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Land use planning policies stemming from the implementation of the SEVESO-II Directive in the EU

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Abstract

A comparative assessment of three approaches in land use planning around chemical sites is presented. Managing the risk from potentially hazardous sites through appropriate choice of the uses of land surrounding the sites is also suggested by the so called 'SEVESO' EU directive already implemented in most of the Member States of the EU. Two general philosophies—one purely 'deterministic' based only on consequences, and one exhibiting, as complete as possible, a quantification of the uncertainties—are presented and compared to a more general multicriteria decision analysis framework. The latter approach explicitly introduces additional to the risk dimensions to the decision problem and avoids the use of ad hoc risk criteria. The comparison of the three approaches is exemplified by an application to a major hazard facility site in Greece.

Keywords: Land use planning; Risk analysis; Multicriteria decision support system

1. Introduction

Land use planning and siting of hazardous chemical sites are two issues constantly gaining attention in risk management. In land use planning, besides minimizing the risk for population and environment, one has to consider other aspects such as the availability of a suitable area, the accessibility of the site to transportation means, and labor resources. The problem of Land Use Planning around hazardous installations originates from the fact that certain industrial facilities have the potential, under certain circum-

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stances, to cause major accidents with consequences extending outside the limits of the establishment harming public health and the environment. For this reason, it is widely recognized that these facilities (and the relevant activities) should be separated from residential and commercial areas by *adequate* distances.

The SEVESO directive (already implemented in many European member states) obliges a significant number of process industries (including refineries, chemical production sites and LPG storages) to perform safety studies and the competent authorities to organize emergency plans and land use policies based on the results of these studies, in order to protect the public and the environment. For historical, geographical, economical, social and political reasons, there are big differences in the way the various countries approach the siting of hazardous facilities and the development of areas in the vicinity of existing installations.

In this paper, two general philosophies, a purely 'deterministic' approach and one exhibiting, as complete as possible, a quantification of the uncertainties, are briefly presented. These approaches are then compared in the framework of a multicriteria decision analysis approach that allows the consideration of benefits along with detrimental effects. The comparison is exemplified by applying the different approaches to a major hazard facility site (refinery) in Greece.

2. Land use planning (LUP) approaches around chemical sites

This section outlines two different LUP philosophies shaped according to the available public descriptions of the policies followed in two member-states of the EU. No claim is made, however, that these descriptions do represent the policies actually followed in those countries.

2.1. Planning on the basis of the 'worst credible accident'

According to this approach, all uses of land around a dangerous chemical installation are determined on the basis of the consequences of a fully defined accident, which is thought to be the 'worst possible' one. In general, the worst possible accident might not be identifiable, or, if it is, its consequences are considered extremely low or 'incredible'. As a result the concept of 'worst possible' is replaced by the concept of 'worst credible accident' which is the worst accident (in terms of consequences) out of a series of 'possible' or credible accidents.

A major representative of this philosophy is France, where reference scenarios and the corresponding criteria are based on the analysis of past accidents, as well as on possible events. There are six main scenarios referring to various types of facilities, as it can be found in Ref. [1]. Each scenario is well-determined in terms of: (a) the conditions under which the accident occurs (release characteristics, meteorological conditions, etc.); and (b) the criteria concerning the maximum acceptable effects (thermal radiation, overpressure or toxic dose).

Then, safety analysis procedure leads to the calculation of two distances (risk zones): (i) the distance (R_1) at which the first death occurs conditional on the occurrence of the accident (corresponding to probability of fatality 1%); (ii) the distance (R_2) at which irreversible health effects occur conditional on the occurrence of the accident.

These two distances are calculated for each of the six reference scenarios (if applicable to the installation) and the largest calculated distances define three zones Z1, Z2 and Z3.

In zone Z1 ($R < R_1$) only 'housing and public building' developments not resulting in an increase in population density are allowed [1]. In zone Z2 ($R_1 < R_2$) authorization is given for developments with limited density, that is, all categories of 'housing and public building' developments with the exception of high-rise buildings and establishments receiving the public. Industrial installations can be permitted in these zones if certain minimum conditions are fulfilled [1]: (i) limited number of staff trained to respond in emergencies in neighboring installations; (ii) compatibility with industrial activities; and (iii) possible emergency training of staff in neighboring installations.

No restrictions apply for zone Z3 ($R > R_2$).

2.2. Planning on the basis of quantitative risk assessment

A second basic philosophy which can be followed in land use planning (LUP) around chemical installations is one based on quantified risk assessment. According to this approach, LUP is not based on the consequences of the worst credible accident, but on the consequences of all possible accidents weighted by their occurrence probability.

This philosophy allows both for the combination of accidents different in nature (e.g. toxic releases, explosions, fires, etc.) and for the accounting of prevention and mitigation measures taken on-site and affecting either the probability of occurrence or the consequences. According to this philosophy, which is mainly followed in the Netherlands, the criteria defining the various zones is not the intensity of physical phenomena but rather measures of quantified risk.

Two measures of risk are usually used [2,3]: (i) the *individual risk*, defined as the probability of fatality due to any accident in the installation for an individual being at a specific point, and (ii) the *societal risk*, defined for different groups of people, which is the probability of occurrence of fatalities greater than or equal to a specific number and owing to a single accident. Individual risk is usually presented by the isorisk curves, while the societal risk is presented in terms of F–N curves.

Recently, following the safety report for the international airport of Amsterdam (Schiphol), the Dutch policy for LUP can be summarized as follows: (i) within 5×10^{-5}/yr individual risk zone (zone Z1): No new housing construction is permitted; existing houses are demolished; (ii) within 10^{-5}/yr individual risk zone (zone Z2): No new construction is permitted; existing houses can be replaced by new ones; (iii) within 10^{-6}/yr individual risk zone (zone Z3): An overall risk policy adopted; restrictions on the construction of new houses are set; societal risk is taken into account; (iv) in an even larger area, the construction of new dwellings is restricted to some extent (zone Z4).

2.3. Implementation to a Greek site

To illustrate the above mentioned LUP approaches, as well as the proposed methodology, a Greek Chemical site has been selected for which a complete Risk Analysis

Table 1
(a) Zones identified in the French approach by the worst reference scenario

Scenario	Example of application	Distance corresponding to criteria for first death (R_1)	Distance corresponding to criteria for first irreversible effects (R_2)
BLEVE	Spherical gasholder of 3000 m^3 of butane	1420 m (1% Fatalities)	2145 m (1% 2nd degree burns)

(b) Zones identified in the Dutch approach

Zone	Average radius
10^{-5}/yr individual risk (zone Z2)	750 m
10^{-6}/yr individual risk (zone Z3)	1500 m

according the SEVESO Directive Requirements has been performed. The site is a Refinery containing both flammable (hydrocarbons) and toxic (HF) substances. For the French approach, calculations have been done according to the prescriptions given in Ref. [1]. The quantitative risk assessment methodology used is the one described in Refs. [4,5]. The results of the study are given in Table 1.

3. The multicriteria analysis methodology

As the LUP problem touches a number of issues (human health, environment, economic growth) and has multiple consequences impacting the above mentioned items, it can be considered as a multicriteria decision problem. To that end, a methodological approach drawing from the theory of multicriteria decision analysis has been developed in LSRIS [6–8] to support the choice of land development patterns in the vicinity of major hazard facilities, when various alternatives compete on multiple criteria.

The problem setup is as follows.

(1) The area of and around the Refinery is subdivided into 2500 cells of 100 m $\times$ 100 m each, which are further grouped to zones as described in (3) below.

(2) For each cell, a number of possible land development types (LDT) is defined. The LDTs used in this application are given in Table 2.

(3) The area under analysis is subdivided into zones, each containing a number of cells. Each zone is characterized by the same land use policy; i.e. the cells in each zone must have the same LDT. The zones for each of the two approaches presented in Section 2 are defined as follows.

(3.1) *Deterministic approach*: Three zones: Z1, Z2, Z3. In Z1 only LDT1 is allowed. In Z2 LDT1 or LDT2 are possible. In Z3 all three, LDTs are possible.

(3.2) *Probabilistic approach with constraints*: Four zones: Z1, Z2, Z3, Z4. Z1 does not exist in this example. In Z2, only LDT1 is allowed. In Z3, LDT1 or LDT2 are possible. In Z4, all three LDTs are possible.

A third approach proposed in this paper is using risk-based zones but it is constraint free, in that it does not set any particular individual or societal risk constraints.

(3.3) *Probabilistic approach without constraints*: Eighteen zones are defined, each one characterized by the same individual risk level. (Z1: 1×10^{-5}/yr > risk > 7.5×10^{-6}/yr, ...,Z18: risk < 10^{-9}/yr). All three LDTs are allowed in each and every zone.

(4) A land development patterns (LDP) over the whole area is defined when the LDT of each zone is defined. Let J denote the number of zones and m_j denote the number of

Table 2
Land development types—associated parameters

Land development type	Population density	Economic benefit
LDT1 No Development	0	0
LDT2 Recreation	10 people/cell	0.2 monetary units
LDT3 Residential	100 people/cell	1 monetary unit

possible LDTs for the j^{th} zone. Then, the number of alternative land development patterns N is:

$$N = \prod_{j=1}^{J} m_j \tag{1}$$

(5) Evaluation criteria considered in this example are: (a) the expected acute fatalities over the plant lifetime (30 yr); and (b) the net land development benefits. Let i be index over the I evaluation criteria: $i = 1, \dots, I$.

(6) Each cell n ($n = 1,2,\dots,2500$) is assigned to a zone j and it is characterized by the number of alternative LDTs for that zone, indexed by k_n ($k_n = 1,2,\dots,m_j$). The expected value of the ith criterion $c(i,n,k_n)$ is calculated on the basis of the results of QRA.

(7) Assuming no interaction effects between LDTs in neighboring cells, the consequence C_i of a particular land development pattern (i.e., one where for each cell n an LDT k_n has been defined) is given by:

$$C_i = \sum_{n=1}^{N} c(i,n,k_n) \tag{2}$$

(8) The constrains that must be observed either over the total of the study area or over individual cells are defined. For example, the cell occupied by the refinery itself are considered not amenable to further development. The same is valid for the sea, where the above mentioned LDTs are not applicable.

Given any two alternative LDPs, they are compared in terms of their implied consequences measured in terms of the two criteria, number of deaths and total benefit. If one is better than the other in both criteria, then the first is said to *dominate* the other. An alternative is called efficient if it *is not dominated* by any of the possible alternatives. The developed methodology includes an algorithm for the fast generation of all efficient alternatives (efficient frontier). It is noteworthy that development of the efficient frontier does not require value judgment between human life and benefit. Choice of one alternative out of those constituting the efficient set does, however, imply explicitly or implicitly a value trade off.

Perusal of the efficient set both in terms of the implied consequences and in terms of the specific LDTs corresponding to each efficient solution can help a decision maker identify the most preferred solution.

4. Results and conclusions

Fig. 1 presents the overall risk profile of the installation, namely isorisk curves 10^{-5}, 10^{-6} and 10^{-7}/yr. Fig. 2 shows the three zones Z1, Z2 and Z3 of the ‘French’ approach. Fig. 3 presents the efficient frontier of solutions for the two measured consequences of our study: benefit vs. number of fatalities. The fine continuous line depicts the set of solutions that are possible under the proposed ‘no constraints’ probabilistic approach. The solutions range from the ‘no development’ everywhere,

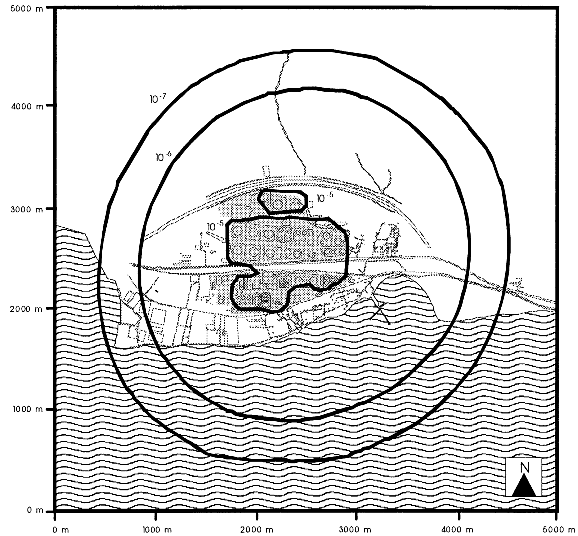

Fig. 1. Installation with isorisk curves.

resulting in zero benefit and fatalities, to a 'full development' everywhere, resulting to maximum benefit and fatalities. Point #1 on the frontier corresponds to the maximum possible development under the 'Dutch' approach when only the individual risk constraints are used. Point #2 is the solution corresponding to the maximum development when the societal risk constraint is added. Point #3 corresponds to the maximum development under the 'French' approach which is slightly suboptimal as can be seen in

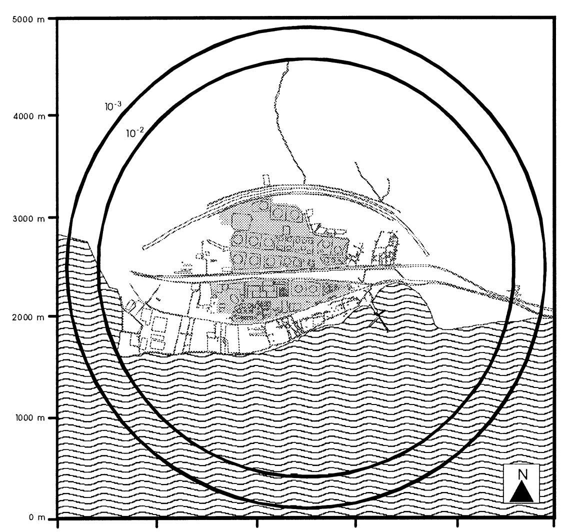

Fig. 2. Installation with conditional isorisk curves (BLEVE), French approach.

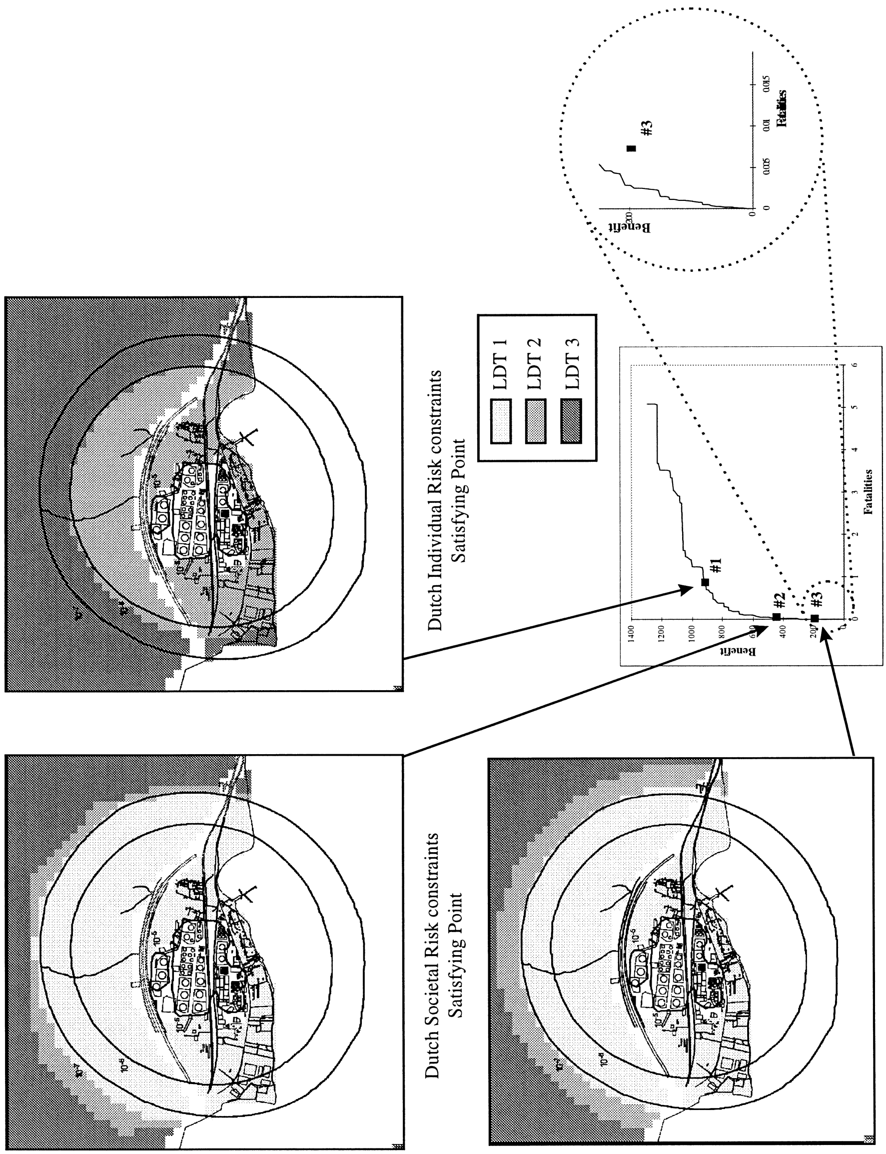

Fig. 3. Three LDPs and their mapping on the efficient frontier.

the ‘zoom’ area of Fig. 3. Each point of the efficient frontier depicts a thoroughly defined LDP in the study area as can be seen in Fig. 3, where the LDPs corresponding to the three points mentioned above are also presented (each LDT is depicted with a different gray tonality and corresponds to different population density and benefit).

When observing the efficient frontier, it is worth mentioning that in the left outmost region of the curve a dramatic increase in benefit can be achieved without substantial increase of the fatalities, while in the right outmost region of the same diagram, one has the inverse phenomenon, i.e., significant increase of fatalities minor increase of benefit. This means that one could easily restrict the region of efficient solutions in that between points #1 and #2 (see Fig. 3). Choosing a specific point in the region (#1, #2) can then be assisted by a simultaneous perusal of the implied LDT by each point. An important feature of the proposed approach is that it allows for the assessment of the relative ‘value’ of ‘violating’ one or more proposed criteria.

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