5TH FRAMEWORK PROGRAMME

ACCIDENTAL RISK ASSESSMENT METHODOLOGY FOR INDUSTRIES IN THE CONTEXT OF THE SEVESO II DIRECTIVE

Contract number: EVG1 – CT – 2001 – 00036

ASSESSMENT OF THE ENVIRONMENT VULNERABILITY IN THE SURROUNDINGS OF AN INDUSTRIAL SITE

J. Tixier, A. Dandrieux, G. Dusserre

Industrial and natural risks department, LGEI, Ecole des Mines d'Alès, 6 Av. de Clavières, 30319 Alès CEDEX, France

R. Bubbico, L.G. Luccone, B. Mazzarotta, B. Silvetti

Università di Roma "La Sapienza", Dip. Ing. Chimica, Italy

E. Hubert

Centre SITE, Ecole des Mines de Saint Etienne, France

June 2003

1 Introduction

ARAMIS project aims at developing an integrated risk index based on, among others, the environment vulnerability. Indeed, environment vulnerability is scarcely taken into account in risk assessment, and its integration in ARAMIS project is therefore of great interest. The idea developed is to assess the vulnerability index to identify and characterize the vulnerability of targets located in the surroundings of a Seveso industrial site. To summarize, the figure 1 explains the problematic and ARAMIS project must answer to the following question : Is the area 1, which is composed of human, environmental and material targets, more or less vulnerable than the area 2 also composed of human, environmental and material targets, but in different quantity and of different nature?

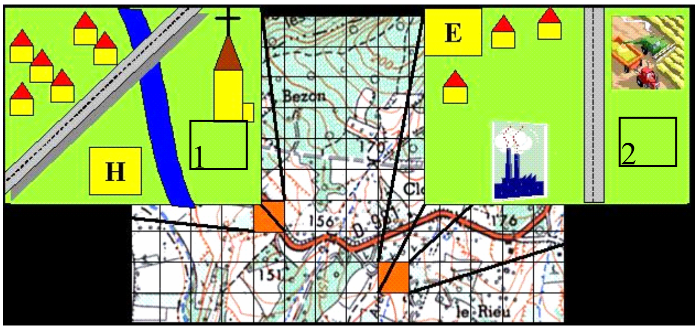

Figure 1: Problematic of vulnerability definition. How can we say that area 1 is more vulnerable than area 2?

To solve this question, several steps are necessary, namely, the definition of the study area, the definition of the targets and also the choice of available databases which are essential to characterise the environment. Then, a specific methodology for the assessment of the vulnerability is required.
The methodology used to obtain a semi quantitative approach of vulnerability is a multicriteria decision method (Saaty's method) based on the experts judgements.
Another critical step is to make a census of the targets in the study area. This step can be supported by the use of GIS (Geographic Information System) databases and tools. The chosen databases are available for all the EC countries and cover information concerning the population, and the characteristics of natural and man made environment. GIS software and tools allow to display the geographical information on maps, and to make operations on the various types of geographical items.

2 Characterisation of the study area

2.1 Size of the study area

On the base of previous studies and data concerning the effects distances of major accidents, a study area of 400 kilometers square is retained. This area is expected to cover all the consequences of flammable and explosive events and the greatest part of the consequences of toxic events, but it will not include the impact area of a very large toxic cloud under particular atmospheric conditions. However, in our opinion, the grid size of 20 km x20 km will fit our scope, requiring a reasonably limited amount of territorial information. In order to have a more accurate representation of the vulnerability index, it is convenient to cut into meshes the study area. The size of these meshes is of 250 meters in a first approach but it may, in the future, depend on the distance source – targets. In fact, close to the industrial site it may be interesting to have a smaller size of the meshes (for example 50 x 50 meters) and far from the industrial site to have a bigger size of the meshes (for example 500 x 500 meters).

All these considerations permit to validate the proposed size of area to answer to the problematic in order to determine the vulnerability of targets in front of major accidents. Now it is necessary to define the environment by the mean of databases.

2.2 The available databases

Two databases have been retained:
The Corine Land Cover database provides homogeneous geographical information about land use in each country of Europe. The main exogenous data included in this database correspond to topographical map, vegetation and type of forest map and finally soil and network description. There are five main types of territory description:

- ✓ artificial territory
- ✓ land for agricultural use
- ✓ forest and natural areas
- ✓ humid areas
- ✓ water areas

The five previous types are described by forty four classes in order to characterise the natural environment.

The Teleatlas database is made of local data collection activities in all European countries and in the USA. The included themes are:

- ✓ road and street center-lines
- ✓ address areas
- ✓ administrative areas
- ✓ postal districts
- ✓ land use and cover
- ✓ railways
- ✓ ferry connections
- ✓ points of interest: built-up areas
- ✓ settlement centers
- ✓ water

These two databases fill most of our objectives to describe the natural environment and man made targets. Concerning the human targets, specific data provided by each country must be used. The information concerning the population will be obtained with the data provided by the INSEE for France which gives a status of the French population in 1999 by district. In Italy, ISTAT (the National Institute for Statistics) also gives this type of information based on the 1991 and 2001 census of Italian population by district or census unit.
To use these population data, some rules must be assumed to allocate a number of people to each mesh included in a district, as discussed in the paragraph concerning the quantification of environmental targets. If more precise results are required, information at the cadastral level should be taken into account. This second approach is more time consuming than the first one.
It has to be pointed out that other more specific information concerning some important environmental features, such as parks or protected zones are available from national environmental organisations, such as ANPA in Italy, or Natural zone of faunistic and floristic interest in France (ZNIEFF).
Finally, some other information, such as that concerning the industrial site, has to be provided directly from the user, since it is not available to the general public. A specific procedure is proposed to fill these data.

2.3 The targets typologies

The aim of this paragraph is to take into account the environment of an industrial site to determine the risk level of an industrial installation. It is therefore necessary to propose a set of target types to characterize with accuracy the environment, while keeping in mind the importance of the transferability of the method and its flexibility. Indeed, it is necessary to find a just balance between the number of targets to be taken into account and the limitations due to the multicriteria decision method.
First of all, targets were divided into three categories and each of these categories is then detailed in a list of generic targets:

- ✓ Human (H)
  - ➢ Staff of the site (H_1)
  - ➢ Local population (H_2)
  - ➢ Population in an establishment receiving public (H_3)
  - ➢ Users of communications ways (H_4)
- ✓ Environmental (E)
  - ➢ Agricultural areas (E_1)
  - ➢ Natural areas (E_2)
  - ➢ Specific natural area (E_3)
  - ➢ Wetlands and water bodies (E_4)
- ✓ Material (M)
  - ➢ Industrial site (M_1)
  - ➢ Public utilities and infrastructures (M_2)
  - ➢ Private structures (M_3)
  - ➢ Public structures (M_4)

From these typologies, the multicriteria decision method can be applied..

3 The vulnerability index

3.1 Generalities on the multicriteria decision method of Saaty

In a general way, a decision-taking is a complex process which is not only based on a set of information about a subject. It depends also on feelings which correspond to a more or less vague vision of the reality and on the influence of such or such person of the group of decision. In fact, personal preferences and persuasion can have more importance in the process of decision than a clear and rigorous logic. So logic intervenes in a second time to order words and ideas and to lend weight to the decision taken previously.

A multicriteria hierarchical method brings an organization of information and appreciations which intervene in the process of decision-taking.
The purpose of this method is an assessment of priorities. In this goal, the first point is to have a consensus on the objective, then in a second time, to decompose the complex and not structured situation in its main constituents. The types of results can be a classification, an allocation of numerical values of subjective judgments or the synthesis of judgments to determine variable having the biggest priorities. The multicriteria hierarchical method allows to obtain a decision-taking of group in a consensual way due to a better coherence of judgments.
The multicriteria hierarchical method of SAATY is based on three main steps:

- ➢ a construction of hierarchies,
- ➢ an assessment of priorities,
- ➢ a validation of coherence.

The construction of a hierarchical structure requires the creation or the identification of links between the various levels of this structure.
Each element of a functional hierarchy takes place at a given level of the structure. Its upper level corresponds to the global objective (or dominant element). Some binary comparisons are done between all the elements of a given level according to the element of the upper level, in order to rank the elements among them. The various levels of a hierarchy are, consequently, interconnected.
A complex situation can be analyzed by a systematic approach with the help of the hierarchical structure. The priorities have to be assessed. This process is done by a comparison of elements two by two (binary comparison). This one gives the ranking of elements according to their relative importance. Finally, the logical coherence confirms the whole applied process. To do the binary comparisons, it is necessary to use a scale based on classic numerical variables or more qualitative variables contributing to take into account intangible qualities as showing in the table 1.

Table 1: Scale of binary comparison

Degree of importance	Definition
1	Equal importance of two elements
3	Weak importance of an element with regards to the other one
5	Strong importance of an element with regards to the other one
7	Certified importance of an element with regards to the other one
9	Absolute importance of an element with regards to the other one
2, 4, 6, 8	Intermediate values between two appreciations
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Reciprocal values of the previous appreciations

3.2 Application to the determination of the index of vulnerability

This part consists in the description of the environment (figure 2) in order to have a well understanding of the situation. In this aim, three typologies are proposed:

- ✓ a typology of targets which is composed of three main classes of targets (human, environmental and material). Each main class of targets is characterised by four types of targets as described in the paragraph 2.3.
- ✓ a typology of physical effects. Four types of effects are considered (overpressure, thermal flux, gas toxicity and liquid pollution).
- ✓ a typology of impacts. Three impacts due to physical effects are considered to characterise the effects of major accidents on targets:

  - ➢ Sanitary or integrity impact which qualifies the effect on respectively human or environmental and material structures
  - ➢ Economical impact which qualifies an effect in terms of loss of production or of rehabilitation.
  - ➢ Psychological impact which qualifies an effect in terms of influence on a group of people.

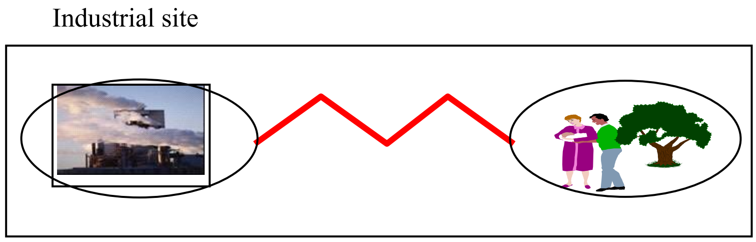

Figure 2: Description of the system

It is necessary, then to organise these typologies in order to answer to the vulnerability problematic.

The following step consists, therefore, in the structuring of the information. It is ensued from the following definition of the vulnerability.
For a class of targets and a given physical effect, the vulnerability of each type of targets in comparison with the other one is evaluated by the way of binary comparisons in function of characterisation criteria which are the three impacts.
The result is the vulnerability of one class of target for one physical effect. The associated hierarchical structure is presented on the figure 4 for the human vulnerability

For a class of targets, the importance of each physical effect in comparison with the other one is evaluated by the way of binary comparisons (figure 3). The result is the vulnerability of one class of target.

And finally, the vulnerability of each class of targets is compared to the other one (figure 3).
The result is the global vulnerability.

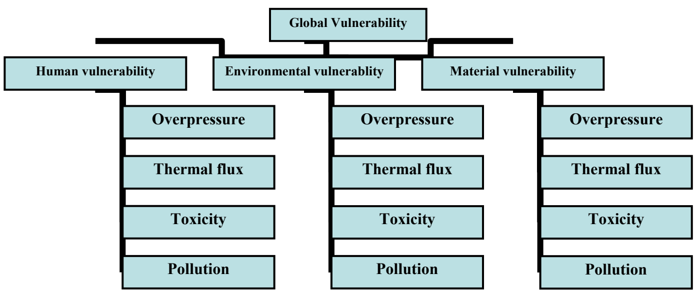

Figure 3: Hierarchical structure of the global vulnerability characterisation

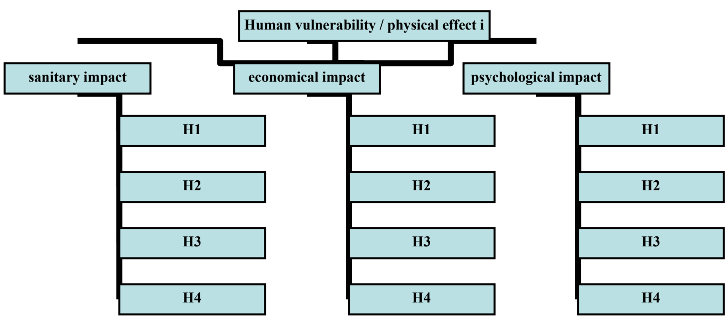

Figure 4: Hierarchical structure for the human vulnerability per physical effect characterisation

The same hierarchical structure, as mentioned on the figure 4, can be deduced for environmental and material vulnerability as for human vulnerability.
From this definition and from hierarchical structures too, the matrixes and the functions of the vulnerability index are deduced. The matrixes are translated into a questionnaire which allows to collect the expert judgement for the evaluation of each coefficient of vulnerability of vulnerability functions.

3.3 The vulnerability factors and functions

Thirty eight experts have already been consulted in an individual way. The repartition of experts per country and type are presented in the figure 5. A great part of the experts are French or Italian. Concerning the type of experts, about 60 % are risks experts (from public or private structures).

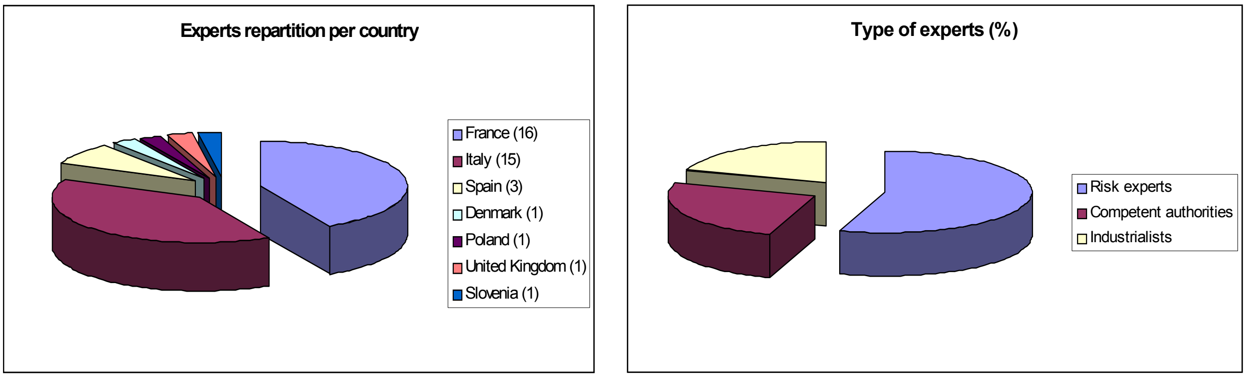

Figure 5: experts repartition per country – type of experts

A specific treatment must be done to aggregate the appreciation of the above mentioned experts. Each appreciation is aggregated by the mean of geometrical average. So a new questionnaire which is a synthesis of the appreciation of all experts consulted is built. All obtained evaluations are reported into the matrixes and the factors of vulnerability can be assessed. Results are given in the following paragraph.

To assess the vulnerability factors of each function, the eigenvectors of the matrixes must be calculated. The solutions correspond to the factors of vulnerability. The following tables present the results. These ratios must have a value lower than 10 % for each matrix to validate the coherence of the ratios and therefore the results.

Table 2: Global vulnerability function

Function	RC%
$V_{global} = 0{,}752 \times V_H + 0{,}197 \times V_E + 0{,}051 \times V_M$	0,17

The results obtained for the function of global vulnerability (table 2) show a great importance about 75% for human vulnerability. The vulnerability factor of environmental targets represents 20% while the material vulnerability represents only 5% of the function.

For human targets (table 3), the main effect is “gas toxicity” (47%). The effects of “overpressure” and “thermal radiation” have about the same importance (respectively 24% and 23%). On the contrary, the effect of “liquid pollution” has a weak influence on human targets (only 7%).

Table 3: Human vulnerability functions

Functions	RC%	Functions	RC %
$V_H = 0,242 \times V_H^{op} + 0,225 \times V_H^{tr} + 0,466 \times V_H^{tox} + 0,067 \times V_H^{poll}$	0,43		
Overpressure		Thermal radiation	
$V_H^{op} = 0,666 \times V_H^{op}{}_S + 0,111 \times V_H^{op}{}_E + 0,222 \times V_H^{op}{}_P$	0	$V_H^{tr} = 0,648 \times V_H^{tr}{}_S + 0,122 \times V_H^{tr}{}_E + 0,230 \times V_H^{tr}{}_P$	0,3
$V_H^{op}{}_S = 0,366 \times H_1 + 0,278 \times H_2 + 0,233 \times H_3 + 0,124 \times H_4$	2,5	$V_H^{tr}{}_S = 0,354 \times H_1 + 0,354 \times H_2 + 0,161 \times H_3 + 0,131 \times H_4$	1
$V_H^{op}{}_E = 0,404 \times H_1 + 0,340 \times H_2 + 0,139 \times H_3 + 0,117 \times H_4$	1,72	$V_H^{tr}{}_E = 0,409 \times H_1 + 0,350 \times H_2 + 0,158 \times H_3 + 0,082 \times H_4$	0,86
$V_H^{op}{}_P = 0,150 \times H_1 + 0,368 \times H_2 + 0,282 \times H_3 + 0,200 \times H_4$	4,57	$V_H^{tr}{}_P = 0,167 \times H_1 + 0,333 \times H_2 + 0,333 \times H_3 + 0,167 \times H_4$	0
Gas toxicity		Liquid pollution	
$V_H^{tox} = 0,735 \times V_H^{tox}{}_S + 0,069 \times V_H^{tox}{}_E + 0,196 \times V_H^{tox}{}_P$	0,35	$V_H^{poll} = 0,594 \times V_H^{poll}{}_S + 0,157 \times V_H^{poll}{}_E + 0,249 \times V_H^{poll}{}_P$	4,62
$V_H^{tox}{}_S = 0,227 \times H_1 + 0,424 \times H_2 + 0,227 \times H_3 + 0,122 \times H_4$	0,57	$V_H^{poll}{}_S = 0,212 \times H_1 + 0,497 \times H_2 + 0,191 \times H_3 + 0,100 \times H_4$	0,86
$V_H^{tox}{}_E = 0,351 \times H_1 + 0,351 \times H_2 + 0,189 \times H_3 + 0,109 \times H_4$	0,57	$V_H^{poll}{}_E = 0,283 \times H_1 + 0,490 \times H_2 + 0,152 \times H_3 + 0,076 \times H_4$	0,57
$V_H^{tox}{}_P = 0,140 \times H_1 + 0,456 \times H_2 + 0,263 \times H_3 + 0,141 \times H_4$	0,55	$V_H^{poll}{}_P = 0,138 \times H_1 + 0,479 \times H_2 + 0,256 \times H_3 + 0,128 \times H_4$	0,53

Table 4: Environmental vulnerability functions

Functions	RC%	Functions	RC%
$V_E = 0,071 \times V_E^{op} + 0,148 \times V_E^{tr}\ 0,277 \times V_E^{tox} + 0,503 \times V_E^{poll}$	0,4		
Overpressure		Thermal radiation	
$V_E^{op} = 0,333 \times V_E^{op}{}_S + 0,333 \times V_E^{op}{}_E + 0,333 \times V_E^{op}{}_P$	0	$V_E^{tr} = 0,550 \times V_E^{tr}{}_S + 0,240 \times V_E^{tr}{}_E + 0,210 \times V_E^{tr}{}_P$	1,58
$V_E^{op}{}_S = 0,122 \times E_1 + 0,227 \times E_2 + 0,424 \times E_3 + 0,227 \times E_4$	0,53	$V_E^{tr}{}_S = 0,195 \times E_1 + 0,231 \times E_2 + 0,426 \times E_3 + 0,148 \times E_4$	2,54
$V_E^{op}{}_E = 0,289 \times E_1 + 0,246 \times E_2 + 0,289 \times E_3 + 0,175 \times E_4$	3,36	$V_E^{tr}{}_E = 0,227 \times E_1 + 0,227 \times E_2 + 0,424 \times E_3 + 0,122 \times E_4$	0,57
$V_E^{op}{}_P = 0,168 \times E_1 + 0,239 \times E_2 + 0,395 \times E_3 + 0,198 \times E_4$	3,36	$V_E^{tr}{}_P = 0,200 \times E_1 + 0,200 \times E_2 + 0,400 \times E_3 + 0,200 \times E_4$	0
Gas toxicity		Liquid pollution	
$V_E^{tox} = 0,691 \times V_E^{tox}{}_S + 0,160 \times V_E^{tox}{}_E + 0,149 \times V_E^{tox}{}_P$	0,48	$V_E^{poll} = 0,710 \times V_E^{poll}{}_S + 0,155 \times V_E^{poll}{}_E + 0,135 \times V_E^{poll}{}_P$	1,58
$V_E^{tox}{}_S = 0,286 \times E_1 + 0,142 \times E_2 + 0,286 \times E_3 + 0,286 \times E_4$	0	$V_E^{poll}{}_S = 0,227 \times E_1 + 0,122 \times E_2 + 0,227 \times E_3 + 0,424 \times E_4$	0,53
$V_E^{tox}{}_E = 0,340 \times E_1 + 0,140 \times E_2 + 0,239 \times E_3 + 0,280 \times E_4$	3,36	$V_E^{poll}{}_E = 0,278 \times E_1 + 0,123 \times E_2 + 0,231 \times E_3 + 0,367 \times E_4$	2,55
$V_E^{tox}{}_P = 0,205 \times E_1 + 0,169 \times E_2 + 0,338 \times E_3 + 0,288 \times E_4$	3,36	$V_E^{poll}{}_P = 0,140 \times E_1 + 0,140 \times E_2 + 0,262 \times E_3 + 0,458 \times E_4$	0,53

Table 5: Material vulnerability functions

Functions	RC%	Functions	RC%
$V_M = 0,446 \times V_M^{op} + 0,410 \times V_M^{tr} + 0,069 \times V_M^{tox} + 0,075 \times V_M^{poll}$	0,39		
Overpressure		Thermal radiation	
$V_M^{op} = 0,571 \times V_M^{op}{}_I + 0,286 \times V_M^{op}{}_E + 0,143 \times V_M^{op}{}_P$	0	$V_M^{tr} = 0,443 \times V_M^{tr}{}_I + 0,387 \times V_M^{tr}{}_E + 0,169 \times V_M^{tr}{}_P$	1,58
$V_M^{op}{}_I = 0,200 \times M_1 + 0,400 \times M_2 + 0,200 \times M_3 + 0,200 \times M_4$	0	$V_M^{tr}{}_I = 0,246 \times M_1 + 0,298 \times M_2 + 0,210 \times M_3 + 0,246 \times M_4$	3,36
$V_M^{op}{}_E = 0,288 \times M_1 + 0,338 \times M_2 + 0,169 \times M_3 + 0,205 \times M_4$	3,36	$V_M^{tr}{}_E = 0,400 \times M_1 + 0,200 \times M_2 + 0,200 \times M_3 + 0,200 \times M_4$	0
$V_M^{op}{}_P = 0,143 \times M_1 + 0,286 \times M_2 + 0,286 \times M_3 + 0,286 \times M_4$	0	$V_M^{tr}{}_P = 0,143 \times M_1 + 0,286 \times M_2 + 0,286 \times M_3 + 0,286 \times M_4$	0
Gas toxicity		Liquid pollution	
$V_M^{tox} = 0,200 \times V_M^{tox}{}_I + 0,400 \times V_M^{tox}{}_E + 0,400 \times V_M^{tox}{}_P$	0	$V_M^{poll} = 0,260 \times V_M^{poll}{}_I + 0,413 \times V_M^{poll}{}_E + 0,327 \times V_M^{poll}{}_P$	4,62
$V_M^{tox}{}_I = 0,142 \times M_1 + 0,286 \times M_2 + 0,286 \times M_3 + 0,286 \times M_4$	0	$V_M^{poll}{}_I = 0,127 \times M_1 + 0,313 \times M_2 + 0,280 \times M_3 + 0,280 \times M_4$	1,2
$V_M^{tox}{}_E = 0,204 \times M_1 + 0,347 \times M_2 + 0,204 \times M_3 + 0,246 \times M_4$	3,36	$V_M^{poll}{}_E = 0,204 \times M_1 + 0,347 \times M_2 + 0,204 \times M_3 + 0,246 \times M_4$	3,36
$V_M^{tox}{}_P = 0,100 \times M_1 + 0,300 \times M_2 + 0,300 \times M_3 + 0,300 \times M_4$	0	$V_M^{poll}{}_P = 0,127 \times M_1 + 0,280 \times M_2 + 0,313 \times M_3 + 0,280 \times M_4$	1,2

For human targets and for all the physical effects, the sanitary impact is the dominating impact (about 65%). The psychological impact represents about 25 % of the vulnerability factors and the economical impact represents only 10%.

For all physical effects, the targets “staff of the site” (H_1) and “local population home-body” (H_2) have a more important vulnerability than the two other types of targets (H_3 and H_4). By considering the psychological impact, the vulnerability factors of the type of targets H_2 are always the more important. By considering, the sanitary and economical impacts, only the vulnerability factors of the types of targets H_1 and H_2 have an important value.

For environmental targets (table 4), the effects of overpressure and thermal radiation have a small effect (respectively 7% and 15%) while the effects of gas toxicity and liquid pollution have a great importance (28% and 50%). For three physical effects (thermal radiation, gas toxicity and liquid pollution), the sanitary impact is dominating to assess the environmental vulnerability (more than 75%) whereas the other impacts have a value lower than 25%. By considering the effect of "overpressure", the different impacts have nearly the same importance, indeed the value of the vulnerability factors are very similar. For the physical effects of "overpressure" and "thermal radiation", the type of targets E_3 (specific natural area) has the higher vulnerability factor for all impacts. By considering liquid pollution, the type of targets E_4 (wetlands and water bodies) has an important vulnerability. The two other categories E_1 and E_2 (agricultural area and natural area) seem to be less vulnerable to this physical effect than E_3 and E_4.

Concerning material targets (table 5), the effects of overpressure and thermal radiation represent the main parts of the vulnerability factors (respectively 45% and 41%). For an overpressure effect and a thermal radiation effect, the integrity and the economical impacts are more important than a psychological impact. On the contrary, for a gas toxicity effect and a liquid pollution effect, the economical and the psychological impacts are more important than the integrity impact. For the effects of gas toxicity and liquid pollution, the factors of vulnerability have about the same value for all types of targets except for the type of target M_1. For a thermal radiation effect, the factor of vulnerability for an economical impact of the type of target M_1 has a dominating value.

All the ratios of coherence (RC) are lower than 10%, so the vulnerability factors based on the thirty eight questionnaires mentioned above are validated.

To complete the functions of vulnerability, quantification factors of each type of targets are implemented. They are developed in the following paragraph.

3.4 The quantification factors

The quantification factors aims at doing a normalized census of each detailed type of targets (H_1-H_4, E_1-E_4 and M_1-M_4). They are dimensionless variables assuming values in the range 0-1.
The quantification factor H_i relevant to each of the i-th types of human targets falling in the area under exam can be generally determined as:

Hi = Ni / Nmax i

	H_1	H_2	H_3	H_4
N_i	N_1	N_2= PDxA	N_3	N_4
$Nmax_i$	Nmax1= 2000 persons	Nmax2 = PDmax2xA= 15000 persons	30000 persons	Default or users

with
N_i: total number of people of the i-th human target type in the area under exam;
$Nmax_i$: maximum number of people of the i-th human target type in the area under exam.

PD population density (person/km²)
A surface (km²)

Accordingly, in order to determine the quantification factors for human targets, it is preliminarily necessary to set the maximum value which the number of people belonging to each i-th human category type can reach in the area, $Nmax_i$.

The maximum value for the number of people belonging to the staff of the site, present at the same time in the area under exam, based on the number of workers of single, rather large plants, can be assumed as 2000 persons.
The target local population home-body typically belongs to the distributed target typology, being referred to a surface area.
$PDmax_2$, can be determined based on the individual values of population density of a great number of built-up aggregates. To this end, the individual population density values were calculated for about 60 000 Italian built-up aggregates, limiting the analysis to those covering areas larger than the average mesh size (from 0.0625 to 0.25 km^2). The expected maximum value of population density was then taken as the upper 98% limit (i.e. the value that was exceeded only in 2% of the cases), which corresponds to about 15000 people/km^2. Due to the rather high population density in the built-up areas in Italy, this value can be assumed to hold all over the EC.
Therefore the value of the maximum population density for people belonging to the local population home-body is: $PDmax_2$ = 15000 people/km^2.

Some information concerning the location of establishments receiving public is available from databases, but, in most cases, additional information regarding the number of people in each establishment should be found and added by the user. Moreover, the location of some establishments may not be available from the databases, so requiring also this information to be inserted by the user. However, it is possible to provide the user with some default values based on the type and size of the establishment.
The establishment receiving public will be generally considered as point targets, even if particularly large installations may be treated as distributed targets, also depending on the mesh size.
The expected maximum value of people in an establishment receiving public may vary considerably depending on the type of establishment. It can be assumed that the largest number of people present at the same time in a specific place is obtained for some events as sport matches or rock concerts taking place in stadiums, where the number of people may reach or even exceed 80000 persons. However, it seems not practical to set the maximum number of people to this extremely high value, since this will mean that, in the absence of this specific type of establishment, the quantification factors will come out very low, due to the much lower number of people who may be present in most of the other types of establishments, such as theaters, schools, restaurants, etc. Accordingly, the maximum number of people in an establishment receiving public will be set at 30000 persons.

Users of communication ways include people travelling on roads, rails and waterways. Some databases, such as TeleAtlas, give information concerning location and type of the communication ways, but, generally, no data is available concerning the population travelling on such communication ways. Therefore, the data should be inserted by the user, based on locally available information concerning traffic data, average number of people travelling on each mean (cars, trains and boats), etc.
The target users of communication ways typically belongs to the distributed target typology, and can be conveniently expressed as number of people per unit length of the communication way (road, railway, waterway). The number of users of each type of communication way can be inserted by the user or can be estimated using default procedures.

The quantification factor E_i, relevant to each of the i-th types of environmental targets falling in the area under exam can be determined as:

$$E_i = A_i / A_{mesh}$$

	E_1	E_2	E_3	E_4
A_i	A_1	A_2	A_3	A_4
A_{mesh}	A_{mesh}	A_{mesh}	A_{mesh}	A_{mesh}

with
A_i extension of the area covered by the i-th type of environmental target within the boundaries of the area under exam (km^2);
A_{mesh} total extension of the area under exam (km^2).

The quantification factor M_i, relevant to each of the i-th types of material targets falling in the area under exam can be determined as:

Mi =Ai/Amesh

	M_1	M_2	M_3	M_4
A_i	A_1	A_2	A_3	A_4
A_{mesh}	A_{mesh}	A_{mesh}	A_{mesh}	A_{mesh}

with
A_i extension of the area covered by material target within the boundaries of the area under exam (km^2);
A_{mesh} total extension of the area under exam (km^2).

Should some point target, belonging to the target type utilities and infrastructures and artistic items, be present, the quantification factors, M_2 and M4, have to be modified as follows:

M2 = A2/ Amesh +I2/I2max

M4 = A4/Amesh +I4/Imax4

with
I_2 factor representing the importance of all the vital utilities and infrastructures present in the area under exam;
$Imax_2$ maximum value related to the importance of vital utilities and infrastructures.
I_4 factor related to the importance of all the artistic items present in the area under exam;
$Imax_4$ maximum value related to the importance of artistic items

Due to the difficulty in estimating an actual “value” of a vital utility or infrastructure or of an artistic item, it is suggested to set a scale of importance, in the range 0 – 1: in this case the maximum value of the importance of a vital utility or infrastructure is:
$Imax_2 = 1$ or $Imax_4 = 1$.
It has to be remarked that it should always be: M_2 and $M_4 \leq 1$: this means that if $M_2 > 1$ or M4>1, it should be taken $M_2 = 1$ or M_4=1.

4 Towards an operational tool with Geographical information system

This paragraph is devoted to do a synthesis of the presented methodology. It also present how it can be applied on an area for which vulnerability must be assessed.

4.1 Description of the objectives of the GIS tool

The studied area is a square of 400 km² with the industrial in the middle. In order to assess the vulnerability index, the following steps have to be done:
- ✓ to divide the studied area into meshes
- ✓ to assess the vulnerability for each mesh

- ✓ to identify the targets (H_1-H_2, E_1-E_4 and M_1-M_4) which are included into the mesh in function of the proposed typologies
- ✓ to quantify the number of the targets
- ✓ to calculate the vulnerability index
- ✓ to store the data into a table
- ✓ to map the results, three levels of results can be obtained

All these actions must be repeated for the whole meshes of the studied area.

4.2 The expected cartographical results

The provided results in the previous phase are mapped with the help of a scale of vulnerability which translates a value of vulnerability index into a class of vulnerability.

Three types of results can be obtained:

- ✓ a cartographic representation of the global vulnerability of the studied area
- ✓ a cartographic representation of the vulnerability of a class of target (human, environmental or material)
- ✓ a cartographic representation of the vulnerability of a physical effects for a class of targets

5 Conclusion

In conclusion, a structured methodology is proposed to quantify the vulnerability index of an area in the surroundings of an industrial site. This methodology is based on the expert judgments and hierarchical structures to organize the data to answer to the problematic of vulnerability calculation. This methodology must be implemented with a geographical information system to obtain an operational tool for the risk manager like the competent authorities, the industrialists and the risks experts. By this way, the end users will have a formalized representation of the situation of the environment in order to manage risks.

This article has been prepared as a contribution to the ESREL 2003 conference. The final version of this document can be found in: Proc. ESREL 2003, June 15-18, 2003, Maastricht, The Netherlands, p. 1543, ISBN 90 5809 551 7.