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A Risk Severity Index for industrial plants and sites

E. Planas [a,*], J. Arnaldos [a], B. Silvetti [b], Agnès Vallée [c], J. Casal [a]

[a] Centre d'Estudis del Risc Tecnològic, Universitat Politècnica de Catalunya, Diagonal 647, 08028 Barcelona, Catalonia, Spain
[b] Department of Chemical Engineering, University of Rome "La Sapienza", Roma, Italy
[c] INERIS, Verneuil-en Halatte, France

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Abstract

A risk index (Risk Severity Index, *S*) has been devised to allow the assessment of the risk level originated by a given installation or site over the affected zone. A set of threshold levels for thermal radiation, toxic concentration and overpressure, together with the probabilities and frequencies associated to critical events and their effects have been the basis for calculating the values of *S*. A computer tool has been designed to perform a quick calculation of the diverse Risk Severity Indexes (for a critical event, for a dangerous phenomenon, for a type of effect and for the whole installation) and to plot a map of the risk severity levels around the site. The methodology has been applied to diverse test cases and it has proved to be useful for risk assessment, for comparative studies and for land use planning.

Keywords: Risk analysis; Risk index; Accident severity

1. Introduction

There is a need to establish a method allowing the assessment of the risk associated to an industrial installation – a plant or a site – which integrates the preventive measures implemented by the operators. Such a method is a prerequisite to reach the goals of the Seveso II Directive.

In this sense, the objective of the Aramis methodology is the characterization of the risk through independent parameters related to the severity evaluation of the scenarios, the prevention management effectiveness and the environmental vulnerability estimation describing the sensitivity of the potential targets located in the vicinity of the Seveso II establishments.

An extensive bibliographical search proved that, although a number of "risk indexes" exist, none of them allows the representation of the severity of the risk associated to an industrial installation.

This paper describes the so-called Risk Severity Index, a parameter representing the severity of the diverse possible accidental scenarios.

A risk index is a measure, quantitative or qualitative, oriented to integrating into a numerical value or into a descriptive adjective a set of factors, which have an influence on the hazards or the risk of a system. Thus, a risk index can be applied to a given plant, to a process unit or to a project to identify risk levels or to establish comparative rankings.

Certainly, including and summarizing in a single parameter all the factors having an influence on the risk associated to a given installation implies a negative aspect: most information is lost and, although contained in some way inside this parameter, it is no more evident at all. However, the use of a parameter representing the risk or the severity can be very useful for mapping the risk in a given zone or for comparing the risk corresponding to different situations or scenarios.

In the following sections, the Risk Severity Index (*S*) is described and its application to two cases is commented.

2. Basis of the Risk Severity Index

The risk index has been based on a set of reference values, taken from threshold limits applied in European countries,

Abbreviations: CE, critical event (for example, a pipe failure); DP, dangerous phenomenon (for example, a fire, an explosion); LFL, lower flammability limit; ME, major event (for example, thermal radiation, overpressure); TEEL, Temporary Emergency Exposure Limit

* Corresponding author. Tel.: +34 934011736; fax: +34 934017150.
E-mail address: eulalia.planas@upc.edu (E. Planas).

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Nomenclature

c	concentration (ml m^{-3})
d	distance (m)
f	frequency of occurrence (year^{-1})
I	thermal radiation intensity (W m^{-2})
n	parameter depending on the substance (–)
P	probability of occurrence (–)
t	exposure time (s or min)

Table 1
Levels of effects considered

Level of effect	Description
1	Small or non effects
2	Reversible effects
3	Irreversible effects
4	Start of lethality and/or domino effects

and on the frequency of occurrence of the critical events and dangerous phenomena associated to the reference accidental scenarios corresponding to a given site.

2.1. Threshold levels

The Risk Severity Index has been defined taking into account the threshold levels used in the European countries. A survey of these levels over diverse countries showed that it does not exist a uniform criterion concerning the values of thermal radiation, overpressure, etc., even though several similar threshold values were found.

First of all, a decision was taken to consider four levels of effects (see Table 1), which in some way are representative of the criteria used in the aforementioned countries. Then, a set of values was finally established, corresponding to these four categories or levels of effects; these values have been summarized in Table 2. It should be pointed out that Table 2 is not an attempt to propose a new set of harmonized threshold levels, as this was not among the targets of the Aramis project. Table 2 is only to be used for the calculation of the Risk Severity Index; nevertheless, the index developed can be applied to any other threshold values.

2.1.1. Thermal radiation

The threshold values for thermal radiation have been obtained from the values of thermal radiation intensity and exposure time applied in different countries for “start of lethality” and “start of irreversible effects”, and by applying the usual expression for the dose:

$$\text{dose} = I^{4/3} \cdot t \tag{1}$$

In the case of instantaneous thermal effect (flash fire), the threshold values are related to the concentration of flammable product in the cloud. Thus, the flammable concentration corresponding to 0.5 lower flammability limit (LFL) was set to correspond to the level of effects 4, assuming that inside the flammability contour the effects are lethal and outside it there are no consequences.

2.1.2. Blast

For blast effects, the value of 50 mbar was taken for irreversible effects. For reversible effects, taking a conservative criterion a value of 30 mbar was assumed (values for Italy and Spain, respectively, 30 and 50 mbar). Finally, 140 mbar is the threshold value for lethality applied in Italy and France.

2.1.3. Missiles

In the case of missiles the criteria to establish the threshold values was to consider only two possibilities: maximum level (level 4) of effects for any point at a distance smaller than the distance were 100% of the missiles are found, and the minimum level (level 1) for higher distances.

2.1.4. Toxicity

Finally, for toxic effects, several reasons make the definition of the threshold levels more difficult than in the previous cases:

- most of the countries only agree in one threshold value, corresponding to the start of irreversible effects, taken as the IDLH;
- many exposure guidelines exist, the selection of one of them being very difficult because the scientific and statistical background is in all cases rather poor;
- each guideline covers only a limited number of substances;
- the effects of toxic substances on humans are in most cases related to the dose and not to a given concentration;

Table 2
Definition of the thresholds for the diverse levels of effects

Level of effects	Radiation[a] (kW m^{-2})	Instantaneous radiation	Blast (mbar)	Missiles[b] (%)	Toxic effects	Description
1	<1.8		<30	0	<TEEL1	Small or non-effects
2	1.8–3	<0.5 LFL	30–50	0	TEEL1–TEEL2	Reversible effects
3	3–5		50–140	0	TEEL2–TEEL3	Irreversible effects
4	>5	≥0.5 LFL	>140	100	>TEEL3	Start of lethality and/or domino effects

[a] For 60 s exposure.
[b] Range distance of the indicated percentage of missiles.

- the dose does not depend only on the concentration and exposure time, but also on another parameter (n) which depends on the substance; n is not known for all the substances.

After several trials, the threshold levels for toxicity were based on the Temporary Emergency Exposure Limits (TEELs). TEELs are temporary levels of concern defined by the U.S. Department of Energy [1] to be used when Emergency Response Planning Guidelines (ERPGs) are not available. Like ERPGs, they do not incorporate safety factors; rather they are designed to represent the predicted response of members of the general public to different concentrations of a chemical during an incident. The TEEL methodology prescribes using the ERPGs when available. TEEL values are established for about 2000 substances, while ERPGs are available for about 100 substances.

All the effects represented in Table 2 refer only to humans or structures, but not to the environment. However, the most important effect on the environment will be mainly due to toxic substances, and in this case a reference concentration for the affected target could be taken into account.

2.2. Accidental scenarios

For a given site, a set of *reference accidental scenarios* can be identified from the application of the MIMAH and MIRAS methodologies [2]. MIMAH gives a set of *critical events* (for example, pipe failure), each one having several *dangerous phenomena* (for example, pool fire). The MIRAS methodology allows the reduction of these critical events to a lower number by taking into account the prevention and protection barriers. However, the Risk Severity Index can be applied to any set of critical events obtained for a given accidental scenario by any other methodology.

As for the description of the accidental scenario, a set of data are required for each critical event: equipment type, design/rupture pressure and temperature of the equipment, height of the liquid, properties of the substances, amount of substance involved in the accident, operating conditions, frequency of the occurrence of the critical event, probability of each dangerous phenomenon, ignition sources on site, wind rose, etc. As in many risk analysis, some data will have to be assumed according to usual criteria; thus, for toxic substances, $n = 2$ if unknown, or pressure at vessel failure = 1.21 set pressure, etc.

3. Risk Severity Index for the diverse dangerous phenomena (S_{DP})

A Risk Severity Index (S_{DP}) can be determined for each dangerous phenomenon associated to a given critical event. S_{DP} will be always a number ranging between 0 and 100. This scale has been arbitrarily divided in four categories, corresponding to the four levels of effects previously mentioned (Table 3).

Table 3
S_{DP} Risk Severity Index categories

S_{DP}	Level of effects
0–24	1
25–49	2
50–74	3
75–100	4

For the threshold values corresponding to these four categories, the corresponding distances can be calculated, i.e. the distances at which the associated value of thermal radiation, blast, etc., will occur. This is done by applying the usual mathematical models of the dangerous phenomena (pool fire, vapor cloud explosion, etc.). A set of five *characteristic distances*, d_0, d_1, d_2, d_3 and d_4, is thus found (Table 4). In the zone between two consecutive distances, a lineal variation of the value of S_{DP} is assumed.

The values of thermal radiation, concentration of flammable product (for instantaneous thermal effect), blast and toxic concentration corresponding to the distances d_0 to d_4 can be established by using the information contained in Tables 5a–5d.

In the case of steady thermal radiation (for example, from a pool fire), a set of threshold values were established for each category of Risk Severity Index S_{DP} (Table 5a); the minimum ($S_{DP} = 0$, d_0) and maximum ($S_{DP} = 100$, d_4) values were set arbitrarily as $1000\,\mathrm{W\,m^{-2}}$ (radiation from sun in a sunny day) and $8000\,\mathrm{W\,m^{-2}}$, respectively. However, a transformation will have to be applied usually to the initial threshold values, as these correspond to exposure times of 60 s. The new threshold value for another exposure time is calculated by assuming that, over a reasonable range of values, a thermal radiation dose is equivalent to the same dose obtained with a different exposure time, i.e.:

$$I_1^{4/3} \cdot t_1 = I_2^{4/3} \cdot t_2 \quad (2)$$

For example:

$$1800^{4/3} \cdot 60 = I_2^{4/3} \cdot t_2; \qquad I_2 = 38,805t^{-3/4}$$

Thus, the equivalent thermal radiation intensity for a given exposure time t can be calculated with the expressions included in Table 5a.

For instantaneous thermal effects, diverse values – as a function of LFL – were established for each threshold value of S_{DP} and, therefore, for each distance d_0 to d_4. As $S_{DP} = 75$

Table 4
Distances corresponding to S_{DP} values

S_{DP}	Distance
0	d_0
25	d_1
50	d_2
75	d_3
100	d_4

Table 5a
Threshold values for the calculation of the S_{DP} Risk Severity Index: relationship between the continuous thermal radiation values and the characteristic distances

S_{DP}	Radiation ($W\,m^{-2}$) (t = 60 s)	Equivalent radiation ($W\,m^{-2}$) for an exposure time t (s)	Distance (m)
0	1000	$21558t^{-3/4}$	d_0
25	1800	$38805t^{-3/4}$	d_1
50	3000	$64675t^{-3/4}$	d_2
75	5000	$107791t^{-3/4}$	d_3
100	8000	$172466t^{-3/4}$	d_4

Table 5b
Threshold values for the calculation of the S_{DP} Risk Severity Index: Relationship between the instantaneous thermal radiation and the characteristic distances

S_{DP}	Distance (m)	Concentration of flammable product
0	d_0	1/60 LFL
25	d_1	1/6 LFL
50	d_2	1/3 LFL
75	d_3	1/2 LFL
100	d_4	LFL

was attributed to the start of lethality (0.5 LFL), and a lineal variation of the risk index is assumed between two consecutive distances, the rest of values in the table were obtained; a value of LFL/60 was arbitrarily attributed to $S_{DP} = 0$ (d_0) (Table 5b).

The values for blast were obtained from the threshold levels (Table 2); a minimum value of 1 mbar was attributed to d_0 ($S_{DP} = 0$) (Table 5c).

The same treatment was applied to the threshold values for toxic clouds. The TEEL values are devised for an exposure of 1 h, while in most accidental events the exposure time will be lower. The Haber law can be then applied:

$$\mathrm{TEEL}^n \cdot 60 = c^n \cdot t \tag{3}$$

where c is the average toxic concentration and t is the exposure time (min). The corresponding expressions to calculate the equivalent concentrations at which the characteristic distances d_0 to d_4 must be determined have been included in Table 5d.

4. Risk Severity Index for a critical event (S_{CE})

The Risk Severity Index for a given critical event, at a certain distance d, will be a combination of the Risk Severity Indexes (S_{DP}) associated to each of the dangerous phenomena that that critical event implies; this is the way to take into account the probabilities of occurrence of each dangerous phenomenon:

$$S_{CE}(d) = \sum_{i=1}^{n} (P_{DP_i} \cdot S_{DP_i}(d)) \tag{4}$$

In this expression, n is the total number of dangerous phenomena (DP) associated to the critical event, P_{DP_i} the probability of occurrence of the DP_i and S_{DP_i} is the severity index associated to the DP_i at a given distance d. The value of S_{CE} will usually range between 0 and 100, although in some cases it could be greater than 100, especially for low values of d.

Each critical event will have a frequency of occurrence associated to it. These frequencies must also be included in the Risk Severity Index corresponding to the whole plant.

Table 5c
Threshold values for the calculation of the S_{DP} Risk Severity Index: relationship between the overpressure and the characteristic distances

S_{DP}	Distance (m)	Overpressure (mbar)
0	d_0	1
25	d_1	30
50	d_2	50
75	d_3	140
100	d_4	250

5. Risk Severity Index for a major event (S^{ME})

Risk severity indexes (S^{tox}, S^{overp}, S^{therm} and S^{poll}) can also be calculated for the diverse major events. The following types were considered: toxic concentration, overpressure, thermal radiation and pollution. The corresponding equations are:

$$S^{tox}(d) = \sum_{i=1}^{n} f_{DP_i} \cdot S^{tox}_{DP_i}(d) \tag{5}$$

$$S^{overp}(d) = \sum_{i=1}^{n} f_{DP_i} \cdot S^{overp}_{DP_i}(d) \tag{6}$$

$$S^{rad}(d) = \sum_{i=1}^{n} f_{DP_i} \cdot S^{therm}_{DP_i}(d) \tag{7}$$

$$S^{poll}(d) = \sum_{i=1}^{n} f_{DP_i} \cdot S^{poll}_{DP_i}(d) \tag{8}$$

The results obtained from these expressions will be in the scale 0–1000 (Table 6). The sum of the results obtained from these four equations should be equal to the overall Risk Severity Index (S) of the installation.

Table 5d
Threshold values for the calculation of the S_{DP} Risk Severity Index: relationship between the concentration of a toxic substance and the characteristic distances

S_{DP}	Distance (m)	Concentration (1 h exposure)	Equivalent concentration for exposure time t (min)
0	d_0	0.1TEEL^1	$0.1\text{TEEL}^1 \cdot \left(\frac{60}{t}\right)^{1/n}$
25	d_1	TEEL^1	$\text{TEEL}^1 \cdot \left(\frac{60}{t}\right)^{1/n}$
50	d_2	TEEL^2	$\text{TEEL}^2 \cdot \left(\frac{60}{t}\right)^{1/n}$
75	d_3	TEEL^3	$\text{TEEL}^3 \cdot \left(\frac{60}{t}\right)^{1/n}$
100	d_4	$\text{TEEL}^3\ (6^{1/n})$[a]	$\text{TEEL}^3 \cdot \left(\frac{360}{t}\right)^{1/n}$

[a] This value has been set in such a way that the received dose be the same as in the TEEL^3 but only in 10 min of exposure.

6. Risk Severity Index for a whole installation (*S*)

The Risk Severity Index, *S*, for a whole installation – a plant, an industrial site – is a combination of the Risk Severity Indexes associated to each one of the critical events considered and to their respective frequencies of occurrence; thus:

$$S(d) = \sum_{j=1}^{m}(f_{\text{CE}_j} \cdot S_{\text{CE}_j}(d)) = \sum_{j=1}^{m}\left(f_{\text{CE}_j} \cdot \sum_{i=1}^{n}(P_{\text{DP}_i} \cdot S_{\text{DP}_i}(d))\right) = \sum_{j=1}^{m}\sum_{i=1}^{n}(f_{\text{DP}_{i,j}} \cdot S_{\text{DP}_{i,j}}(d)) \quad (9)$$

In this expression, m is the total number of critical events (CE) associated to the installation, f_{CE_j} the frequency of occurrence of the CE_j and S_{CE_j} is the risk severity index associated to the CE_j.

The values obtained after the application of Eq. (9) are not any more in the range 0–100, and the scale defined in Table 3 cannot be applied. The values obtained will usually range between 0 and 1.2. In the computer tool they have been normalized in order to have them ranging between 0 and 1000. The scale shown in Table 6 must therefore be applied to establish in a qualitative way the Risk Severity Index level.

7. Procedure for the calculation of *S*

7.1. Evaluation of the effects at distances d_0 to d_4

The general procedure for obtaining the Risk Severity Index corresponding to a given accidental scenario or to a critical event is indicated in Fig. 1. Once the required information gathered, the threshold levels for each major event (thermal radiation, blast, etc.) must be established, taking them from Tables 5a–d and/or calculating the equivalent values for I and c. Then, the usual mathematical models must be applied to each dangerous phenomenon (pool fire, explosion, etc.) to calculate the distances d_0 to d_4 at which these threshold values exist. Up to this point, the calculations performed are essentially those usually done when the effects of an accident are evaluated.

Table 6
Risk Severity Index for the whole installation

S	Risk Severity Index level
≥750	Extremely high
$300 \leq S < 750$	High
$50 \leq S < 300$	Medium
<50	Low

Note: These values also apply for S^{ME}.

7.2. Evaluation of S_{DP}, S_{CE}, S^{ME} and S and mapping

The second part of the procedure corresponds to the calculation of the diverse Risk Severity Indexes: Risk Severity Index for the diverse dangerous phenomena (S_{DP}), Risk Severity Index for the diverse critical events (S_{CE}), Risk Severity Index for the diverse major events (S^{ME}) and, finally, the Risk Severity Index for the whole installation considered (S). This would represent a significant amount of work if done by hand. Thus, in the frame of Aramis project a computer code has been developed: the results from the calculations described in 6.1 are introduced in the GIS severity tool and automatically the values of S are plotted on a GIS. The maps of risk on a given area are therefore obtained in a very fast way.

8. Severity tool and severity maps

The Risk Severity Index was implemented into a Geographic Information System (GIS) tool, developed by means of ArcView 3.2 software. The following set of values has to be introduced into the GIS, for each "dangerous phenomenon" (pool fire, flash fire, vapor cloud explosion, etc.) associated to the diverse "critical events" (breach on a tank, pipe breaking, etc.):

- a code for the dangerous phenomenon;
- d_0, d_1, d_2, d_3, d_4;
- the frequency of the dangerous phenomenon;
- the type of major event (overpressure, thermal radiation, . . .);
- the wind rose.

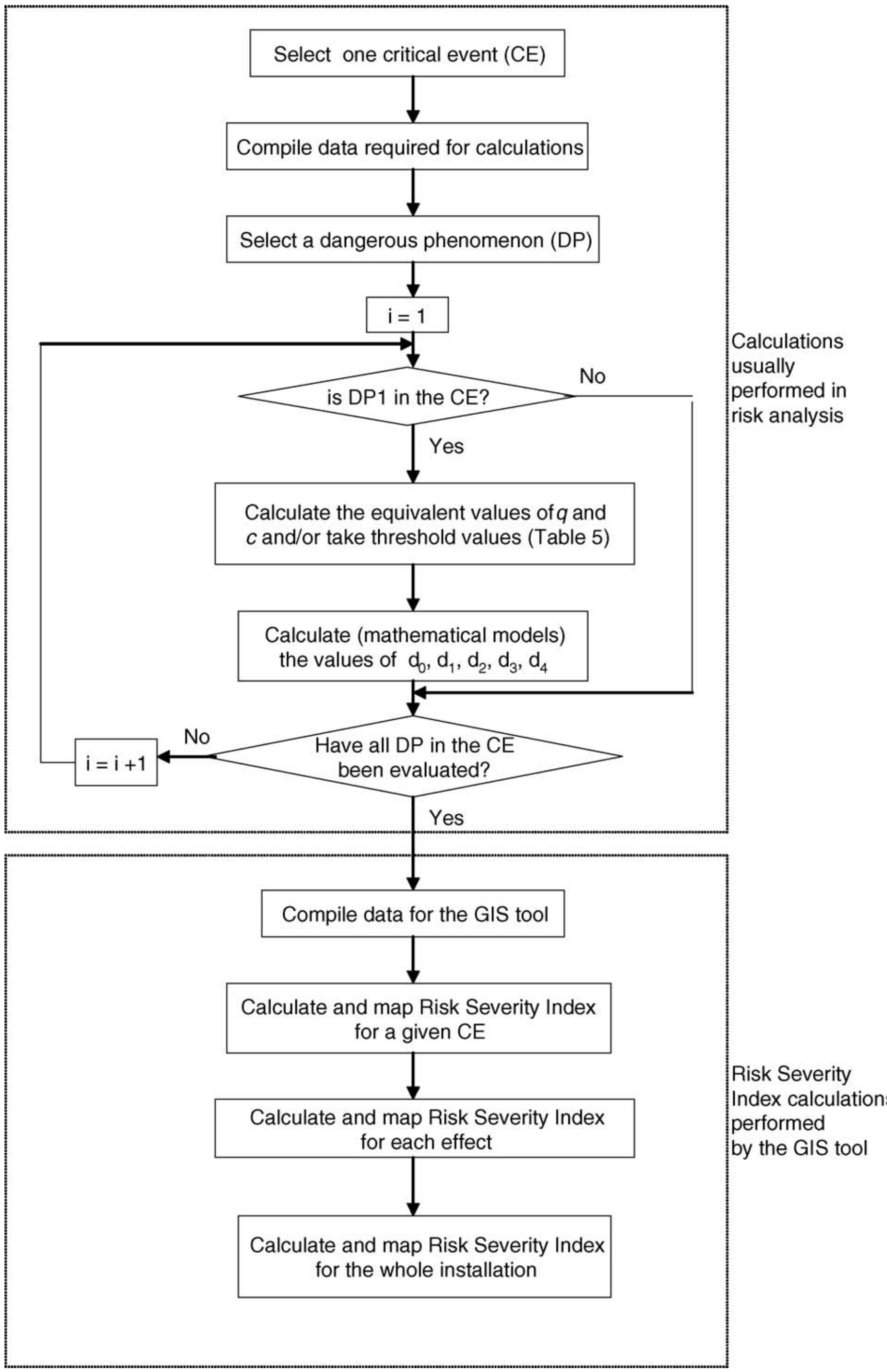

Fig. 1. Schematic diagram of the Risk Severity Index calculation.

This tool allows obtaining severity maps for the area surrounding the industrial installation, which can be compared with vulnerability maps of the same zone. The study area is a square, centered on the installation, 20 km × 20 km in size, which is assumed as the maximum area where the consequences of a critical event may impact. This zone is divided into square meshes, 500 m × 500 m in size; moreover, the inner area, 2 km × 2 km in size, which actually covers the plant and its immediate vicinity, is divided into smaller meshes (50 m × 50 m), allowing a better detail for the severity of critical events with short effect distances.

The severity index is associated to each mesh, based on the distance to the center of the mesh from the center of the grid: should more than one distance of interest fall into the same mesh (case which may occur for dangerous phenomena with small impact areas) the severity index of that mesh will be assumed as the maximum of the corresponding severity index values.

The study area is automatically projected over the plant site, by inserting its geographical coordinates; the other input data are the probability of wind direction and the distances corresponding to the severity thresholds, for each dangerous phenomenon associated to each critical event, and the expected probabilities and frequencies of these last. The tool assists the user when inserting the data by means of pull-down menus and masks, and creates different maps.

The following maps can be obtained from the severity GIS tool:

- Map of the Risk Severity Index for a dangerous phenomenon (S_{DP}) (for example, explosion). The results obtained for this index will range between 0 and 100.
- Map of the Risk Severity Index for a critical event (S_{CE}) (for example, map of the Risk Severity Index associated to the failure of a propane tank). The numerical values will also be in the scale 0–100, but in some cases values higher than 100 could be obtained, especially for low distances.
- Map of the Risk Severity Index of the installation for a given type of effect or major event (S^{ME}). The results obtained from these maps will be in the scale 0–1000 (Table 6). The sum of the results obtained from these four indexes (S^{tox}, S^{overpr}, S^{rad} and S^{poll}) should be equal to the overall Risk Severity Index (S) of the installation.
- Map of the overall Risk Severity Index of the whole installation (S). The results obtained from these maps will be in the range 0–1000 and have been classified according to four categories (Table 6): low, medium, high and extremely high.

The maps are automatically shown according to a scale of five shades of colour, which becomes more intense as the severity index increases: the default minimum and maximum value of the scale are set to the corresponding values of the severity index of each map. Both the number of intervals and the minimum and maximum values of the scale can be changed by the user, which may be useful when comparing the severity maps associated to different critical events or effects, for the same installation, or when comparing the global severity maps of different installations.

9. Example of application

The Risk Severity Index methodology has been applied to a set of industrial sites (located in different countries) to test and improve it. Some results corresponding to two of these sites are commented as an example of application in the following sections.

9.1. Storage of ethylene oxide

A 230 m^3 cylindrical (vertical) tank filled in 80% with liquefied ethylene oxide at 7.5 bar abs. and 278 K; the tank has two safety valves with a set pressure of 12 bar abs. and a retention bund with a surface of 420 m^2 and a height of 1 m.

The considered critical event is a large breach (80 mm) on the shell in the liquid phase zone (at a height of 2 m). Among the diverse dangerous phenomena, and taking into account their frequencies of occurrence, six of them are considered (Table 7).

For each dangerous phenomenon the set of distances d_0, d_1, d_2, d_3 and d_4 have been calculated (Table 8). With these data, the diverse risk indexes have been calculated and mapped by the GIS tool. Fig. 2 shows the map of the Risk Severity Index for the dangerous phenomenon *toxic cloud*. The influence of the wind rose on the atmospheric dispersion is clearly seen; the numerical values of S_{DP} correspond to the scale 0–100 (Table 3). In Fig. 3, the overall Risk Severity Index for the whole installation – including all the dangerous phenomena – has been plotted. According to Table 6, the value of S is inside the category "Low risk".

Table 7
Dangerous phenomena (storage of ethylene oxide)

Dangerous phenomenon	Frequency (year^{-1})	Effects
Pool fire with limited source term	1.07×10^{-5}	Thermal
VCE with limited source term and effects	4.9×10^{-6}	Overpressure
Fully developed jet fire	1.5×10^{-5}	Thermal
Fully developed VCE	3×10^{-6}	Overpressure
Fully developed flash fire	1.5×10^{-6}	Thermal
Fully developed toxic cloud	1.9×10^{-6}	Toxic dose

Table 8
Characteristic distances (storage of ethylene oxide)

Dangerous phenomenon	d_0 (m)	d_1 (m)	d_2 (m)	d_3 (m)	d_4 (m)
Pool fire	74	58	48	39	32
VCE	6500	345	223	98	59
Jet fire	47	38	31	23	12
VCE	7600	405	260	114	69
Flash fire	555	148	99	78	51
Toxic cloud	10000	10000	2300	555	198

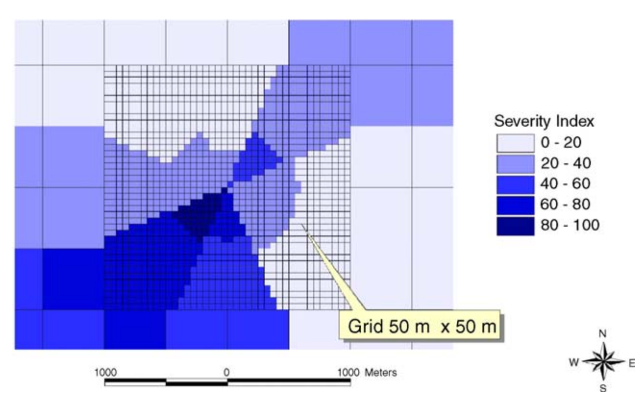

Fig. 2. Risk Severity Index for the dangerous phenomenon "toxic cloud" (storage of ethylene oxide).

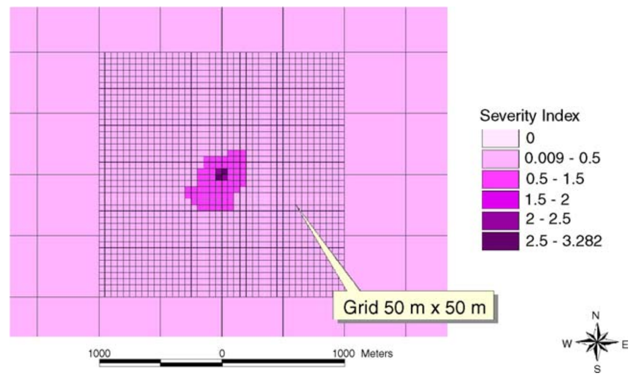

Fig. 3. Overall Risk Severity Index for the ethylene oxide storage plant.

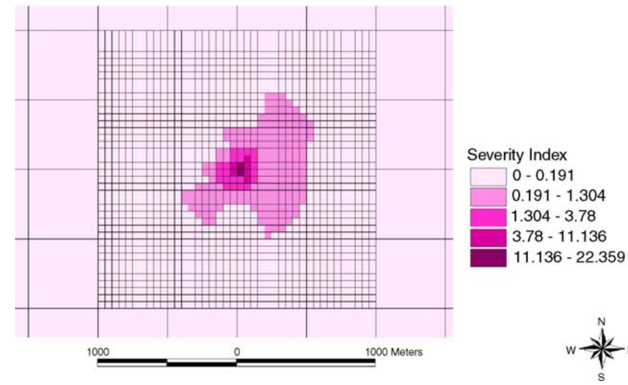

Fig. 5. Risk Severity Index for toxic effect (chemical process plant).

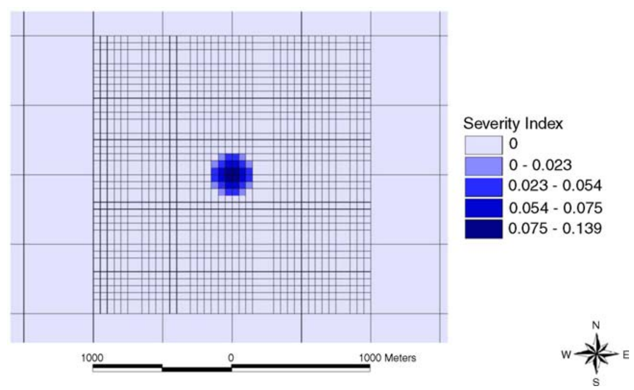

Fig. 4. Risk Severity Index for overpressure (chemical process plant).

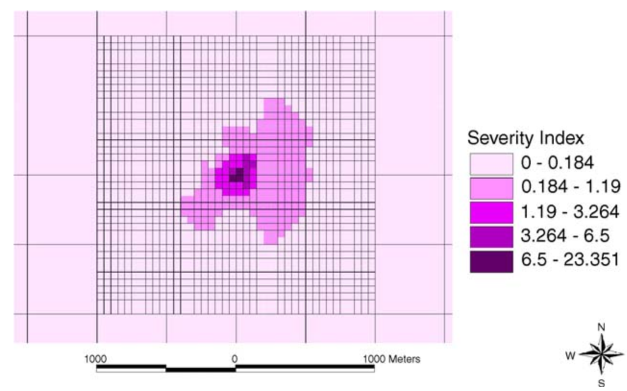

Fig. 6. Overall Risk Severity Index for the chemical process plant.

9.2. Chemical process plant

A plant manufacturing chemicals for the textile and painting industries, with five tanks (35 m^3 each one) storing flammable, corrosive and toxic materials, located inside a bund of 120 m^2; there are also chemical reactors, etc.

In this case, six critical events have been considered. Table 9 shows them together with the associated dangerous phenomena and the corresponding frequencies and probabilities. The characteristic distances d_0 to d_4 have been calculated for each dangerous phenomenon (Table 10). In Fig. 4, the Risk Severity Index corresponding to overpressure has been plotted. Fig. 5 shows the mapping of the Risk Severity Index for toxic effect; the numerical values of the index are considerably higher than those corresponding to overpressure and, thus, they have a significant influence on the overall Risk Severity Index for the whole installation (Fig. 6).

In both sites, the range of values of S corresponds to the category "Low". A Quantitative Risk Analysis was developed for these two sites. The comparison of both methodologies has shown that "Low" category corresponds to values of individual risk of 10^{-4} $year^{-1}$ or lower. Taking into account that

Table 9
Critical events and dangerous phenomena (chemical process plant)

Critical event	Frequency ($year^{-1}$)	Dangerous phenomenon	Probability	Effect
Catastrophic failure of toluene tank	2×10^{-5}	Pool fire	0.065	Thermal
		Toxic cloud	0.935	Toxic
Fire in a warehouse (acrylic acid)	8.8×10^{-4}	Fire	0.05	Thermal
Runaway in a polymerization reactor (acrylic acid)	5×10^{-6}	Pool fire	0.065	Thermal
		Toxic cloud	0.935	Toxic
		Physical explosion	1	Overpressure
Continuous release from a hole in a reactor (MEK)	4.5×10^{-4}	Pool fire	0.065	Thermal
		Toxic cloud	0.935	Toxic
Fire in a warehouse (benzyliden acetone)	8.8×10^{-4}	Fire	0.05	Thermal
Catastrophic failure of an ammonia tank	1×10^{-5}	Toxic cloud	1	Toxic

Table 10
Characteristic distances (chemical process plant)

Critical event	Dangerous phenomenon	d_0 (m)	d_1 (m)	d_2 (m)	d_3 (m)	d_4 (m)
Catastrophic failure of toluene tank	Pool fire	50	41	35	30	25
	Toxic cloud	644	136	43	20	10
Fire in a warehouse (acrylic acid)	Fire	30	25	22	19	16
Runaway of a polymerization reactor (acrylic acid)	Pool fire	62	51	44	38	34
	Toxic cloud	1500	372	32	8	8
	Physical explosion	176	41	24	7.5	6
Continuous release from a hole in a reactor (MEK)	Pool fire	46	37	31	26	23
	Toxic cloud	192	51	51	5	5
Fire in a warehouse (benzyliden acetone)	Fire	32	26	22	19	16
Catastrophic failure of an ammonia tank	Toxic cloud	974	263	102	44	28

this is considered to be a tolerable value for industrial zones, that the “Low” category was established for the worst zone (nearest to the sites) and that it decreases significantly as the distance from the site increases, to values of individual risk of the order of 10^{-6} year^{-1} or even lower, the risk associated to these two sites must be considered to be tolerable for the population.

10. Conclusions

The Risk Severity Index summarizes in a number – for the nodes of a selected mesh – the severity of the diverse accidents, which reasonably can occur in a given industrial installation. Based on a set of reference threshold values concerning the diverse possible effects (thermal radiation, blast, toxic concentration, fragments ejection) and on the essential aspects of the accidental scenarios (source term, meteorological conditions, frequency of occurrence, etc.), the Risk Severity Index integrates the severity associated to the diverse dangerous phenomena (fires, explosions, dispersion of toxic clouds, etc.) which can affect the influence zone.

The calculation of the *S* index has two steps. The first one is similar to the usual accident effects evaluation: the physical effects of explosions, fires, etc., must be calculated at five characteristic distances for the diverse dangerous phenomena involved. In the second one, these data are used to calculate the value of *S* at the desired locations; this second part is quickly and easily solved thanks to the computer tool developed in the frame of the ARAMIS project.

This tool allows also the automatic plot of the diverse indexes on a GIS, thus obtaining “risk severity maps” of the analyzed zone in which the value of the risk index is calculated for all the nodes of a mesh.

Besides the map of the overall Risk Severity Index (*S*) for the whole plant or site, maps for more specific indexes can also be obtained: map of the Risk Severity Index for a dangerous phenomenon (S_{DP}) (for example, fire), map of the Risk Severity Index for a given critical event (S_{CE}) (for example, for the explosion of a propane tank or a pipe failure), and map of the Risk Severity Index for a given type of effect (toxicity, S^{tox}; thermal radiation, S^{therm}; overpressure, S^{Overp}; pollution, S^{poll}).

The simplicity of the Risk Severity Index – a number and a scale with four categories – implies that detailed information is not disclosed. Nevertheless, this simplicity makes the Risk Severity Index especially useful for comparative studies of diverse situations and for the analysis of the risk over a given zone; furthermore, the results are very comprehensible for people who are not specialized in risk analysis.

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