse dei Servizi*) in the territory adjacent to the 08 end runway. In the future scenery will be similar.

For the principal road, the SP 70 and the SP 53, it is calculated the value of the risk, that is the monetary benefit that would be gotten by their removal by the territory (table 3 and table 4).

**Table 3 CBA results relative to the removal SP 70 Road**

	Risk bands		
	SP 70 Road – Present scenery		
	$> 10^{-4}$	$10^{-4} \div 10^{-5}$	$10^{-5} \div 10^{-6}$
Road length	20 m	513 m	938 m
Exposed people		33	60
$\alpha$ coefficient		0,54	0,29
Value of the risk		16806 €	1650 €
Removal cost		$> 100000$ €	$> 100000$ €
	SP 70 Road – Future scenery		
	$> 10^{-4}$	$10^{-4} \div 10^{-5}$	$10^{-5} \div 10^{-6}$
	0	436 m	1318 m
Road length	0	436 m	1318 m
Exposed people		28	84
$\alpha$ coefficient		0,84	0,28
Value of the risk		22226 €	2238 €
Removal cost		$> 100000$ €	$> 100000$ €

**Table 4 CBA results relative to the removal SP 53 Road**

	Risk bands		
	SP 53 Road – Present scenery		
	$> 10^{-4}$	$10^{-4} \div 10^{-5}$	$10^{-5} \div 10^{-6}$
Road length	46 m	208 m	700 m
Exposed people		13	42
$\alpha$ coefficient		2,47	0,73
Value of the risk		28916 €	2893 €
Removal cost		$> 100000$ €	$> 100000$ €
	SP 53 Road – Future scenery		
	$> 10^{-4}$	$10^{-4} \div 10^{-5}$	$10^{-5} \div 10^{-6}$
	35 m	208 m	695 m
Road length	35 m	208 m	695 m
Exposed people		13	42
$\alpha$ coefficient		3,28	0,98
Value of the risk		38711 €	3861 €
Removal cost		$> 100000$ €	$> 100000$ €

The values of the risk are inferior to the costs of removal. The road sections that extend to the inside of the areas submitted to a level of individual risk  $>10^{-4}$ , moreover, are very short. The removal of the roads, therefore, is inopportune both in the present scenery and in that future.

The values of the risk are smaller of the costs of removal always. The road sections that extend to the inside of the areas submitted to a level of individual risk  $>10^{-4}$ , moreover, are very short. The removal of the roads, therefore, is inopportune both in the present scenery and in that future.

## 5. CONCLUSIONS

This paper describes a study in support of airport Public Safety Zone (PSZ) policy. The study has been undertaken in two parts. In the first part it have proposed a procedure to trace simply, but with good precision, the lines of equal individual risk. In this way the PSZ's extension can be characterized simply.

In the second part of the study it have proposed an original methodology in order to define Public Safety Zones policy based on cost benefit analysis (CBA).

The proposed methodology, finally, has been used for the determination of PSZs policy both in the present scenery and in future scenery relative to Catania's Airport.

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