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Land Use Planning and Chemical Sites Summary Report

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Abstract A methodology for land-use planning involving chemical sites has been developed for making decisions in local and regional administrations. The methodology treats land-use planning as a multi criteria decision and structures the planning process in seven steps, where one can loop through the steps several times. Essential for the methodology is the specification of objectives setting the frame in which the alternatives are assessed and compared. The complete list of objectives includes the following items: safety and accidents, public distortion and health, environmental impact, cultural and natural heritage, societal and company aspects, with focus laid on the safety related items. An approach based on efficient frontier curves has been used for comparison of alternatives having land-use pattern as variable. Central to the application of the proposed methodology is a GIS based software platform enabling the users to generate alternatives, select the preferred ones and peruse efficient solutions both in terms of the implied land use patterns and the corresponding consequences. Study material has been gathered from planning cases in Sweden, Denmark and Greece.

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Contents

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Abbreviations in Text

LUPACS	Land Use Planning and Chemical Sites
LUP	land use planning
MCDA	multi criteria decision analysis
LDT	land development type
LDP	land development pattern

Preface

A general objective in land-use planning concerning chemical sites is to manage industrial risks in such a way that net land development benefits are maximised and the various categories of costs and unwanted consequences are minimised. Under the EU research program *Environment & Climate* the LUPACS project (Land Use Planning And Chemical Sites) was started in 1996. The aim is to develop a method to support the local planners by establishing a sound basis for their decision making on such issues as site selection, safety distance and restrictions onoperation. The project deals specifically with the decision tasks of planners in local administrations, who are faced on one side with industry's applications for making changes and building new plants, and on the other side with the range of conditions and impacts to review and evaluate in order to fulfil Seveso Directive II (COMAH Directive), Environmental Impact Assessment and other relevant legislation.

This report presents the project work through a collection of summaries produced by the work package leaders. Also given are a publication list and a list of persons, who have contributed to the work and who have been present during at least two plenary meetings.

The objective of the project is to present an overall methodological framework for supporting decisions on the location or on larger modifications of chemical complexes and the land-use patterns around them. The method shall address situations like the following: a) given the location of hazardous installations determine the development (land-use) patterns in the area, b) given a specified land-use pattern determine the siting of hazardous installations and c) determine both the siting of hazardous installations and the land-use patterns around them simultaneously.

Land-use planning is a complex process involving actors at different decision making levels with different interests. The boundaries and conditions for the land-use planning problem in question can be defined and influenced by different aspects, e.g. physical, geographical, political or organisational factors. Decision support in land-use planning will reflect contributions form a variety of disciplines such as risk analysis, management science, computer science, economics, operations research, planning, psychology and biology.

The developed frame emphasises safety related aspects, but the method can be adjusted to include other objectives, e.g. public distortion and health; environmental impact; cultural heritage; natural heritage; social/economic aspects; company aspects. The intention has been to prepare a dynamic method which can be updated and revised by the users on basis of experiences gained from other land-use planning situations and lessons learned from accidents occurring in the society.

The LUPACS project consortium includes:
Swedish Rescue Services Agency
Joint Research Centre (Ispra)
National Centre for Scientific Research "Demokritos" (Greece)
Université Paris VI Laforia (France)
Emergency Management Agency (Denmark)
County Board of Södermanland (Sweden)
County Board of West Zealand (Denmark)
Fredericia Community (Denmark)
Risø National Laboratory (Denmark)

The LUPACS project includes three principal activities according to the work program[i], with the central one having the highest priority:

Activity A. State of the art: A brief description of the state of the art with notes on other relevant projects and scientific work.

Activity B. Methodology: Identification and analysis of present options for efficient land-use planning processes concerning chemical industrial complexes and communities. The development of a methodological framework for supporting decision makers concerning the location of chemical industrial complexes and land-use patterns around them including practical case studies in Denmark and Sweden.

Activity C. Education: The development of an education programme which involves an introduction to land-use planning principles and training with the LUPACS method in selected problems.

Also given in the work program are a series of work packages together with the responsible parties. During the project period a few modifications were considered appropriate and agreed by the project team, the most important ones being:
interchange of work package leaderships between wp's 2.1 User Needs and 2.2.1 Skeleton
delaying the start time of wp 3 Education one year
leaving the distinction between draft 1, draft 2 and final realisation (wp's 2.2.2, 2.2.3, 2.2.4) and substituting one delivery, for which Demokritos became work package leader.

After modification the list of work packages and principal reports is the following

Wp 1.1, Methods for land use planning
Wp 1.2, Problem Characterisation
Wp 1.3, Decision Support Systems
Wp 2.1, User Needs
Case # 1 Danish case
Case # 2 Swedish case
Case # 3 Swedish case
Case # 4 Danish case
Wp 2.2, Methodology Report
Wp 3.1, Education
Project Summary Report

1 Methodologies for Land Use Planning

1.1 Overview

The objective of this work package was the determination of land use planning approaches in the European Union member states participating in the project, as well as established and available approaches in other member countries. The countries analysed were: Greece, Sweden, Denmark, the Netherlands, the United Kingdom and France.
The information contained in this report was generated by addressing to each partner a questionnaire containing the following issues.

1. *Methodology for Land Use Planning in general.*
2. *Methodology for Land Use Planning of Hazardous Chemical Sites.*
3. *Classification and Identification of Chemical Sites regarding their hazard level.*
4. *Risk Analysis Methodologies of Chemical Sites.*
5. *Control exercise over the use of land in a certain area (local, supralocal or centralized).*
6. *Decision making Procedure. Who is involved.*
7. *Risk and Siting criteria. Qualitative/Quantitative.*
8. *Impact Physical Phenomena like Earthquakes, Floods, Typhoons etc.*

On the basis of the responses a summary assessment was made for the three member countries participating directly in the project (Denmark[ii] Greece[iii], Sweden[iv],[v]). Information on three additional member countries was obtained from the open literature[vi] (France, Netherlands, U.K.).

According to the data selected, the systems already in use are presented and evaluated : how major hazard installations are identified, how the siting of new major hazard installations is controlled, how the hazards are assessed, how control is exercised over the use of land within their vicinity, and how decisions are reached. This screening will go beyond the major hazard installations in order to identify all significant risk objects.

In addition to that the administrative organisation of LUPACS member countries is also presented.

1.2 Conclusions drawn from the survey

- The difference in size and population of each country led to a stricter definition of the terms “region”, “municipality” and “prefecture” so that a comparison among various approaches became possible.
- The term “Land Use Planning” was used with a slightly difference sense in each country regarding the establishment of safety zones, zones of building restriction etc. so some additional description of how the term is used in each country was needed.

- An attempt was made to establish the areas of concern of the land use planners in each country with further analysis to measurable objectives.
- It can be concluded from the survey that as far as the LUPACS member countries are concerned, the strongest level in LUP in Sweden is the local one while in Greece and in Denmark is the regional one.
- It can also be concluded that there is a lack of a specific legislation regarding the siting of chemical installations in the majority of the member countries.
- The methodology for assessing risk induced by dangerous chemical installations is known to all of the member states but its use is still not so wide spread as to be a standard tool in the hands of both competent authorities and engineering professionals.

2 Problem Characterisation

The following questions are discussed in the work package:

What should the land use planning process achieve?
What is the current land use planning process achieving?
What are the effects of the process?
Which are the crucial problems?

The last decade of implementing the Seveso Directive has been characterised by development of methods for safety work inside the chemical plants like Hazard Operational Analysis (HAZOP), internal control activities and ISO 9000 and ISO 14000. The methods used on site have had a mathematical/probability and quantitative approach. Some general conclusions about the present situation can be drawn. Our investigations indicate, that in the next 5-10 years there will most probably be only a few new "Seveso-industries", instead questions concerning expansion or alteration on site will be more frequent.

Our work has been conducted according to the principle that the land use planning process should contribute to protect and save life, the environment and property. In work package 1.2[vii] we have especially looked into the land use planning processes in Sweden, Denmark and Greece.

We have found that decisions on the land use planning process are made at different levels.

In Sweden decisions are made at a local level and in Denmark and Greece at the regional level.

In general the land use planning process as a tool for health and safety improvement has not been examined and thoroughly analysed, thus there has been a lack of knowledge in the ways the planning process can be improved and on what grounds the planning authorities should make their decisions. An important problem to handle is how to handle safety zones and other zones. Could or should safety zones and safety regulations be mutually defined between local authorities and chemical sites and if so on what grounds? We found that there is also a lack of feed-forward of experiences from accidents, near misses and disturbances to improve the land use planning process.

There is therefore a real need to develop methodologies and expert systems to improve the planning process. Tools for visualisation of the possible effects of a new localisation or alterations or expansions on - and off site are needed. One way to handle this is to develop GISs. If GIS should be more integrated in the physical planning process as a tool for handling different aspects of health and safety it must be combined with high quality data from different authorities on environment issues, rescue service, planning, population statistics etc.

3 Decision Support Systems

The concern and awareness of the authorities on taking major accident hazards into account in Land-Use Planning (LUP) has clearly been expressed both in the early attempts to establish risk tolerability criteria and in the performance of a number of area risk studies. Without doubt, the procedures, methodologies and criteria developed by each country reflect – and should reflect – its safety culture and attitude towards risk, and they are in accordance with the general administrative and legislative system. In the European environment, significantly different procedures exist in the various Member States and the different practices are used. In broad terms, there are:

- countries which have already established well-structured procedures for taking major accident hazards into account in land-use planning, and
- countries in which such procedures are under development, and no explicit regulations for land-use planning in the vicinity of hazardous installations exist up to now.

The Netherlands, United Kingdom, France and, to some extent, Germany, have already developed comprehensive LUP procedures. Southern European countries, such as Italy, Greece, Spain and Portugal, belong to the second category, while some countries such as Austria and Denmark are very close in establishing procedures and criteria for land-use planning. Such Member Countries do not show less concern about major hazards but the control of land-use planning in the vicinity of hazardous installations is covered up to now by the legislation for physical planning and consists of procedures in which accident hazards are not explicitly considered in land use policies. However, in view of the Seveso II requirements, specific and explicit new regulations are currently under development.

From the methodological point of view, the approaches followed in those countries where consolidated procedures and criteria have been established can be divided in three categories:

- The determination and use of *"generic" separation distances* depending on the type of activity rather than on a detailed analysis of the specific site. These safety distances usually derive from expert judgement and are mainly based on historical reasons, experience, rough consequence calculations or the environmental impact of the plant. Generic separation distances according to the type of activity have been established and used in Germany and Sweden and have been proposed in other countries. As an example, tables of the method may suggest certain separation distances between establishment and residential area according to the quantity of LPG stored. The use of similar tables of generic distances for screening purposes, i.e. as a checklist to ensure compatibility of land uses at an early stage of the analysis, which is in use in many countries, should be distinguished.

- The *"consequence based"* approach, that focuses on the assessment of consequences of a number of conceivable scenarios (reference scenarios). Certain endpoints of the consequences are determined, in terms of the levels of the physical magnitudes (concentration, thermal radiation, overpressure) that cause harm, corresponding to certain levels of the undesired effect (fatalities or irreversible effects). Decisions on land-use policy are based on the distance to these endpoints corresponding to the worst among these reference scenarios. Example reference scenarios include BLEVE, VCE, fire, and explosion of flammables, instantaneous release of the total amount of the toxic content of tanks (and continuous release from pipelines at the maximum flow-rate), and explosion of the biggest amount of explosives present. Example threshold criteria are 5 kW/m^2 and 3 kW/m^2 for thermal radiation (seen – for the determined period of exposure – as thresholds for 3rd and 1st degree burns, respectively), the $LC_{1\%}$ and IDLH concentration levels for toxic releases, and the 140 and 50 mbar of overpressure, for explosions. The method is used in France and has been proposed for many other countries.

- The *"risk based"* approach, that focuses on the assessment of both consequences and probabilities of occurrence of the possible accident scenarios. The results are quantified in terms of individual risk (probability of fatality for an individual located at a certain point around the plant and continuously exposed to risk) and societal risk (probability of occurrence of any accident resulting at fatalities greater than or equal to a specific figure) and criteria have been set for both these measures. The approach is followed in the United Kingdom and the Netherlands (however, with different criteria and practical details) and has been proposed for many other countries. In the Netherlands a case resulting in individual risk higher than 10^{-6} or in societal risk above the $10^{-3} / N^2$ line in the F-N curve is considered unacceptable, while for lower risk always the ALARA (As Low As Reasonably Achievable) principle is applied. In UK, three zones are determined, corresponding, for toxic releases to 10^{-5}, 10^{-6}, and 3×10^{-7} levels of individual risk of receiving a dangerous dose or worse, and for thermal and explosion effects to certain levels of dose. In each one of these zones, the types of developments allowed are then specified.

For a given installation, the "consequence based" approach will show the consequence area for lethal effects and serious injuries resulting from the scenarios assessed, while the "risk based" approach will show an area within which there is a given probability of a specified level of harm resulting from the large number of possible accident scenarios. A more extensive analysis of the approaches and details on their practical implementation can be found in Section 3 of the LUPACS Final Report on the methodology, as well as in references[viii] and [ix] .

4 User Needs

The objective of this work package is to present user requirements to possible support tools for land use planning decisions. This identification has been carried out in accordance with the work programme, through the collection and collation of the needs expressed by the end users of the method, i.e. decision makers and physical planners at a local and regional level, together with the needs derived from the technical domain. Close contacts have been held with the end users in Sweden and Denmark during the development of the case studies and the methodology in 1997-1998. This summary reflects the discussions. The introduction of decision support should have the following purposes in mind:

- generation of new ideas and new solutions
- handling of large volumes of information
- addressing multiple objectives in a systematic and efficient manner
- ensuring that all relevant topics are dealt with.

Land-use planning concerning a specific plant is essentially a decision process characterised by an evaluation of alternatives where objectives of different types and values are weighted out. Briefly our proposed decision process is divided into the following steps/states:

- detailed hazard identification and risk assessment (made by the industry)
- ranking of the problems and formulation of the decision situation
- description of the case
- specification of objectives
- development of alternatives
- assessment of benefits, costs and consequences
- evaluation (ranking of alternatives) and selection of the best solution
- presentation and communication together with important feedback of information concerning disturbances, near misses and accidents to the decision makers to improve the planning process.

The methodology is aiming at supporting the end user in the formulation of possible solutions to the land use problem at hand. The procedure includes a straightforward centre line and the possibilities for creating loops between all steps. The decision making process is evoked by many stimuli, originating both inside and outside the organisation. The process is not linear but more circular. By cycling within one step or between two steps, the decision maker gradually acquires a better understanding of a complex issue. The objectives to be used in the decision process will often be identified by a more in-depth analysis leading to the determination of the evaluation objectives. A proposal for subdivision of objectives is presented. The development of alternatives is important and the following questions should be clarified:

- will it be convenient to distinguish between basic alternatives and variations?
- how many alternatives/variations can be handled?
- will it be possible to help the users to assess to which degree the developed alternatives cover the possible solutions to the land-use-planning problem?

The preparation of alternatives can be seen as a complex, iterative process, where the decision maker begins with a vague image of some ideal solutions. For each alternative - in order to make them comparable - the benefits, costs and consequences shall be assessed and therefore it is necessary to keep the number of alternatives and variations at an operational level.

We have found that the user needs could be grouped in the following areas:

Risk identification

- inventory of hazards and objects at risk

Risk analysis

- questions regarding health and safety in surroundings
- analysis of zero-alternative
- rough analysis methods
- knowledge bank with failures and incidents in chemical sites. Mostly qualitative
- methods and tools for analysing health and safety.

Risk evaluation (a multi criteria perspective)

- introducing and evaluating safety zones
- checklists
- methods and tools for health and safety assessment.

Visualisation

- risk maps with sources and objects
- visualisation of installations, consequences, different alternatives etc.
- integrating data from several sources in GIS (population, environment, rescue services)
- defence against objections and later appeals brought to court. (Documentation. Consistent evaluation of relevant aspects at one level.)
- consequences of a choice, outside one's own region

Risk communication

- public hearings
- citizens as a knowledge bank.

Education and training

The need for education and training, especially on multi criteria analysis and development of alternatives were stressed. The education issues mostly have a universal relation to the overall structure of the decision process in land-use planning and do not relate strictly to particular steps in the planning process.

5 Indices to be used in a Multicriteria Decision Analysis approach

5.1 Introduction

Land Use Planning around hazardous installations originates from the fact that certain industrial facilities are able under certain circumstances to cause major accidents with consequences extending outside the borders of the establishment and to harm this way humans 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.

These differences are more accentuated if one considers the criteria and indices on which the decision making process can be based. Indicatively one refers to the domains that may be influenced by such a decision like the human health and prosperity, the economy, the environment, the touristic and historical value of a region etc.
This chapter refers an overview of possible indices which could be used in the decision making procedure of LUPACS is done, with emphasis to the environmental ones.

5.2 Classes of Indices regarding LUPACS

The classes of indices that could be used in a LUPACS approach are given below:

2.1 Human health, individual risk
2.2 Environmental Criteria

2.3 Technical-economic criteria

2.4 Socio-cultural criteria

2.4.1 Property value impacts
2.4.2 Income generated, gross and net
2.4.3 Local economic impacts (employment, income)
2.4.4 Short-term socioeconomic effects
2.4.5 Long-term socioeconomic effects
2.4.6 Population at risk
2.4.7 Perceived risk
2.4.8 Social acceptability
2.4.9 Public opposition
2.4.10 Socioeconomic effects at plant site
2.4.11 Fairness

5.3 Conclusions drawn from the survey

- The first class of criteria (individual risk) is adequately well defined and quantifiable.
- Among the environmental criteria two broad categories can be distinguished: a) the *explicit* ones (like geology, topography, hydrology, climate etc.) and b) the *implicit* ones (like the magnitude and intensity of the activity the nature and volume of wastes produced etc.). Unless they are used as inclusion /exclusion criteria, all of them suffer from the point of view of quantification so as to be used directly in a Multi Criteria Decision Analysis Methodology. Additionally, sometimes they seem irrelevant as far as LUP is concerned.
- Technical - Economic criteria can be incorporated in the socio-cultural criteria as the former refer to the satisfaction of basic engineering requirements considered as "internal" to the operation of the facility.
- Among Socio-cultural criteria there are some that can be quantifiable (like property value, income generated, population at risk etc.) and other that are qualitative (like social acceptability, public opposition, fairness etc.). These latter cannot be used directly in a Multi Criteria Decision Analysis Methodology.
- There are some examples of quantified environmental indices used in impact analysis of surface water (VERIS-2) which , however, are of limited use.

References: [x],[xi],[xii],[xiii],[xiv]

6 Methodology Report

6.1 Introduction

Improvement of plant safety can result in both reducing the likelihood of accidents and the consequences of an accident. Reduction of offsite accident consequences can be also achieved by controlling the uses of land in the vicinity of major hazard facilities to reduce the number of exposed individuals. Furthermore, offsite consequences may be reduced by appropriate choice of the location of the installation if such a question is being addressed for a new installation. Finally a combination of both these approaches may be used. The objective of the proposed methodology is to support relevant land-use planning decisions when risk is a consideration.

6.2 Methodology Step 1, Generation of alternatives

Determination of the available alternative courses of action from which one must be chosen constitutes the first step in the MCDA paradigm. In the land use planning context alternative uses of land around a hazardous site constitute alternative courses of action and hence alternatives in the sense of the MCDA paradigm. On the other hand the use of land around a site could be given and fixed and the alternative causes of action could consist in the location of a new installation or an extension of an existing installation. In both these cases, however, the changes in the sources of risk must have a geographical dimension in order to be characterized as a land use planning alternative. As a result, one might have either only a few alternatives to choose from or a lot. The developed methodology can handle either case but is more useful when there is a great number of alternatives to choose from.

The fundamental concept of the proposed methodology is that the area under consideration is divided into a number of smaller parts called **cells.**

Next a number of alternative **land development types** (LDT) are defined for each and every cell.

A Land Use Pattern has been defined over the area of concern whenever the LDT for each and every cell in the area has been determined. A Land Use Pattern represents an alternative course of action and the number of possible Land Use Patterns represents the number of alternatives to choose from. This latter number depends on two quantities: Firstly on the number of cells comprising the area of concern, and Secondly on the number of alternative LDTs available for each cell.

The number of cells of an area depends on the shape and the dimensions of each cell. Any shape and dimension is acceptable by the methodology and the particularities of each cell are to be determined by the governing concerns of the land-use planners. Nevertheless, the developed methodology has considered the following types of cells:

(1). Orthogonal Cells of User Defined Dimensions

This was actually an approach employed in earlier attempts to develop the methodology and it has been preserved for the shake of completeness.

(2). Ring Shaped Cells of Specified Dimensions

This approach is equivalent to the *'safety zoning'* concept, where *'zones'* around a hazardous installation are defined in terms of distances.

(3). Iso-risk Cells of Any Shape

Cells are defined as areas characterized by the same level of individual risk or by a level of individual risk within a certain range.

(4). General Cells of Any Type

Any type of shape and size of cells where these characteristics are determined by other land-use planning (e.g. existing development patterns), or geographical considerations.

The second element in the generation of alternatives is the land-development types available for each cell. The methodology accepts in general alternative LDTs that may be different for each cell. Of course similar alternative LDTs for every cell are possible. A fundamental property that an alternative course of action must have in order to be meaningful in a decision analysis context is that it must differentiate itself in terms of the expected consequences from other alternatives. For this reason the LDT ought to be defined in terms of characteristics that change the consequences that are part of the problem. For this reason an alternative approach to the problem set up and to the methodology would be to first define the consequences against which the alternative courses of action are to be evaluated. In any event the two stages of the methodology i.e. generation of alternatives and consequence assessment are interrelated and interactive in nature, so that they ought to be meaningful in the context of risk informed land use planning. For example, two different building development types having different economic value but resulting in the same population density although of interest from a number of reasons (e.g. employment) are not of interest in the context of problem set-up if the set of consequences does not distinguish among various economic consequences. If only a comprehensive overall economic consequence is considered the LDT with the best performance will always be better from the other since they will be equivalent from the risk point view (owing to the same population density). Since the developed methodology was mainly focused on the risk aspects of the problem, the LDTs considered and developed were those that differentiate the risk-related consequences. An example of LDTs developed for and used in one of the case studies of the project is given in Table 2 below.

The cells are divided into three general categories:

(i). Cells that can not be changed in terms of their present use.
(ii). Cells that presently are not used for residence.
(iii). Cells that presently are used for residence.

Cells of category (i) are not part of the problem and are excluded from further consideration. Cells in category (ii) are amenable to any of the following four types of LDT. (See table 1)

Similarly, cells of category (iii) are amenable to any of the four types of LDT in table 2 (1,2,3,4,5). with the following remark. The change from residential use to a non-residential one should include compensation to the present residents. This is reflected in table 2 where LDT5 is used to indicate the value of a presently residential use when converted to something else.

Another aspect of the alternating course of actions is that they refer to the eventual steady-state conditions.

This means that if a particular LDT is chosen for a cell this represents the final state of development. Present populations density might be lower but whatever density is implied by the LDT chosen at the end might be achieved sometime in the future.

Table 1

1.	'Protected Land'	Every thing remains as is, no further development is allowed
2.	'Agricultural Use'	Only agricultural activity is allowed in the area
3.	'Residential Use'	This use implies a particular population density and a specific economic value as shown in Table 2
4.	'Industrial Use'	This use implies a different type of building and economic activity resulting in the economic and population characteristics shown in Table 2

Table 2 Land Development Types.

Land Development Types - Associated Parameters		
Land Development Type	Economic Benefit	Population density
LDT1Protected	0.5 monetary units/cell	0.5 persons/cell
LDT2Agricultural	1.0 monetary units/cell	1.2 persons/cell
LDT3Residential	13.32monetary units/cell	40 persons/cell
LDT4Industrial	10 monetary units/cell	30 persons/cell
LDT5Existing residential Relocation possible with compensation	26.64 monetary units/cell	40 persons/cell

6.3 LUPACS problem set-up

Solving a land-use planning (LUP) problem requires that the latter is structured in a suitable way. The LUPACS methodology is intended to support the user in structuring the land-use situation and specifying the objectives to ensure that the selected objectives cover the relevant elements of the decision process in order to achieve community goals. The LUPACS methodology is also intended to support the user in the development of possible alternative solutions to the land-use problem, and by comparing different alternatives to identify areas of compatible and conflicting land-use and consequently assess the patterns of conflicting land-use interests. The decision making procedure includes a straight-forward line, while there exist the possibilities for creating loops between its constituent steps, namely: a) The formulation of the decision situation, b) The description of the case, c) The specification of objectives, d) The development of alternatives, e) The assessment of benefits, costs and consequences, f) The evaluation and choice, and g) The presentation and communication of the decision.

More precisely, the LUPACS methodology presented in this report is concerned with the land development patterns around a major hazard facility and is related to a number of concepts. If a number of candidate land development types for the various parcels of land around a site are available, the problem consists in choosing the one that satisfies the goals and aspirations of the decision makers. There are several Objectives potentially applicable in the LU Planning problem and actually used, like:

Economic
Public Health
Environment
Scenery
Cultural History

A formal approach to the determination of the evaluation criteria for these objectives starts with a very general position/objective that the decision to be made is trying to satisfy. This objective is then decomposed into a number of sub-objectives all contributing to the satisfaction of the general objective. Each sub-objective is further subdivided into simpler sub-objectives so that a *hierarchy* of objectives is developed where the objectives in one level are serving the more general objectives of the immediately higher level and are themselves served by the objectives of the lower level.

In general, two broad classes of goals are used:

- maximize net land development benefits
- minimize various categories of costs (public health, environmental, economic).

Land use planning in the presence of major hazard facilities is thus set as a problem of "multicriteria decision analysis" (MCDA). An MCDA problem is one in which a choice of one alternative ought to be made out of a number (small or very large) of given alternatives where each alternative is evaluated in more than one criteria. The classical approach to these kind of problems can be distinguished in four steps: (Keeney and Raiffa[xv])

Determination of alternatives
Determination of consequences (which serve as decision criteria)
Preference Assessment
Determination of "best" alternative

The first two steps are common in MCDA problems regardless of the specific methodology followed in the last two. The specific form of these steps in the land use planning context is next discussed.

6.4 Methodology Step 2, Determination of Consequences

This step of the methodology consists in the development of the set of attributes that are used to evaluate each alternative course of action. As mentioned in the previous step of alternative-generation these two steps are in practice interactive and iterative in sequence. First a hierarchy of objectives is developed. The hierarchy is such that elements at each level represent subobjectives serving the satisfaction of the objectives of the immediate level above. The development of the hierarchy stops when each and every objective at the lowest level of development can be quantified by a scalar quantity. Since the project was mainly focused on the risk aspects of the problem the set of the objectives developed has been detailed in the risk area and more general in other areas of concern. An example of the objectives and associated criteria or attributes is the following:

Objectives	Attributes
Reduce the number of fatalities in the general population (resulting from an accident)	Potential Loss of Life (PLL) (=expected number of deaths)
Reduce the number of fatalities in sensitive segments of the population (resulting from an accident)	Potential Loss of Life in sensitive segments (PLLS)
Reduce the number of injuries (resulting from an accident)	Expected number of Injuries
Reduce the level of risk at which population is exposed	Number of People exposed to a certain level of individual risk
Reduce the level of noise at which population is exposed	Number of People exposed to a certain noise level (in dBs)
Increase the overall Socio-economic well being of the population	Total Socio-economic Benefit

Consequences, that is the value of each attribute for each alternative course of action can be calculated as follows:
Health and environmental type of consequences are based on two types of information. First the intensity of the potential impact from a major accident in the chemical facility(ies) in the area is necessary. Thus, for health impacts measured in terms of loss of life the individual risk profile is needed. This profile gives for each point in the area of interest, the probability that an individual of the general population will die as a result of an accident in the chemical facility. Similar profiles for risk of death for sensitive individuals or for risk of injury are necessary for the corresponding attributes. For environmental impacts other types of profiles as concentration of a particular substance at each point of the area of interest is necessary. Such profiles are obtained from detailed quantitative risk analysis.

Second, necessary element for attribute evaluation is the population profile exposed to the various types of health risk or environmental impacts.

If the location of the sources of hazards are given and invariable for the problem at hand then the risk profiles and the environmental impact profiles are given and fixed for each and every alternative course of action. What changes in this case with each alternative is the population profile exposed to each type of risk. If the location of the hazardous sources are varying as part of the alternative courses of action and the land use patterns are fixed then the population profiles are also fixed, while the risk profile ought to be recalculated with each alternative. Finally, both risk profiles, as well as, population profiles are possible to vary with each alternative.

In the general case the risk analysis results in a probability density function over the possible range of populations at risk. In this project only some special cases of this general case are considered, namely cases when summary measures of the existing uncertainty are sufficient to express preference attitudes of the decision maker, as explained in the following sections.

6.5 Methodology Step 3, Generation of the Efficient Frontier

Classical MCDA approaches, after the determination of alternatives and the evaluation of each alternative on the set of attributes, involve two final steps: the assessment of preferences by the decision-maker; and the choice of the most preferred alternative. This in general comprises the assessment of a value function and/or of a utility function quantifying preferences among certain and uncertain alternatives, respectively. A prescriptive procedure for assessing multiattribute value and utility functions can be found in reference xiv. This approach, however, is not very practical or useful in a policy context where these decisions are negotiated among a number of policy actors. As a result the LUPACS methodology has adopted a different approach. Corner stone of this approach is the fact that value tradeoffs among highly debated issues, as for example, economic benefits and public health consequences are not formally set. Such tradeoffs are unavoidable and are always made implicitly or explicitly when the final decision is made. The LUPACS methodology, however, aims not at making such a decision but rather at facilitating or creating a platform to facilitate the final choice by the appropriate people at the appropriate fora. In order to achieve this the LUPACS approach uses the concept of dominance.

An alternative I is said to dominate another II, if I is either better or equivalent in each and every attribute of evaluation and strictly better in at least one attribute. Comparisons in one dimension (one attribute) are rather easy since they do not involve value tradeoffs. So if an alternative results in 40 deaths and 10^6 monetary units of benefit, it is definitely more preferred to one that results in 50 deaths and the same economic benefit. An alternative is called dominant or efficient if there is no other alternative in the feasible set that dominates it. The set of all efficient alternatives constitutes the efficient set or the efficient frontier. The efficient set is usually a small subset of the original set of all possible alternatives. Determination of the efficient frontier for continuous decision variables is achieved with the help of techniques of multiobjective optimization. In the LUPACS approach both the decision space and the consequence space are discrete. A particular mathematical algorithm is adopted that allows for the fast determination of the efficient alternatives out of the very large number of alternatives. This algorithm has been developed before and outside of the LUPACS project and it is valid in the following two cases:

1. When expected values are sufficient to characterize attitudes towards uncertainty in each attribute (one-dimensional risk neutrality).
2. When risk aversion or risk Proneness in each dimension (attribute) can be characterized by an exponential function.

Details about the generation of the efficient frontier and the various special cases covered in the LUPACS project are given in the detailed final report on the methodology, ref.xvi.

6.6 Decision support system using the efficient frontier

Direct Use of the efficient frontier

The efficient set is usually a small subset of the original set of all possible alternatives. Further choice among the alternatives requires a preference assessment. In several instances, however, knowledge of the efficient frontier limits the practical alternatives to such a degree that the choice of the most preferred alternative is greatly facilitated.

The LUPACS approach advertises the "efficient frontier" as a useful tool since it provides a platform that can facilitate the discussion between the various stakeholders. In particular the proposed approach can remove from the debate a large number of "what if" questions since it can explore a very large number of alternative solutions and keep only those that can not be rejected on "technical" or "scientific" arguments. Perusal of the efficient frontier can then narrow the discussion to potential solutions in a specific narrow range of it where the actual choice might also include "sub-optimal" solutions that include other intangible considerations not included in the quantified analysis.

For example, it can be argued and easily accepted by the various stakeholders that solution (F) would be more preferable than solution (A) (see Fig. 1) since it implies a substantial decrease in PLL while the corresponding decrease in benefit might be judged as not equally significant. Furthermore, it could be argued that F is more preferred to G since the latter solution implies a large decrease in benefit with marginal decrease in PLL. The whole discussion can be concentrated on whether the gains in PLL from the level implied by point A to the level implied by point F justifies the corresponding reduction of benefits. If the answer is affirmative and if, furthermore, further gain in PLL from F to G is judged marginal, then any solution around point F might represent an acceptable solution.

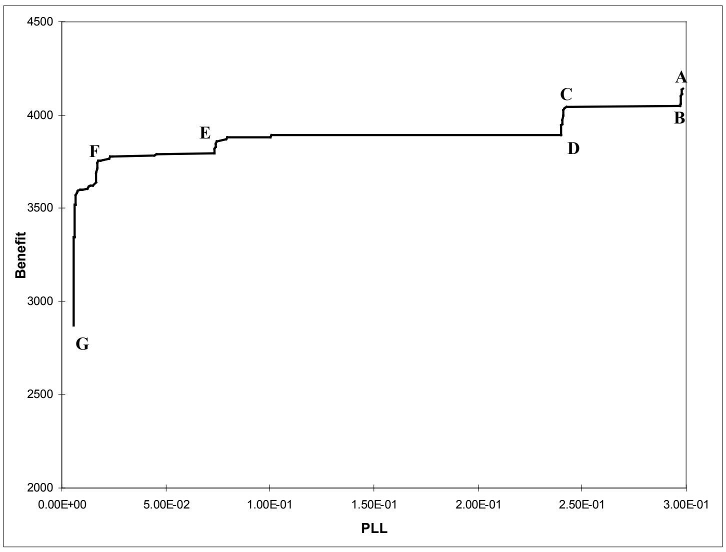


Figure 1. Efficient frontier in case #1 (below)

The concept of efficient frontier can be used also to support decisions about alternative expansion or location for hazardous facilities. Each potential expansion alternative is associated with an efficient frontier representing the available land development patterns in the general area of the installation. Then a superposition of all efficient frontiers reveals in the overall efficient frontier which may contain points(non-dominated solutions) of all the others.

Other methods using less direct approaches can also be adopted by the LUPACS approach. One such method wille be summarised here - the reference point methodology – another method uses iso-preference lines (reference xii).

Use of the Reference Point

In order to provide additional help to the Decision Maker in selecting the most-preferred solution and to stimulate/facilitate meaningful discussions on the problem, the Reference Point method was implemented. This is one of the most commonly used methods for forming an order of preferability between non-dominated alternatives[xvi]. It is based on the conceptual and mathematical model of the decision-maker's levels of aspiration. It is therefore an interactive model, normally used in problems where the number of the alternatives involved is very large, in which the decision-maker can progressively identify different preferences until he manages to obtain a solution that he considers satisfactory. It differs from the value maximization framework, rather following a learning oriented perspective.

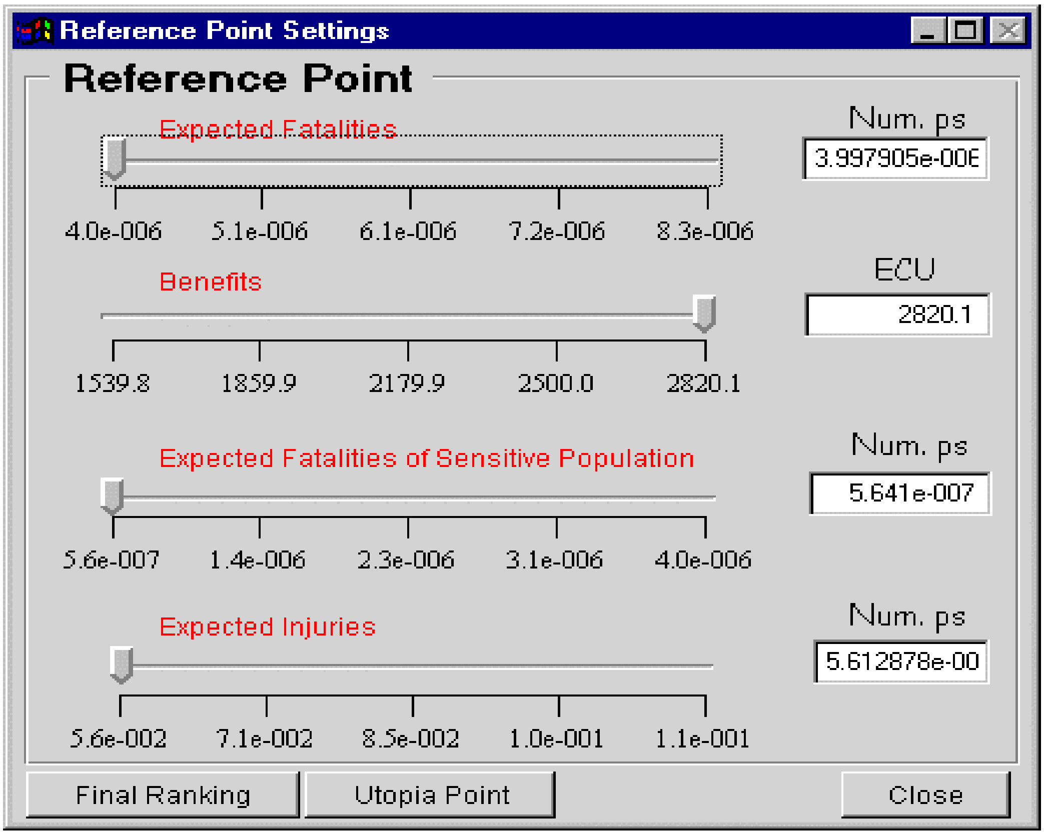


Figure 2 Ranking according to Utopia Point - 4 criteria

This method consists in identifying a point in the criteria space expressing the decision-maker's aspirations: this point is conventionally called the 'reference point'. Within this approach, in fact, the decision-maker is iteratively asked to specify this reference point. Once this point in the criteria space is chosen, a function can be found to express the deviation with respect to the reference point for each of the alternatives of possible actions. The deviation function measures how severely an alternative deviates from the target, i.e. from the reference point. So the idea of the reference point is that we search through the set of feasible alternatives looking for the one which deviates least seriously from the target. In general, the deviation function applied is the so-called p-norm function, where p = 1 for Canonic metric, p = 2 for Euclidean metric, and p = 3 for Tchebychev metric.

Since the method is based on the calculation of the distance between alternatives, the concept of distance must be meaningful in all criteria. Given that the various criteria taken into account in evaluating the alternatives are measured in different units, the evaluation matrix needs to be normalised. The method used here is based on normalisation of the raw score to the total range for each criterion.

For the implementation of the above method in LUPACS and in order to demonstrate its application, a computer tool was developed. The aim of this tool is to show the application of this particular MCDA module to the specific class of problems tackled in LUPACS. The tool receives as input the set of non-dominated alternatives, possible constraints in the criteria space, and the values of the Reference Point defined by the Decision Maker. It gives a complete ranking of the alternatives according to their distance from the Reference Point and provides a visualisation of these alternatives. Following, the Decision Maker can modify his aspiration levels changing the Reference Point and perform a new iteration.

Methodology report: see reference[xvii] Further references: [xviii], [xix], [xx], [xxi], [xxii]

7 Case #1, Statoil study, Denmark

7.1 Introduction

The Statoil refinery is situated south of the city of Kalundborg (see Fig. 3) about 2.5 km from the centre. The city has about 30.000 citizens. The refinery is located close to the coast with a relatively large harbour. The refinery is regulated after the Risk Directive and in 1991 submitted an application to the county concerning the establishment of a new process plant and storage facilities.
The decision process involved different actors:

- the municipality (officials and politicians)
- the county (officials and politicians)
- Danish Emergency Management Agency: approval according the emergency legislation and on the extent of safety zones,
- Working Environment Service and the local office: adviser on safety level, safety zones, approval of safety levels
- the company staff
- during the planning period two public hearings were arranged with invitations to the public and non government organisations to comment on the draft approval of the expansion
- experts working as private consultants for the refinery were involved with the preparation of the safety report submitted in 1989.

7.2 The Land Use Planning Problem

Taking into consideration the alternatives and with the assumption that the expansion has not been decided yet, the following alternatives have been considered taking into consideration the risk induced by the operation of this new expansion versus the benefits all over.

1. No expansion within Vestsjællands Amt (Zero option or basis), code B
2. Expansion at the Kalundborg site. This alternative has 4 variants:
    - South of refinery (north of Asnæs Skovvej) code K1
    - East of refinery, K2
    - West of refinery, K3
    - South of Asnæs Skovvej, K4
3. New refinery unit at Stigsnæs, code S.

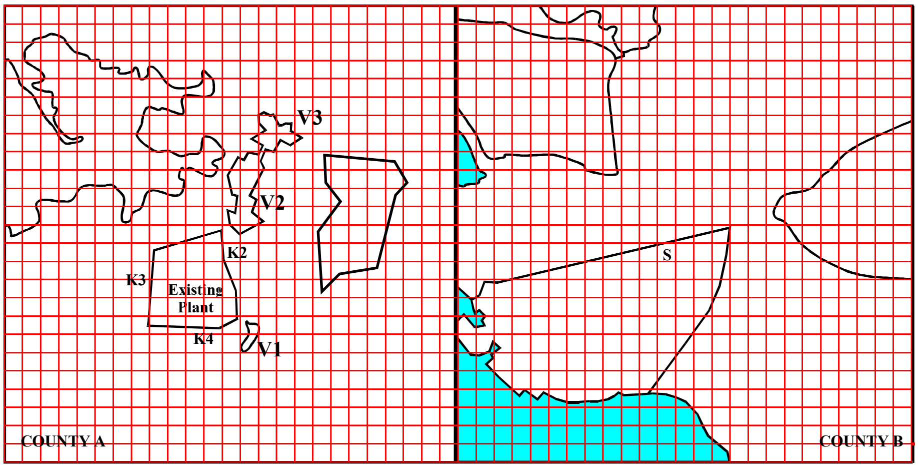


Figure 3. General area around the existing oil refinery in Kalundborg, possible extensions around the existing site as well as in Stigsnæs and division of both areas into cells

7.3 Conclusion drawn from the application of the Multicriteria Analysis Methodology

In preparing the input, the following *objective*-related aspects have been selected: a) Determination of individual risk (IR) contours, in order to determine potential loss of life (PLL) by combining IR with population densities, b) Determination of noise contours, in order to determine the number of people affected by too high noise levels and c) Determination of the economic benefit of both land use pattern and plant extension in terms of capital gain (*net present value*).

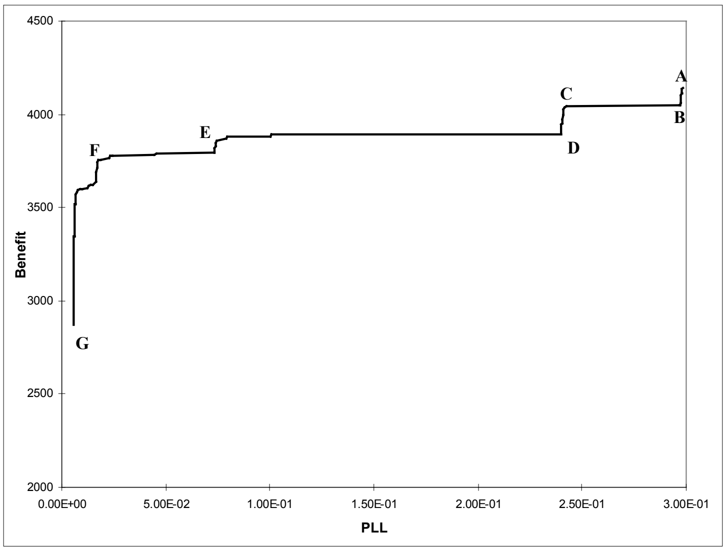


Figure 4 Efficient frontier for expansion for Alternative K2

The results of the analysis according to the MCDA methodology are the following: Each potential expansion alternative is associated with an efficient frontier representing the available land development patterns in the general area of the installation. The efficient frontier for expansion alternative K2, for example, is given in

Figure 4 . Following the constraints set forth by the planning team only solutions implying reduction of population have been considered. Point A in the efficient frontier represents the existing situation and corresponds to the solution with maximum benefit and maximum PLL. The LDP corresponding to point A is shown in Figure 5. An alternative land development pattern is the one corresponding to point F of the efficient frontier and shown in Figure 6. Moving from A to F means creating a zone north and east of the existing plant where agricultural use of land is foreseen instead of the heavy industrial use along with relocation of village V1 and half of village V2. Intermediate points represent other possibilities as point C where only the relocation described before is effected, and point E, which is similar to F but without the relocation. Further restrictions in the uses of land lead to point G corresponding to the solution with absolute minimum PLL and EB (Fig. 4).
The efficient frontier can form the basis for a discussion on the available alternatives without formally establishing value tradeoffs.

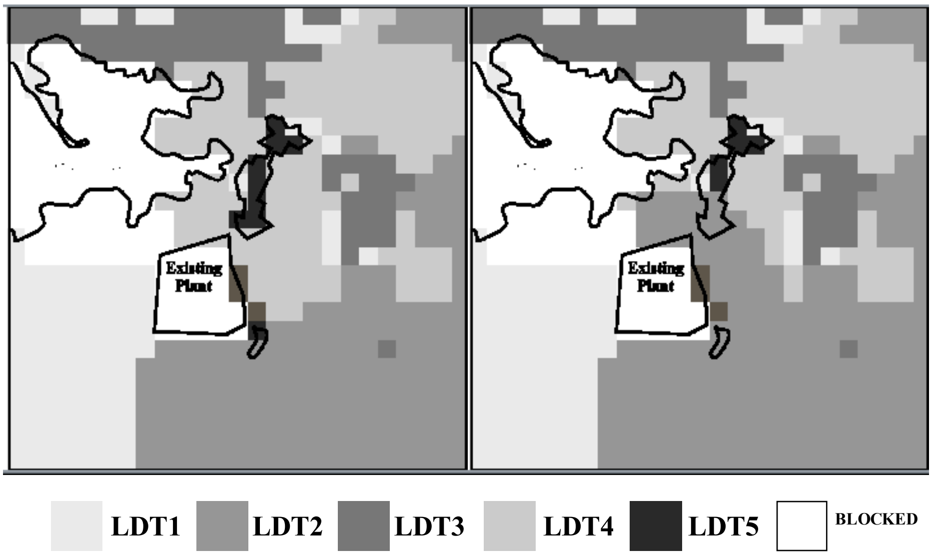


Figure 5 LDP corresponding to point A   Figure 6 LDP corresponding to point F

This case has been reported in [xxiii] and [xxiv]

8 Case #2, first Swedish case study

8.1 Introduction

The installation was first established approximately 200 years ago and has been revamped several times since then. The plant is situated close to a lake and to two communities (about 8 km north of the one with 8000 inhabitants). It occupies an industrial area of 49 ha (see Figure 7) and owns a number of support facilities.
In 1976 the company wanted to acquire more land for expansion of the plant (area 1 + 2, see Figure 7). A new Development Plan had to be made as no land use planning had been done earlier regarding the area of the plant. The local and regional authorities agreed on a suggested plan north of the existing plant which could allow the company to expand and to build new roads both to the west and to the north of the industry. In parallel to the company´s wish to expand its production in 1975-76, the community was also discussing the idea to build 110 semi-detached houses for the employees on land owned by the company.

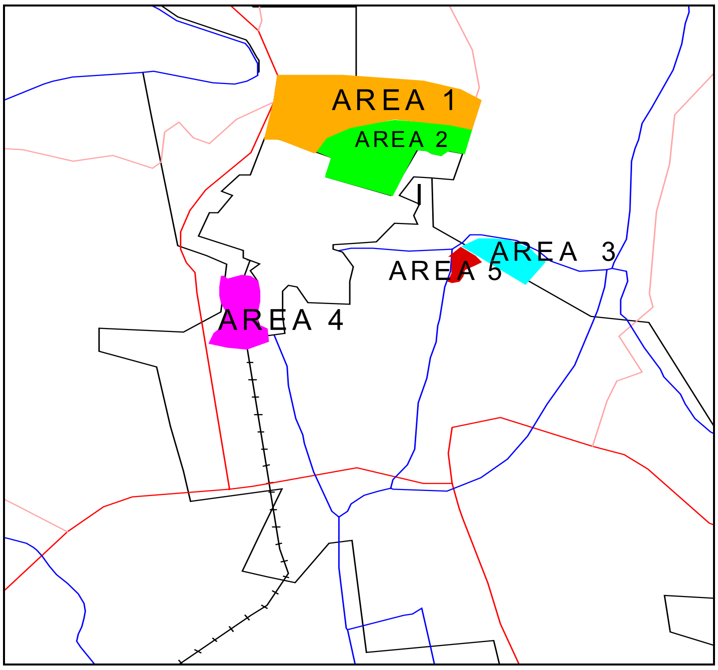


Figure 7 General view of the installation and surroundings

8.2 The Land Use Planning Problem

These general concerns and social conflicts have been formulated in a MCDA problem setting, resulting in the following alternatives (see Figure 7):

1. Build 25-30 houses in Area 1.
2. Expand the plant in Area 2.
3. Build 20-30 houses in Area 3.
4. Build 30-50 houses in Area 4.
5. Add 250 children to school in Area 5, or remove school from Area 5.

8.3 Conclusion drawn from the application of the Multicriteria Analysis Methodology

The criteria used for this analysis were :
Potential Loss of Life, calculated using the mean individual risk in each area and the population for each alternative in each area.
Net Economic benefit, calculated as the value of land of each area, using the data provided by the case study providers, while the *objectives* were formulated as follows: a)Minimise the potential loss of life, and b)Maximise the economic benefit.

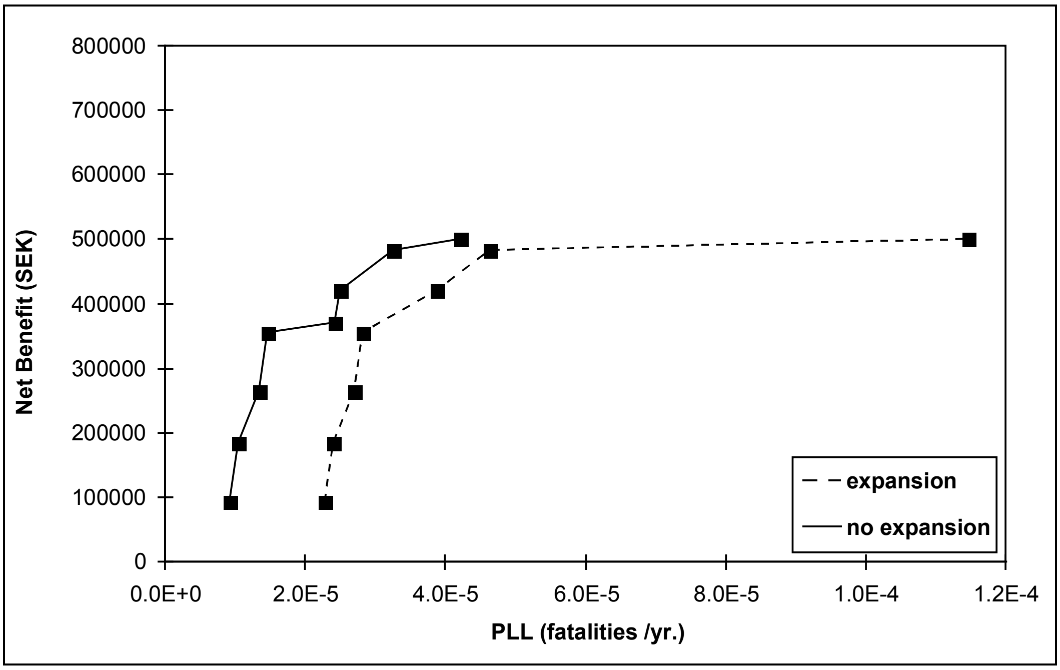


Figure 8 The two efficient frontiers assuming that the value of the plant expansion in Area 2 is 0

Each combination of the LDTs of the Areas under study creates a Land development Pattern (LDP). Two efficient frontiers were generated, one for each alternative in Area 2 (expansion - no expansion). Observation of the two efficient frontiers can be helpful in determining the decision taken for different values of the expansion plant benefit. The efficient frontiers generated for three different values of the expansion benefit are shown in Figures 8 to 10.

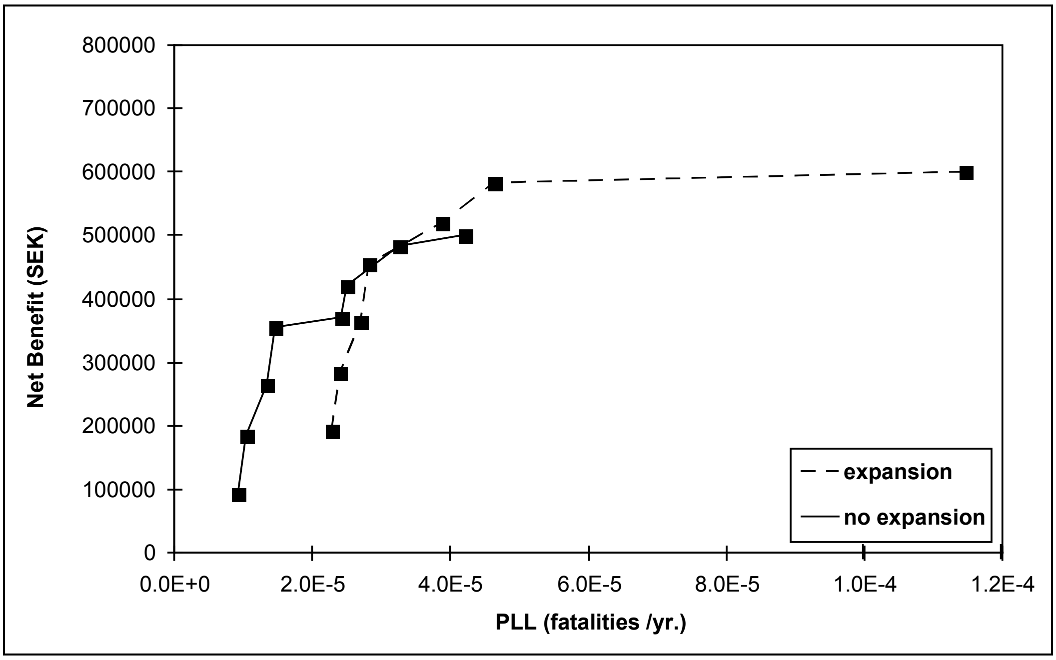


Figure 9. The two efficient frontiers assuming that the value of the plant expansion in Area 2 is 100,000 MONETARY UNITS

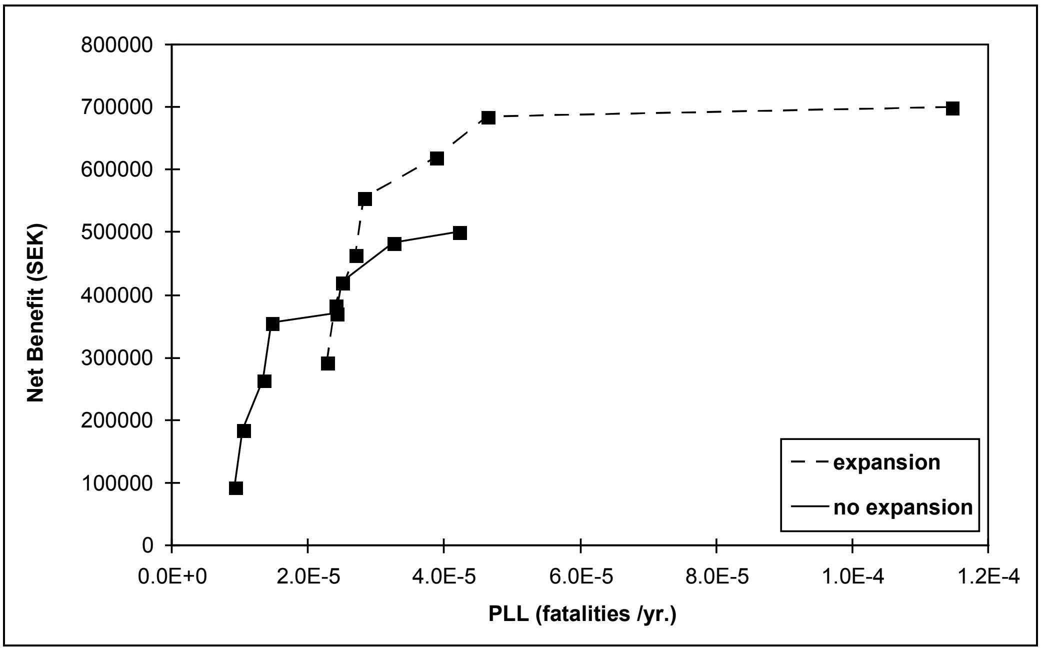


Figure 10. The two efficient frontiers assuming that the value of the plant expansion in Area 2 is 200,000 MONETARY UNITS

9 Case # 3, Kemira study, Sweden

The 3^{rd} case analysed in the LUPACS framework is the case of Kemira in Helsingborg. The case concerns the proximity of a chemical site to both industrial and residential area, and the future plans of the company to extend its activities with production/storage of new products and of the local community with developments in the vicinity of the plant and expansion of the residential area towards an attractive resort. The operation of a railway station connected with a marshalling yard handling dangerous goods during their transportation further complicates the analysis. A detailed description of the case is given in References [xxv] and [xxvi]

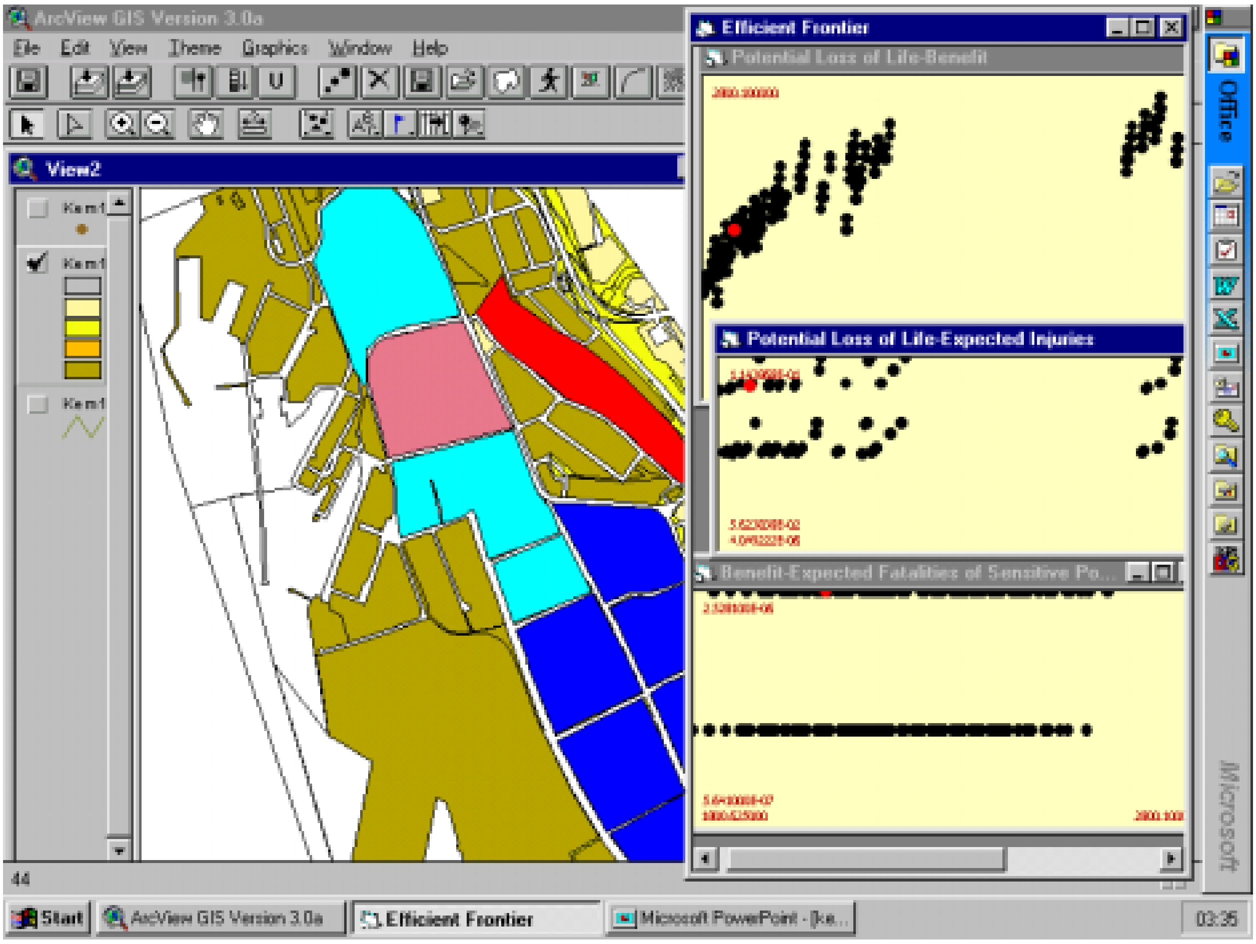


Figure 11. Efficient frontier – 4 criteria: Example of Land Use Pattern

From the methodological point of view, the following issues are of great interest and provide insights in the Land Use Planning (LUP) problem:

- Existence of a source of risk outside the establishment (marshalling yard)
- Division of the area of concern into arbitrary-shaped cells, respecting the physical borders and the morphology of the area
- Use of four criteria, introducing considerations on the number of injuries and on the casualties among the sensitive population
- Application of the Reference Point method for the exploration of the efficient frontier and for selecting the most-preferred solution. Figure 11. Efficient frontier – 4 criteria: Example of Land Use Pattern

The first phase of the analysis concerns description/familiarisation with the problem and preparation of the necessary input, including the calculation of risk profiles. A number of sources of risk were identified and analysed in terms of accident scenarios, respective frequencies of occurrence and consequences. Especially the estimation of accident frequencies was based on the experience from similar installations and events and not on a detailed analysis of the safety systems of the particular installation, since such a task was out of scope of the project. On the contrary, assessment of the consequences was based on detailed calculations, taking the site's meteorological data into consideration. According to the calculations, performed for every point of the space around the establishment, the level of individual risk is below 10^{-6} for most of the populated area (except for the railway station next to marshalling yard), and can therefore be considered as acceptable – according to certain criteria – giving however rise to discussions about possible improvement of the safety situation (ALARA/ALARP principles). It was also clear that slight increase in the level of risk (e.g. due to an increase in the quantities of dangerous substances used) or expansion of the residential area could easily lead into an unacceptable situation.

Following the methodology developed in the LUPACS project, the problem was formulated as a Multicriteria Decision problem by determining *alternatives* and *criteria*. For the determination of *alternatives*, the area of concern was divided into 16 smaller regions/cells. These cells are of arbitrary shape, respecting the physical borders and the morphology of the area. Then, a number of alternative Land Development Types (LDTs) were determined, based on the classification of the National Real Estate Assessment. More specifically, the LDTs considered are:
1 - undeveloped (e.g. agricultural area, forestry, etc.)
2 - industrial
3 - residential / small buildings (i.e. 1 or 2 dwelling buildings, low population density, commercial activities/services included)
4 - residential / large buildings (i.e. apartment houses, increased population density)
5 - residential (small buildings), NOT permitting buildings hosting sensitive population (such as school-children, elderly, etc.)
6 - dense residential (large buildings), NOT permitting buildings hosting sensitive population (such as school-children, elderly, etc.)
7 - camping area
8 - railway station

In order to keep the description realistic, certain restrictions were set on the administration of LDT labels applied to the individual cells (i.e. not all the alternative LDTs described above are applicable for every cell). An alternative Land Use Pattern is determined by the combination of Land Development Types in all geographical cells. In other words, in order to determine an alternative Land Use Pattern, one has to determine the uses of land (LDT) in all geographical cells. Thus a Land Use Pattern would be:

> "Determine geographical areas 1, 2, 3, 4, 7, 8 and 10 as Residential areas (with low population density), area 5 as industrial, area 6 as undeveloped, areas 9, 11, 13 and 14 as dense residential (high population density), area 12 as Residential areas without sensitive population (Residential Restricted), area 15 as camping area and, finally, area 16 as the railway station".

The above definition of alternative LU Patterns (i.e. combinations) gives a total number of about 67 million alternatives from which the Decision Maker should choose the most-preferred one.

The set of objectives / criteria has to reflect the main concerns of the local community, which are related both to safety and to achievement of a high level of local development. In this case, 4 criteria were chosen:
1 - Total Potential Loss of Life (PLL - total expected number of fatalities in the whole area of concern)
2 - Total socioeconomic benefit from the exploitation of the land
3 - Total Expected Loss of Life for Sensitive Population (ELLSP – related to casualties between the schoolchildren). This criterion was directly related to the presence of schools and day-care centres in the area of concern.
4 - Total Expected Injuries (EI)

The *evaluation of alternatives*, that constitutes the next step of the methodology, requires the assessment of each alternative after the criteria adopted. This task requires risk data, population data and data related to the value of land/buildings (taken from the Real Estate Assessment) as input.

After formulating the case as a Multicriteria Decision problem, and preparing the necessary input, the LUPACS methodology was applied using the Land Use Planning Decision Support Tool developed by NCSR 'Demokritos'. For the sake of clarity, two different runs were performed: a first one employing only two criteria, namely, PLL and socioeconomic benefit, and a second run using all four criteria..

A detailed analysis and discussion of the findings and lessons learned from the case can be found in the relevant chapter of the Methodology Report ref. xvi as well as in reference [xxvii] . The run employing only two criteria resulted in 42 non-dominated solutions (LUPs). A careful examination identified a certain small area (expected fatalities ranging from 4.2×10^{-6} and 5.5×10^{-6}) where the "optimum" solution should be selected. Such a selection requires the formal assessment of the Decision Maker's preferences. However, many meaningful conclusions were drawn from this analysis, such as that the camping site can operate without problems, and that the marshalling yard should be relocated if we want to reduce expected fatalities below a certain level. It also proves that extensive use of Undeveloped LDT is not suggested, and that the LDT followed in cell 2 has a strong impact on the level of PLL and Benefit of the overall LU policy.

The application of the Reference Point method also gave interesting results. In order to get insights from the application of the methodology, various Reference Points were analysed, as follows:

- Utopia point: Minimum PLL, Maximum Benefit
- Reference point 1: A point on the diagonal, indicating that the decision maker is indifferent between the two criteria
- Reference point 2: A point on the left side of the diagonal, indicating that the decision maker prefers optimising PLL than Benefit.
- Reference point 3: A point on the left side of the diagonal and at the lower part of the PLL-Benefit diagram, indicating that the decision maker strongly prefers optimising PLL than Benefit.
- Reference point 4: A point on the right side of the diagonal, indicating that the decision maker prefers optimising Benefit than PLL.

The analysis showed that the most-preferred solution and the final ranking between the solutions depend on the location of the Reference Point in the criteria space (which, in turn, depends on trade-off between the criteria and the aspiration levels set by the decision maker) and the shape of the Efficient Frontier.

The complete application of the methodology using all four criteria resulted in 1154 solutions (LUPs). An example of the map of the area with the proposed Land Use Pattern is presented in Figure 11. Again, the Reference Point method was applied for ranking the solutions (see illustration in chapter 6.6 above) and various reference points values were investigated to take insights of the problem and the use of the method.

10 Case #4, ammonia pipeline study, Denmark

10.1 Formulation of the decision situation

In 1991 the chemical company Kemira Danmark A/S submitted an application to the county of Vejle concerning the establishment of an ammonia pipeline between the ammonia storage at Ny Nitrogen A/S in Lyngsodde and the company situated in Fredericia. At that time the ammonia storage was located at Kemira's plant close to the centre of the town and establishment of the pipeline would reduce the risks related to transport and storage of ammonia significantly.

The land-use planning situation can be characterised as a change in the technical configuration for transport, handling and storage of ammonia for production of fertilisers in a mostly urban environment where only minor changes of the land-use patterns near to the pipeline and the transferring equipment are possible.

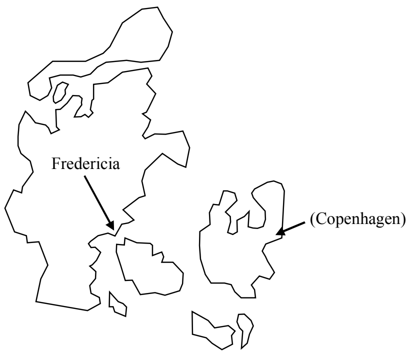


Figure 12. Location of the pipeline in Denmark.

The decision to allow the establishment of a pipeline was based on the Danish environmental protection law (chapter 5, § 33 part 1) including an assessment of the impact on the environment, property and human lives during normal operation and in case of an accident.

The decision process included the following actors:
- the municipality of Fredericia (officials and politicians)
- the county of Vejle (officials and politicians)
- the Emergency Management Department in Fredericia
- the Working Environment Service, county of Vejle
- the Police
- the company staff of Kemira and Ny Nitrogen
- the public and citizens, during the planning period one public hearing was arranged
- experts working as private consultants for the company were involved with the preparation of the safety reports submitted in 1992.

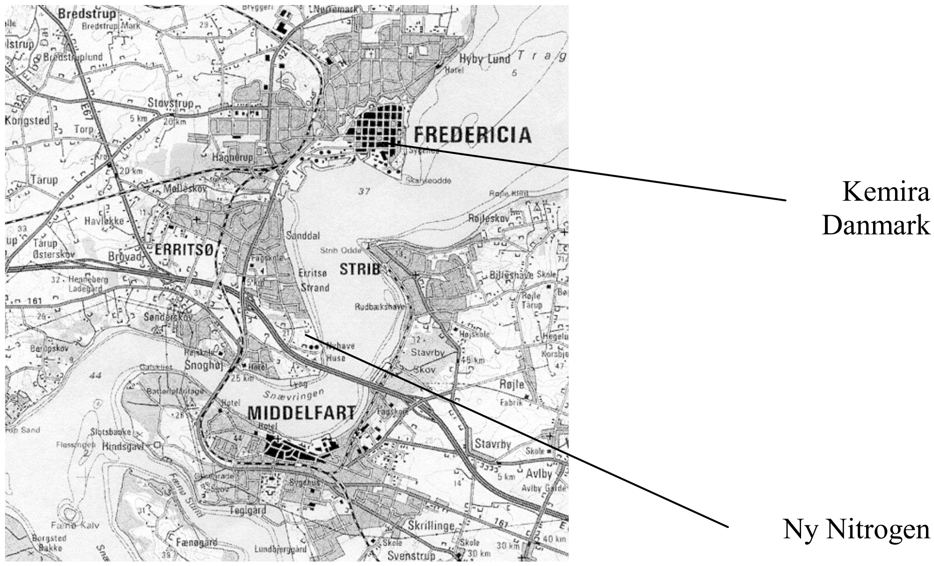


Figure 13. Location of Ny Nitrogen and Kemira Danmark.

10.2 Alternatives

Since 1975 investigations have been carried out for pipeline transport of ammonia from Lyngsodde to the fertiliser production plant - on-shore as well as off-shore.

The following solutions have been investigated:

1) The ”0”-alternative, i.e. status quo with the ammonia storage tank in the centre of the Fredericia and ammonia transport by ship from Ny Nitrogen A/S to Kemira Danmark A/S.

2) An on-shore buried pipeline where the largest part of the track is situated in a traffic corridor along the main road. Other installations are already placed here and no expropriation was needed.

3) An off-shore pipeline at shallow water following the beach from Lyngsodde to the marina close to Fredericia and from there to Kemira along the same track as the on-shore pipeline.

4) An off-shore buried pipeline at deep water. This solution was not chosen because it requires a very large burial depth of the pipeline due to drifting sand banks on the bottom of the sea.

5) An on-shore buried pipeline following the railway. This solution was also abandoned because of the risk for pipeline damage in case of accidents and events at the railway.

10.3 Lessons learned from the ammonia pipeline study

The ammonia pipeline case study has been enlarged considerably compared to the actual handling of the case and approval of the pipeline back in 1992, and alternatives and objectives have been invented for the LUPACS project.

One of the new elements in the ammonia pipeline case study compared to the refinery case study above was application of GIS tools in the decision making process.

The outcome of the ammonia case study was a clear demonstration of the large potential from introducing GIS to the land-use planning process. Full use of GIS is, however a very demanding process:

- Visualisation of relevant aspects in the decision making process: This includes issues relevant for many types of land use decision situations e.g.:
  - Φ public emergency institutions
  - Φ industries and other installations (pipelines, sewer systems, public supply systems etc)
  - Φ population density
  - Φ present land use
  - Φ ground water reservoirs
  - Φ recreational areas
  - Φ natural and cultural heritages.

- Visualisation of case specific aspects: This includes information of special interest for the location of the ammonia pipeline:
  - Φ alternatives for location of the ammonia pipeline
  - Φ alternatives for other ammonia transfer possibilities
  - Φ isorisk curves
  - Φ distances to exposed areas (residential areas, schools, nursing homes).

- Possibilities for linking to relevant data bases/documents/photographs: In the planning process it might be of interest to consider and include other kinds of information, e.g.:
  - Φ physical, chemical and health properties of chemicals
  - Φ meteorological factors (wind direction, atmospheric stability etc.)
  - Φ demographic information (time for public arrangement, e.g. open air con certs, sport matches)
  - Φ actual photographs of technical installations and surroundings.

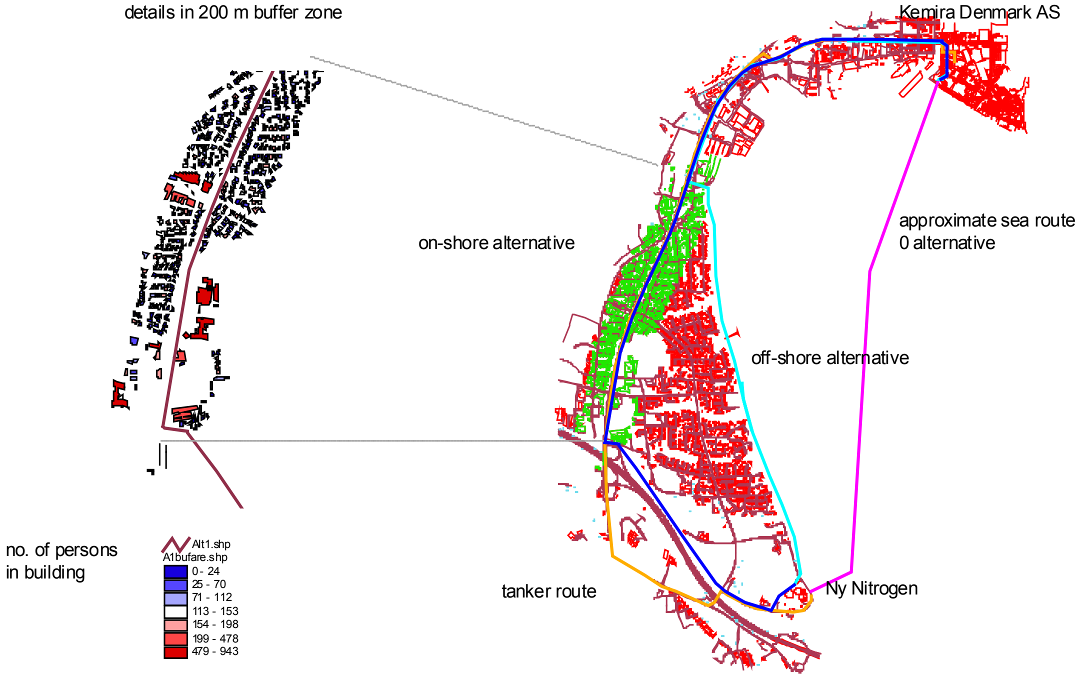
- Disadvatanges: For applying a GIS system one needs the infrastructure providing compatible and reliable digital data and maps to support the planner/decision maker
  - Φ such a infrastructure is not fully implemented in all countries
  - Φ using the system requires specific training.

Figure 14 presents the alternatives, which have been taken into account in the LUPACS discussions. The maps are partly imported and converted CAD drawings and have partly (the routing of the alternatives) been prepared with the GIS tool (Geographic Information System) directly. The overall map of Fredericia shows the location of the three alternatives and the likely road tanker route to be used in maintenance and repair situations. It is seen that the on and off-shore alternatives including the road transport have partly identical routing. The green marked area is a 200 m buffer zone to both sides of a part of the pipeline. Details for this are extracted from the overall database indicated by the "Layer " table and shown on the second map. The houses have been coloured by the number of persons living in or using on average a certain building according to the database information.

The table with the database information is shown just below the map. On the thematic map, red colour is used on buildings to indicating the highest number of persons per building. Further a table with statistics based on the data extracted for the buffer zone is shown. The shown data (prices and persons) are suggested values introduced to demonstrate the system. The areas representing the ground floor size in square meters of the buildings have been easily calculated by the GIS system using the map data. (See figure next page.)

This demonstrates the possibilities of a GIS system to find e.g. large buildings with many inhabitants or visitors. This could be schools, institutions and hospitals, which need special attention. In a similar manner, it is possible to identify objects that might be damaged from hazards at the pipeline causing domino effects. Also the opposite will be possible, namely to identify objects which might damage the pipeline in emergency situations.

The second Danish case study is reported in ref xxiii



groundfloor size m^2	ground price DKK	no. of persons
1	900	0
655	589500	109
268	241200	118
168	151200	2
40	36000	0
267	240300	39
4184	3765600	702
830	747000	183
166	149400	5
4636	4172400	339
284	255600	137

Layer
T_100_BYGNTAG
T_000_BYGVAERK
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Statistics on the details:

persons per building	no. of building	average ground size	average ground price
0	270	25.0000	22836.0000
1	19	136.0000	122211.0000
2	44	151.0000	136268.0000
3	28	141.0000	127093.0000
4	45	148.0000	133200.0000
5	43	151.0000	135921.0000
6	33	143.0000	128591.0000
7	48	149.0000	133650.0000
8	17	132.0000	118376.0000
20	1	352.0000	316800.0000
21	1	249.0000	224100.0000
22	2	252.0000	226350.0000
23	1	229.0000	206100.0000
24	2	465.0000	418500.0000
27	1	215.0000	193500.0000
28	1	206.0000	185400.0000
29	2	248.0000	223200.0000
30	3	314.0000	282300.0000
32	1	206.0000	185400.0000
33	1	286.0000	257400.0000

Figure 14. Structure and application of a GIS database.

11 Education

In the LUPACS project, LIP6 (Laboratoire d'Informatique de Paris 6) were in charge of the Education part. While the participants responsible for the development of LUPACS methodology were working on the objectives and methodology content, the LIP6 assisted their work, examining:

- how can one set the problem of enviromental multi-criteria decision, and
- what were, in other European regions, under the same circumstances, the methods used and what were their results.

In particular, we dedicated one part of our activity to the fact that for multi-criteria decision problems, none of the parties has the possibility to impose his viewpoint without considering the one of other parties.

We insisted on the fact that, to be effective, LUPACS methodology should not propose a "solution to the problem" but had to propose a set of data and knowledge that can be used as a basis to the negotiation for a solution suitable for all parties.

Consequently, it appears that LUPACS methodology would deal with these two aspects:

1 - formalisation and modelisation of the land use planning problem.

2 - determination (by calculus) of a primary solution that could be used as a basis for the seeking of a solution that suits all parties.

We then worked on the specificity of future users of the method and on the fact that explications given to them must corresponds to their functions, needs and educational background.

The set and details of the ideas we developed during the project can be found in the Education Report[xxviii] (which provides explications to future users of LUPACS methodology).

In this document we considered that even if intended users of the methodology will be municipality planners, it has to be taken into account that the majors of the cities are, despite everything, the most important persons in such situations.

Consequently, a "two levels explication" of LUPACS methodology was realised. A first level is aimed to majors and a second one to planners. This distinction is made according to the idea that each of them (majors and planners) have different objectives, obligations, knowledge, etc. and that they don't expect the same things from LUPACS methodology.

In the conclusion of the Education Report, we insisted again on the fact that in land use planning the best solution is not the one that fits completely the interests of one of the protagonist. A good solution is a solution based on negotiations among the parties and, therefore, suits the interests of all of them.

12 Resume

The issue investigated in this project has been development and application of decision support for land use planning, with emphasis laid on cases involving chemical complexes. At the outset, the decision was to be modelled as a Multi Criteria Decision Problem (Work Program, ref.1), but no particular tool or algorithm was prescribed, on the contrary, our first aim was to look through the state of the art. This produced two results with significant influence on the following work, namely 1) schematic reviews of European practices in the field, and 2) a flow model description of planning, picturing the Swedish land use planning process.

The survey revealed national differences in the "planning environment", i.e. where and by whom planning is worked out and decided. Differences in national practices for risk assessment with chemical complexes will be an essential condition, when prospects of using LUPACS like tools are to be judged.

It was specifically decided by the project team during a plenary meeting at JRC Ispra (16-18 april 1997, ref [xxix]) to perform the practical studies with a tool, developed by NCSR-Demokritos prior to the present project (Briassoulis et al 1994, ref.ix). This featured applying Multi Criteria Decision Analysis to land use planning and involved an associated computer decision support system, which could calculate and present efficient frontiers for different land uses (solutions) considering two parameters at the time, for instance risk vs. economic benefits. One of the first development steps was to construct a decision frame (Rasmussen et al 1999, ref.xxii), that unified the multi criteria decision structure with the flow characteristics emphasised by the Swedish process flow model. To conduct Multi Criteria Decisions one needs indices, that measure the fulfilment of the criteria used, a comprehensive set of criteria for land use planning was therefore set up and specific indices were sought[xxx]. While there is a choice of suitable indices for risk criteria, and some socio-cultural criteria can be handled quantitatively as well, many criteria for land use can not be represented directly through quantitative indices.

There has been a high priority on case studies in the project, with the purpose to try out the methodology and to get a direct insight in practical land use planning from the viewpoint of possible decision support. As the project team includes both scientists and experienced physical planners, these cases acquired a central role as "test sites" for decision and as representative images of real life planning. Four cases were provided by the planners in the project group: two cases in Sweden and two in Denmark, described in chapters 7-10 above. Two further cases were provided in Greece, descriptions can be found in the Methodology Report, ref. xvi. The Multi Criteria Decision frame was applied in all cases, but efficient frontiers were not produced in the Danish ammonia pipeline case, mainly due to a shortage of time.

Many practical and theoretical problems were encountered during work with the cases. The option of choosing planning cases, that would be developing in parallel with the LUPACS project, was considered, but was given up rather early, on the argument that synchronizing development work with actual planning work would be most difficult or even impossible. Next, different views were discussed on which authenticity should be required when proceeding with the cases, there is a dilemma between on one side being historically on firm ground, and on the other side getting hold of the best material for inspiration and experiments. Authenticity was compromised by using older cases, i.e. the decisions had already been made, but authenticity could still be administered on plant layouts, process data, accident experience, local geography, population data etc. With slight variations we followed a line, where authenticity was strived for, as long as it could be achieved practically, but deviations were acceptable to improve a case as an experimental object, this consisted mainly in modifying the alternatives considered, or inventing and adding new alternatives to the choice.

It turned out to be difficult for land use planners to conceive the methodology and all its concepts immediately, but through working with the cases, one acquires a better understanding. The gap between scientific views and the planner's work has to be taken very seriously, it proved also difficult now and then for the scientists to view a decision from the planners' viewpoints. At a few occasions, the work and the methodology was communicated to groups of planners outside the project group, using case results for illustration; these contacts showed, that the idea could be roughly communicated and interest in the methodology could be aroused. The practical use of the methodology within the project is far from being a real life test, because the involved planners had to collaborate in each case with a "tool expert" to do the calculations and a "risk expert" to complete the input data.

The issue of educating land use planners to apply this sort of methodology has been investigated. A basic assumption was at the beginning, that with some practical tool formulation, land use planners could perform most of the necessary operations to implement the LUPACS methodology. It is not possible with the work presented here to judge the feasibility of making a planning tool implementing the LUPACS methodology ready for the planners' desks and having it actually used.

13 Conclusion

The LUPACS methodology facilitates a selection of a best choice among several planning alternatives - different solutions, different land uses - under conflicting objectives. The methodology applies classical Multi Criteria Decision Analysis to the siting of process plants and storing of chemicals in a modern society. In our study we used a computerized tool developed by Demokritos, the tool presents the "efficient frontier" (efficient set) of alternatives under the assumption that attribute values are additive, i.e. an attribute value for an area equals the sum of values for all elementary cells. Our conclusion is, that treating land use planning with chemical complexes as a Multi Criteria Decision can probably be done by land use planners, given suitable training, but more investigation and testing is needed to find the key presentations and the proper ways to manipulate objectives and indicators. It remains to find, which parts of the planning work still have to be done by consultants and which can be implemented by planners themselves with a suitable computer support tool. In its present shape, the tool can be very useful to risk consultants and to planners with an extended background in risk analysis.

Actually applying the LUPACS methodology to a real case would make a long step forward compared to present practice in many countries. Consequent and formally executed Multi Criteria Decisions are not yet standard in the risk area; besides the education necessary for would-be users of this sort of decision support, some development in society's risk control will be needed as well. Conducting a Multi Criteria Decision with all indicators quantified is not only a challenge to the procuring of input data, it can also be seen as an effort to deflate the political process part by transferring substance from the political domain to the technical one.

Bringing Multi Criteria Analysis into planning decisions means constructing a more rational decision basis, which in turn may throw more light on biases and unclear objectives. Perhaps the adjustment of objectives and indices, to be made early in the planning process, is the most profitable part, simply because such adjustments make us all wiser on the way, we treat our chemical complexes and our societies.

Project deliverables

Wp 1.1, Methods for . .	**January 1997**	**Demokritos**
Wp 1.2, Problem Characterisation	**February 1997**	**Swedish Rescue Services**
Wp 1.3, Decision Support Systems	**April 1997**	**JRC Ispra**
Wp 2.1, User Needs	**January 1999**	**Swedish Rescue Services**
Case # 1 Statoil, DK	**September 1998**	**Risoe & Demokritos**
Case # 2 First Swedish case	**January 1998**	**SRS & Demokritos**
Case # 3 Second Swedish case	**July 1999**	**SRS & JRC Ispra**
Case # 4 Kemira Fredericia, DK	**May 1999**	**Risoe**
Methodology Report	**July 1999**	**Demokritos**
Wp 3.1, Education	**1999**	**LIP6, Paris**
Project Summary Report	**November 1999**	**Risoe**

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Abstract (max. 2000 characters)

A methodology for land-use planning involving chemical sites has been developed for making decisions in local and regional administrations. The methodology treats land-use planning as a multi criteria decision and structures the planning process in seven steps, where one can loop through the steps several times. Essential for the methodology is the specification of objectives setting the frame in which the alternatives are assessed and compared. The complete list of objectives includes the following items: safety and accidents, public distortion and health, environmental impact, cultural and natural heritage, societal and company aspects, with focus laid on the safety related items. An approach based on efficient frontier curves has been used for comparison of alternatives having land-use pattern as variable. Central to the application of the proposed methodology is a GIS based software platform enabling the users to generate alternatives, select the preferred ones and peruse efficient solutions both in terms of the implied land use patterns and the corresponding consequences. Study material has been gathered from planning cases in Sweden, Denmark and Greece.

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