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Quantitative Risk Assessment of Temporary Hazards and Maintenance Worksites in the Airport Safety Areas: a case study

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Abstract

Airports are complex environments where the operational conditions are subjected to different risks, both due to the intrinsic nature of the manoeuvres themselves and to the external factors, as for human actions or environmental causes.

An important risk factor is the presence of temporary hazards on the runway or taxiway safety area, including work in progress related to maintenance or construction operations.

Both ICAO (International Civil Aviation Organization) and FAA (Federal Aviation Administration) defined their own approach on this topic. The FAA, in the Advisory Circular "Operational Safety on Airports During Construction", states the impossibility of any construction activities within the safety area when the runway is active, while the ICAO, in the Doc 9137 "Airport Service Manual" Part 6, states specific operational restrictions for the airport which allow the presence of temporary hazard in the safety area. This paper analyses the impact of temporary hazards (for example worksites) in the safety areas, according to ICAO requirements, by using a performance approach. The method has been applied to an international airport, using the software RSARA e LRSARA, provided by ACRP (The Airport Cooperative Research Program), in order to calculate the expected risk level within the safety area.

This method provides a rapid and practical evaluation of risk level, according to the ICAO Safety Management System approach, in order to optimize the maintenance operation and construction in the safety area, minimizing the closing time of the runway.

The main aim of this study is to verify if, under temporary restrictive operational condition (such as the limitation on available runway length and on traffic mix and weather conditions) related to the temporary hazard presence, it is possible to guarantee sufficient safety level, without occurring in runway closures.

From the analysis arose that the first factor that affects the risk level for a runway is the temporary hazard dimension: while the environmental conditions (crosswind and pavement conditions) have a minor effect.

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1. Introduction

The runway surface is requested to have high evenness characteristics, to allow a regular run of airplanes (Loprencipe and Zoccali, 2017). For this reason, the runway must be maintained in good condition over its whole service life. This means that the presence of work sites is very common in the airport. The duration of the works is defined by the type of maintenance required. Construction projects in an airport movement area introduce numerous problems due to the necessity to continue the operations as much as possible with an unchanged level of safety. Whether possible, the works (for example, the resurfacing of runways in asphalt) are performed during the night, when the flight activity is stopped. Nevertheless, performing the works by night is not compatible with certain construction technics: for example, the entire reconstruction of the pavement or the reconstruction of concrete slabs.

The presence of site works requires careful assessment of air traffic safety, specific measures to overcome the economic losses of airport manager and social damage (for example, the possible displacement of flights on the adjacent runway with a noise pollution increase (ENAC, 2003)). The runway closure is one of these alternatives, but it affects significantly the airport capacity. Temporary displacement of a threshold is a common measure adopted in case of construction work, providing reduced consequences on the airport capacity (Gael le Bris, 2014) but a sensitive modification in the existing operating conditions that can generate accidents.

Safety statistics show that runway excursions are the most common type of accident reported annually (G.W.H. van Es, 2010, Cardi et al., 2012). A runway excursion is an event in which an aircraft veers off or overruns the runway surface during either take-off or landing. In the area near the runway, another type of accident has a high frequency: the landing undershoot (Cardi et al., 2012). Moreover, a study performed by the Dutch company NLR (G.W.H. van Es, 2010) shows that runway conditions (e.g. wet or contaminated by slush, standing water etc.) play a significant role in overruns and the crosswind on wet/contaminated runways plays an important role in veers-off.

These accidents can produce serious consequences in the areas near the runway both outside (Attaccalite et al., 2012; Di Mascio and Loprencipe, 2016) and inside the airport (Moretti, 2017);in order to mitigate their consequences, safety areas free from obstacles, are located around the runway: the ‘‘Strip” and ‘‘Runway End Safety Area (RESA)”, governed by ICAO regulations. According to Annex 14 of ICAO (ICAO, 2016), the runway strip is intended to reduce the risk of damage to aircraft running off a runway and protect aircraft flying over the airport, during take-off or landing operations from obstacles collision. .”

Annex 14 of ICAO (ICAO, 2016) defines strip requirements in terms of physical dimensions, slopes, levelling, strength and the presence of objects, according to aerodrome code number and type of operation (instrument or visual).

RESA is defined by the same ICAO document (ICAO, 2016) as “an area symmetrical about the extended runway centre line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aeroplane undershooting or overrunning the runway”. ICAO determines a minimum length of 90 m and the width twice that one of the runway. It also recommends that it should extend up to 240 m (or up to the first obstacle located on the extension of the centreline), and that it should reach the levelled part of the strip.

The RESA surface must be clear and levelled and the ground must be strong enough to bear the weight of an aircraft and the support vehicles. Finally, objects that may pose a risk to aircraft must be removed and penetrations in approach surfaces or take-off climb surfaces are not allowed.

A construction site on the runway may increase the risk of accident during the landing and take-off operation.

The FAA (FAA, 2017) forbids all the operation if a work site is present on the runway or in the safety areas around it. Instead, the ICAO considers some operational constrains, but it allows construction work in airside if a risk assessment shows that the level of safety remains over an allowable value (ICAO, 1988).

As a consequence, the construction work in airside requires a formal approach oriented to assess the impacts on safety of any modification regarding the operations, and to mitigate them with adequate measures. In other words, a procedure of Safety Risk Management (SRM) is needed. The SRM is a component of the Airport Safety Management System (SMS), defined by ICAO in Annex 19 (ICAO, 2013) as "a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies, and procedures".

The SRM must evaluate the likelihood of the occurrence of an accident and the consequences on the aircraft and its passengers, if a temporary obstacle is present around/near the runway.

The present study is placed within this risk assessment procedure, in order to evaluate the actual risk level induced by the presence of a temporary construction site in the safety areas of the runway and to establish, if necessary and possible, the proper mitigation measure on the airport system.

The risk in presence of construction site in the airport movement area can be assessed with tools currently available. In the present study this goal has been achieved by the integration of two of them: RSARA - Runway Safety Area Risk Analysis (ACRP, 2008) and LRSARA - Lateral Runway Safety Area Risk Analysis (ACRP, 2011) by the Airport Cooperative Research Program (ACRP) sponsored by FAA. These tools assess respectively the probability of overrun beyond the runway end and the lateral veer-off, considering the local traffic and safety objective.

The study aims to assess the accident risk increase when there is a work in progress at the sides or ends of a runway (temporary hazard, as defined by ICAO, 1988) within the runway safety areas during landing and take-off operations. In particular, the following issues have been investigated:

- to assess the safety conditions of the aircraft operations, during the execution of works near the runway and, if the safety level is not sufficient, evaluate the mitigation measures;
- to evaluate the risk containment of the operational and constructive limitations contained in the ICAO document (ICAO, 1988), compared to the total restriction of FAA circulars (FAA, 2017) ;
- to carry out the sensitivity analysis of the software RSARA and LRSARA regarding some critical parameters such as the position of the obstacles, the traffic volume, the wind direction and the operating conditions.

2. Method

The accident risk evaluation in the runway safety area due to the presence of temporary hazards has been conducted using the ACRP software RSARA and LRSARA. They allow a quantitative accident risk analysis based on a logistic regression considering airport configuration, yearly aircraft operations, and weather data. In order to investigate the increment of risk due to the presence of a temporary hazard and evaluate the possible restriction on the runway operability (even closure), different positions of the obstacle have been considered.

RSARA analyses the overrun and undershoot accidents instead LRSARA considers the case of veer-off and consequent impact with an obstacle within the safety area.

Both ACRP software are based on a probabilistic approach composed of three modules: Event Probability Model, Location Model (Longitudinal and Lateral) and Consequence Model. The first model estimates the probability that an event will occur under certain operational conditions: it uses independent variables associated with causal and contributing factors for the incident occurrence (such as airplane performance, type of operation, runway configuration, weather condition). The second Model evaluates the likelihood that an aircraft, departing the runway-end or the lateral border, stop within the RESA or STRIP, where temporary hazard might be set. Finally, the Consequence Model, using the Location Model outcomes, assesses the likelihood that the aircraft will strike an obstacle (described by its type, size and location) within the safety area. Through this process, represented in Figure 1, the software estimates the probability for an aircraft colliding beyond a certain distance from the runway and strikes an obstacle defined by location, size and characteristics, set in the RSA and its vicinity (ACRP, 2008, ACRP, 2011).

This study focuses on the decrement of the safety operation condition that can occur due to the presence of a temporary hazard in the runway safety areas. ICAO states that only under certain configurations for temporary hazards and environmental conditions, landing and take-off movements are still allowed but affected by operational restrictions (ICAO, 1988). The ICAO, in fact, defines three different "Limit Zones" alongside the runway, as reported in Figure 2: they are rectangular areas starting from the inner border of the runway and characterized by different standard dimensions depending on the runway code number and approaching category system of the runway.

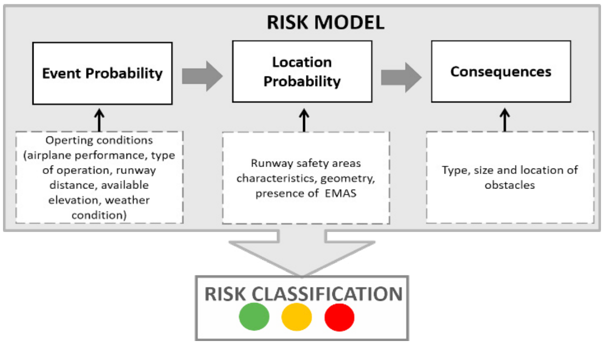
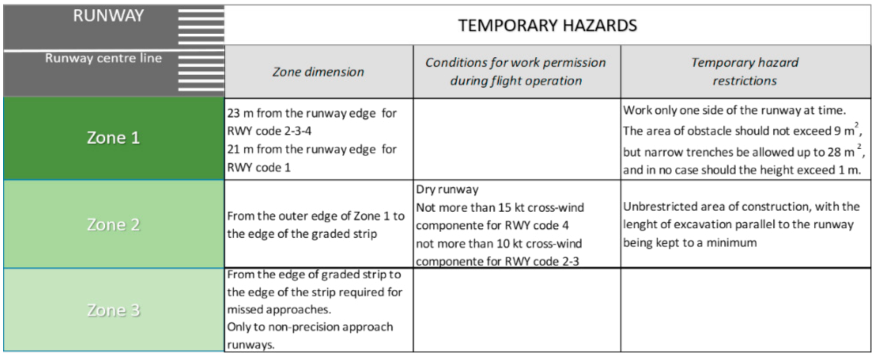


Fig. 1 ICAO Restrictions for dealing with temporary hazards on runway strip (ICAO, 1988)



RUNWAY	TEMPORARY HAZARDS		
Runway centre line	*Zone dimension*	*Conditions for work permission during flight operation*	*Temporary hazard restrictions*
Zone 1	23 m from the runway edge for RWY code 2-3-4 21 m from the runway edge for RWY code 1		Work only one side of the runway at time. The area of obstacle should not exceed 9 m^2, but narrow trenches be allowed up to 28 m^2, and in no case should the height exceed 1 m.
Zone 2	From the outer edge of Zone 1 to the edge of the graded strip	Dry runway Not more than 15 kt cross-wind componente for RWY code 4 not more than 10 kt cross-wind componente for RWY code 2-3	Unbrestricted area of construction, with the lenght of excavation parallel to the runway being kept to a minimum
Zone 3	From the edge of graded strip to the edge of the strip required for missed approaches. Only to non-precision approach runways.		

Fig. 2 ICAO Restrictions for dealing with temporary hazards on runway strip (ICAO, 1988)

In order to apply the temporary hazard restrictions (third column in Figure 2), the obstacles considered in the analysis have been inputed according to obstacles library of the ACRP software :

- The RSARA approach defines, as reported in Table 1, four categories of obstacles as functions of the maximum speed that an aircraft may collide with an obstacle, with small chances of causing hull loss and injuries to its occupants. For this analysis, the temporary hazard has been defined as "Category 2 obstacle (large ditches): Maximum speed 5 knots" (ACRP, 2011).
- The LRSARA approach defines two different types of obstacle: ground obstacles and tall obstacles. According to (ACRP, 2014) the Ground "g" obstacle is a structure below the ground level (e.g., ditches, uneven terrain, terrain drops, etc.), which may cause an accident if aircraft gears pass over it. A tall obstacle is a structure above the ground that may lead to an accident if struck by the aircraft.

The basic idea is the use of the Location Model to estimate the accident occurrences for which the aircraft will have high energy when striking an obstacle, or passing over it, thus resulting in serious consequences.

The first outcome of the methodology is the Safety risk probability distribution, defined as the likelihood or frequency that a safety consequence or outcome might occur (ICAO, 2013), achieved by ACRP software analysis. In this case, the probability distributions of accident occurrence combine the likelihood of a runway excursion with the probability that the aircraft will strike an obstacle. Table 2 represents a common frequency classification (Davis, R.V., 1991) in five categories, each related to an unsafe event or condition, to the description of each category, and to an assignment of a value to each category.

Table 1. Obstacle Classification (ACRP, 2011; ACRP, 2014)

RSARA		LSARA	
TYPE OF OBSTACLE	CODE	TYPE OF OBSTACLE	CODE
Concrete buildings	1	Ground: structure below the ground level (e.g., ditches, uneven terrain, terrain drops, etc.). These obstacles may cause an accident if aircraft gears pass over it and in this case the landing gear dimensions are considered in the analysis.	g
Concrete walls	1		
Cliffs	1		
Large holes	1		
Body of water (undershoot)	1		
Stockpiles	1		
Highways	1		
Flammable material pipeline	1		
Gas station	1		
Body of water (overrun)	2		
Brick wall\\	2		
Non frangible blast fences	2		
Large ditches	2	Tall: structure above the ground that may lead to an accident if struck by the aircraft.	w
Small ditches	3		
Fences	3		
Irregular terrain	3		
Small depressions	3		
Large frangible structures	4		
Localizer	4		
ALS	4		
Frangible blast fences	4		
Non preparated areas	4		
Lights	no code		
Sings (frangible)	no code		

Table 2. Safety risk probability table ICAO, 2013

LIKELIHOOD		MEANING	VALUE
Frequent	10^{-3}	Likely to occur many times	5
Occasional	10^{-5}	Likely to occur sometimes (infrequently)	4
Remote	10^{-7}	Unlikely to occur, but possible (rarely)	3
Improbable	10^{-9}	Very unlikely to occur	2
Extremely improbable	$<10^{-9}$	Almost inconceivable	1

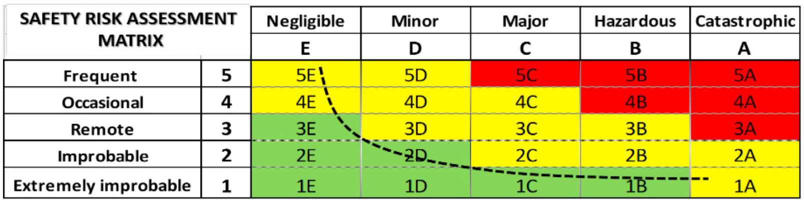
The quantitative assessment of the risk needs also the definition of the severity because the safety risk is defined as the projected likelihood and severity of the consequences or outcomes from an existing hazard or situation (ICAO, 2013). Severity is the measure of how bad the results of an event are predicted to be, so the likelihood should be considered only after determining severity. The severity assessment should consider all possible consequences related to an unsafe condition or object, taking into account the worst foreseeable situation. Table 3 presents a typical severity classification, which includes five levels, denoting the description of each category, and the assignment of a value to each category.

Table 3. Safety risk severity table ICAO, 2013

SEVERITY	MEANING	VALUE
Catastrophic	- Equipment destroyed - Multiple deaths	**A**
Hazardous	- A larger reduction in safety margins, physical distress or workload such that the operators cannot be relied upon to perform their tasks accurately or completely - Serious injury - Major equipment damage	**B**
Major	- A significant reduction in safety margins a reduction in the ability of operators to cope with adverse operating conditions as a result of increase in workload, or as result of conditions impairing their efficiency - Serious incident -Injury to persons	**C**

Minor	- Nuisance - Operating limitations - Use of emergency procedures - Minor incident	**D**
Negligible	- Little consequences	**E**

From the two factors combination it is possible to derive an alpha-numeric matrix, indicating the Safety risk level associated with the runway excursion phenomena. The respective severity/probability combinations (alphanumeric codes) and the Risk equation (R= Probability x Severity, drown with a dotted line) are presented in the safety risk assessment matrix in Figure 3



SAFETY RISK ASSESSMENT MATRIX		Negligible	Minor	Major	Hazardous	Catastrophic
		E	D	C	B	A
Frequent	5	5E	5D	5C	5B	5A
Occasional	4	4E	4D	4C	4B	4A
Remote	3	3E	3D	3C	3B	3A
Improbable	2	2E	2D	2C	2B	2A
Extremely improbable	1	1E	1D	1C	1B	1A

Fig. 3 Safety risk assessment matrix ICAO, 2013

The ultimate purpose of a quantitative risk assessment consists of the evaluation of the acceptability of the calculated risk, evaluating any appropriate mitigation measures if the outcome of the analysis is eventually considered ineligible.

3. Case study

The case of study focuses on an actual commercial service and international airport in the central Italy, set at the sea level with a runway used for both landing and takeoff and characterized by the yearly number of operations reported in the Table 4, while Table 5 summarizes the physical characteristics of the runway and its safety area and approach category.

Table 4. Runway yearly operations.

RWY	Arrival	Departures	Operations for directions	Total operation on the RWY
16	32728	8701	41429	55582
34	9043	5110	14153	

Table 5. Runway operational configuration.

RWY	ILS	TORA [m]	TODA [m]	ASDA [m]	LDA [m]	STRIP [m]	RESA[m]
16	CAT III	3902 x 60	3962 x 60	3902x 60	3902x60	4022 x 300	90 x 120
34	CAT I	3902 x 60	3962 x 60	3902 x 60	3902 x 60	4022 x 300	90 x 120

The information in Table 4 and Table 5 have been inputted in the ACRP software to implement the geometrical airside configuration. Further basic information is necessary to fully describe the runway operational configuration: the total yearly number of operations, the expected traffic growth, the Target Level of Safety TLS (which expresses the acceptable likelihood of accident, considered in this case as “Remote”, according to Table 2) and the Approach Category are required to define the probability risk model for the runway, as summarized in Table 6.

Table 6. Airport basic information.

AIRPORT BASIC INFORMATION	Column A (*t*)
Elevation [m]	4
Annual Traffic Volume	55582
Expected traffic growth	3.5%
TLS	10^7
Approach Category	III

The annual traffic volume on the considered runway is distributed on the two thresholds, and the data show the preferential use of the threshold 16 both for take-off and landing (which is the most frequent maneuvering). The analysis performed compares the risk level associated with the presence of a temporary hazard, defined as a construction site 14x2 m, as narrow trenches with that one defined when no obstacle is present. The site dimension corresponds to the maximum obstacle dimension allowed in Zone 1.

The RSARA tool has been used for the evaluation of the likelihood level associated with landing undershoot or to landing and take-off overrun occurring in the safety area beyond the runway thresholds, such as the RESA. The LRSARA tool has been used for the same purpose in case of veer-off during landing or take-off, involving the lateral safety area such as the Strip. The case of study focuses on a temporary hazard set in Zone 2.

3.1. Runway End Safety Area Analysis

The case of study analyses the effect on risk level caused by the presence, within the RESA , of a limited temporary hazard, consisting of “narrow trench”, with a maximum extension of 14x2 m^2 (according to ICAO, 1988) . Under this condition, landing and take-off are still allowed, stating some operating restrictions to the normal traffic operations.

In order to evaluate the risk level increase due to the presence of limited temporary hazard within the RSA during the normal take-off and landing operations, several configurations have been considered and analyzed using the RSARA software, as reported in Figure 4 a): the obstacle, (represented by a minimum unit of 10 m^2 due to the software limitation), have been located at +/- 45 degrees and +- 90 degrees, increasing the radial distance from the runway end, from 25 m until 100 m. All the geometrical features of the runway and the safety area and the obstacles have been modeled in compliance with the software specifications, as reported in Figure 4 b): the case of temporary hazard set on the centerline, 50m distant from the runway end has been assumed, because, as already said, this location is the most frequent for an accident.

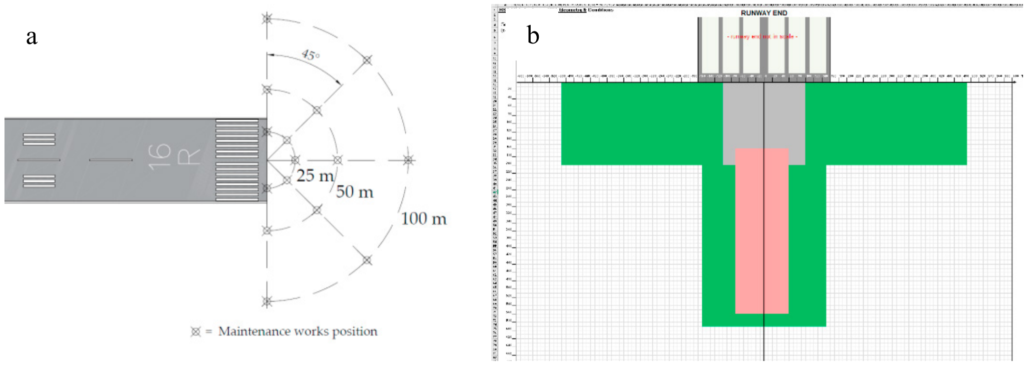
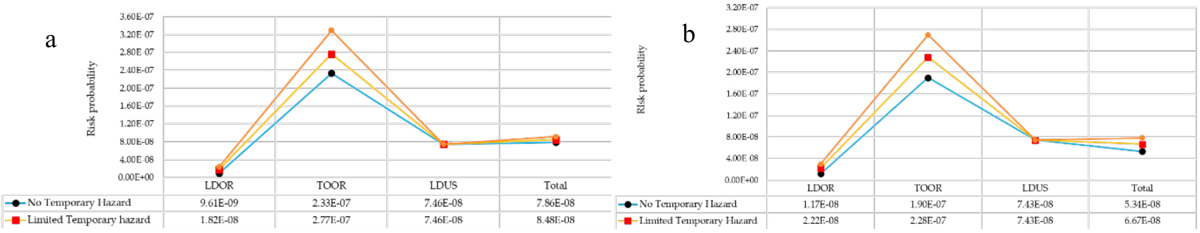


Fig. 4 Temporary hazard position on the RSA; (a) Obstacle location; (b) hazard on centerline

The risk probability due to the presence of limited temporary hazard along the extended centerline (within the three Limit Zones reported in Figure 2), has been calculated and compared to the risk distribution calculated without any obstacles. The results of this analysis are presented in Figure 5 a) and b) for threshold 16 and 34 respectively.



a)

	LDOR	TOOR	LDUS	Total
● No Temporary Hazard	9.61E-09	2.33E-07	7.46E-08	7.86E-08
🟥 Limited Temporary hazard	1.82E-08	2.77E-07	7.46E-08	8.48E-08

b)

	LDOR	TOOR	LDUS	Total
● No Temporary Hazard	1.17E-08	1.90E-07	7.43E-08	5.34E-08
🟥 Limited Temporary Hazard	2.22E-08	2.28E-07	7.43E-08	6.67E-08

Fig. 5 Accident risk distribution for overrun and undershoot in a) RWY 16 and b) RWY 34

The most critical condition is for the occurrence of TOOR for both thresholds: the most critical configuration occurs on the 16 threshold. The presence of limited temporary hazard within the RSA (Zone 2) produces an increase of total accident risk distribution of 27% for RWY 34, and 8% for RWY 16, if compared to the case without obstacles

3.2. Lateral Runway Safety Area Risk Analysis

For the evaluation of the risk level increase due to the presence of limited temporary hazard on the lateral side of the safety area (STRIP), the obstacle has been moved step 500m along the longitudinal axes and performed for the tree Limit Zones (Figure 2). The Figure 6 shows that the maximum value of probability risk distribution along the runway longitudinal axes is registered at 1700 m from the runway threshold 16 where the maximum risk level decrease from $6.5 \cdot 10^{-8}$ in Zone 1 to $5.5 \cdot 10^{-8}$ for a limited temporary hazard in Zone 2, set 50 m from the lateral border of the runway (Zone 2). This distance is the most frequent for a veer-off (Moretti et al., 2018) and it is consistent with the distance assumed in the RSARA model, and has been assumed as critical for the analysis.

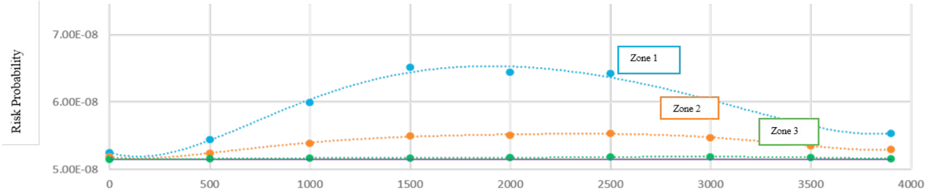


Fig. 6 Lateral risk distribution in case of temporary hazard

3.3. Environmental restriction

A further analysis considers the influence of ICAO environmental restriction on Risk Distribution: it imposes operative restrictions in term of crosswind speed and pavement surface conditions to allow the operation of the runway during the worksite. The analysis has been repeated considering crosswind component below 15 knots and dry runway. Table 7 list the percentage reduction of risk for each threshold and each Limit Zone considering the actual environmental conditions of the airport and the ICAO conditions of restricted operations according to ICAO, DOC 9137.

Table 7. Risk distribution on the RSA due to the presence of limited temporary hazard under normal and ICAO conditions RSARA analysis.

		No T.H.		Zone 1		Zone 2		Zone 3
Normal conditions	16	7.86E-08	8.75E-08	11%	8.48E-08	8%	8.13E-08	3%
	34	5.34E-08	7.31E-08	37%	6.67E-08	25%	5.90E-08	11%
ICAO Conditions	16	7.61E-08	8.46E-08	11%	8.19E-08	8%	7.87E-08	3%
	34	5.05E-08	6.92E-08	37%	6.31E-08	25%	5.59E-08	11%

The data in Table 7 show that the same risk reduction is achieved in both conditions in each zone for runway end excursions. This means that the risk reduction is not susceptible to the reduction of operations during the adverse environmental condition as much as to the dimensions of the obstacle. The risk level for the veer-off accident, considering the ICAO environmental restrictions, presents a reduction of only 4%, Figure. 7, therefore the influence of these conditions has been neglected.

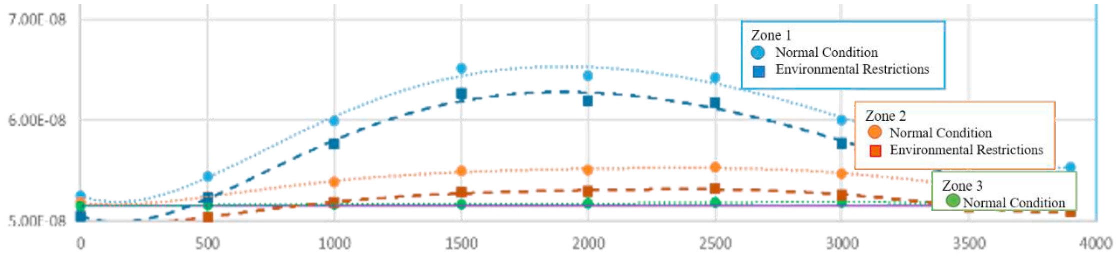


Fig. 7 Lateral risk distribution in case of temporary hazard in normal and environmental restricted conditions

4. Results

All the considered scenarios are within the “Acceptable” area of the Risk Matrix (2A- yellow in Figure.3). In fact, the total risk probability is never greater than$\cdot 10^{-7}$, therefore according to Table 2, the value is “2”; considering the maximum Severity level “A” see Table 3), the resulting risk level is 2A, according to Figure 3.

This means that a limited worksite does not considerable affect the safety of aircraft operations, even stating the ICAO restrictions.

In this condition the safety level can be improved by appropriate mitigation measures, according to the Safety Management System of the airport

In addition, the risk level has been calculated for an extended temporary hazard (120 x 40 m) within the safety area. , We could notice a consistent increment in risk distribution, in both environmental restrictions and normal condition, with an overpassing of the risk level for normal condition (more than $1\cdot10^{-7}$) (Figure 8), leading to an “Not acceptable” risk level (3A- red in Figure 3) according to the Risk matrix.

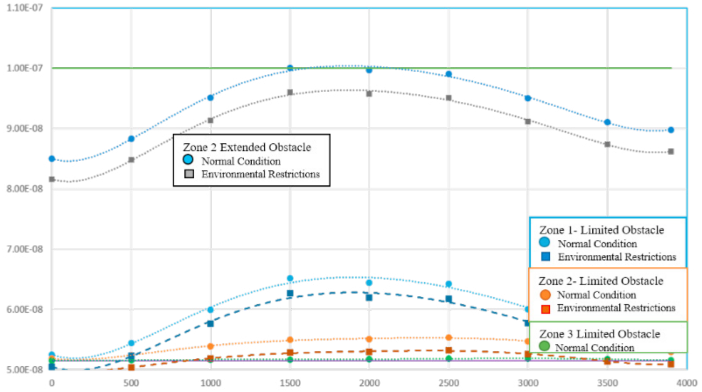


Fig. 8 Lateral risk distribution in case of temporary hazard limited and extended in normal and environmental restricted conditions

In case of limited temporary hazard, the total risk never exceeds the “Acceptable” region of the risk matrix, both for lateral and runway ends excursions. Only the risk of TOOR is placed in the red region of the matrix, but the total risk can be considered “Acceptable” because of the small number of takeoffs on the examined runway (Figure 5). Indeed the total risk is evaluated as the average of the probability distribution for each type of maneuvers (LDOR, TOOR, LDUS), weighted on the relative number of operations.

Conclusions

This study has analyzed the impact of the presence of temporary hazards (for example worksites) in the safety areas around the runway, according to ICAO requirements, by using a performance approach. The method has been applied to an Italian international airport, using the ACRP software RSARA e LRSARA in order to calculate the expected risk level within the safety area.

The first factor that affects the risk level for a runway is the temporary hazard dimension: it is crucial in order to evaluate the operational conditions of the runway affected by the obstacle. Moreover from the analysis also arose the minor effect of the environmental conditions (crosswind and pavement conditions) on the risk level of accident causes by worksite if compared to other conditions.

In order to mitigate the increase of risk level due to the presence of a temporary hazard it is possible to put some restrictions on the number of operations in the period of the site works or, when possible, schedule the work time during the less congested period of the year.

As a further research, the geometrical description of the work site is desirable to better model the actual situation of the safety area. Indeed the present study considers only linear shapes for the obstacles.

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