Technical University of Denmark

Multi-objective decisions in land-use planning involving chemical sites

Rasmussen, Birgitte; Bertelsen, I.; Burchard, V.; Christensen, P.; Duijm, Nijs Jan; Grønberg, Carsten D.; Markert, Frank

Publication date:
1999

Document Version
Publisher's PDF, also known as Version of record

Risø-R-1106(EN)

Multi-objective decisions in land-use planning involving chemical sites

Birgitte Rasmussen, Ib Bertelsen, Vibeke Burchard, Peter Christensen, Nijs Jan Duijm, Carsten D. Grønberg, Frank Markert

Risø National Laboratory, Roskilde
May 1999

Abstract A methodology for land-use planning involving chemical sites has been developed for making decisions in local and regional administrations. The methodology structures the planning process in seven steps, where one can loop through the steps several times. Essential parts of the methodology are the specification of objectives and the development of alternatives where the objectives sets the frame in which the alternatives are assessed and compared. The list of objectives includes the following items: safety and accidents, public distortion and health, environmental impact, cultural and natural heritage, societal and company aspects. Focus is laid on the safety related items, and objectives and attributes related to safety are discussed in detail. An approach based on efficient frontier curves has been used for comparison of alternatives having land-use pattern as variable. In the development of the method case studies from Sweden and Denmark have been used, and essential topics and results from two Danish case studies are presented.

The work described in this report is financially supported by the CEC Environment and Climate Programme (contract no. ENV4-CT96-0241).

ISBN 87-550-2523-4 : 87-550-2524-2 (internet)
ISSN 0106-2840

Information Service Department, Risø, 1999

Contents

1 Introduction

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 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 on operation. 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.

The objective of this report is to present an overall methodological framework for supporting decisions on the location or 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 present report is prepared by Risø National Laboratory in co-operation with the Danish Emergency Management Agency, County Board of West Zealand and Fredericia Community. 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.

- Chapter 2 contains a brief presentation of the framework including a summary of state of the art for land-use planning and a description of the decision process.
- Chapter 3 presents the elements of the land-use planning process and a detailed discussion of each element.
- Chapter 4 discusses specific quantitative objectives and attributes related to safety.
- Chapter 5 discusses economic relationships related to safety within the society related to safety issues.
- Chapter 6 contains the first Danish case study: Expansion of refinery.

- Chapter7 contains the second Danish case study: Ammonia pipeline.
- Chapter 8 emphasises the lessons learned in the project and recommendations for future work, and
- Chapter 9 contains a glossary of terms related to multi-objective decisions.

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) and Risø National Laboratory (Denmark). The LUPACS project contains the following three activities, where the present work is a contribution to activity B:

- Activity A. State of the art: A brief description of the state of the art with notes on other relevant projects and scientific work (Cristou 1997).

- 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.

2 Decisions in land-use planning

2.1 Land-use planning

The accident at Bhopal in 1984 had a range of impacts on the regulatory approaches used around the world to deal with the threats posed by major industrial accident hazards. In the European Union a direct consequence of concerns following this and other accidents leading to major losses of life was a proposal made by the CEC in 1989 to introduce a land-use planning element into the fundamental revision of the existing "Seveso" Directive 82/501/EEC, which had been in force since 1982 (Walker 1995, Cristou & Porter 1999). The Seveso II Directive prescribes a Member State to ensure that its land-use policy includes among its objectives the prevention of major accidents and the limitation of their consequences. The siting or modification of chemical facilities is characterised by the presence of multiple and often conflicting technical, social and economic objectives, and therefore it might be necessary to include other than Seveso-II-aspects in the land-use planning process.

Practices concerning land-use planning vary widely across the CEC member states. Some countries have already established well-structured procedures for taking hazards into account in land-use planning, in other countries such procedures are under development, and no explicit regulations for land-use planning in the vicinity of hazardous installations exist up to now. From a methodological point of view two approaches for risk assessment have been adopted within the European Union: the "consequence oriented" one, in which the consequences of a number of conceivable event scenarios are assessed, and the "risk oriented" approach where both the consequences and the probabilities of the occurrence of all possible event scenarios are assessed. In addition, a third one should be noted. According to this approach separation distances should exist between housing areas and industrial facilities. These distances are mainly based on the environmental impact of the industrial activities and on those characteristics of the industry causing nuisance to their neighbours, e.g. noise, odour, continuous emissions (Cristou 1997).

The users of the LUPACS method will be both generalists and specialists with different backgrounds and experiences. Experts will often be involved in the assessment of specific issues, e.g. calculations of risk contours. The planning process is very often carried out under time pressure and the planners need a method which can support the process and make it more efficient.

Land-use planning can be carried out at local, regional or national level, and the method has to be adjusted to the different applications, i.e. some aspects and questions might not be relevant for all three levels.

2.2 Decision processes

Land-use planning is essentially a decision process characterised by preparation and evaluation of alternatives where objectives of different types and values are weighed out (where an objective is a statement about the desired state of the system). A decision process always implies the following elementary operations:

- generation of data for the decision from available data and ideas
- generation of alternatives
- staging the problem in such a way, that a choice can be made.

The LUPACS method shall 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 method shall support the user in the development of possible alternative solutions to the land use problem, and by comparing different alternatives, users can identify areas of compatible and conflicting land use, then assessing the patterns of conflicting land use interests.

In order to evaluate and select objectives it may be necessary both to look at internal and external factors influencing the problem and the decision. Internal factors are relations, parameters or events having a direct impact on the problem which can be used in the regulation and planning process. External factors are relations, parameters or events which do not have a direct impact but they can have a strong influence on the solution. External factors are difficult/impossible to regulate (Sørensen 1995).

Effective land-use planning depends on the appropriate representation, involvement and participation of the interested and affected parties. It is important to prepare a comprehensive characterisation of the situation which requires input from three kind of actors: a) public officials or other designated decision makers, b) analytical experts such as natural and societal scientists, and c) the interested and affected parties to the decision (Stern & Fineberg 1996).

The land-use planning process can be characterised as a decision process with multiple objectives. During the latest decades a great number of multi-objective methods have been developed and applied for different policy purposes and in different contexts (Keeney & Raiffa 1993, Janssen 1992). According to Janssen definitions of decision support systems range from: "Interactive computer-based systems that help decisions makers utilise data and models to solve unstructured problems" to: "Any system that makes some contribution to decision making". The use of decision support systems in land-use planning can have the following purposes in combination or separately:

- to support the decision maker in the generation of new ideas
- to support the decision maker in handling large volumes of information and data
- to support the decision maker in addressing multiple planning objectives in a systematic and efficient manner
- to support the decision maker in the planning process to ensure that the relevant questions and topics are dealt with.

Several descriptions on decision problems can be found in the open literature. Mintzberg et al (1976) proposes the following central phases and routines in a decision process, which also have been used by Janssen (1992) in the development of multi-objective decision support for environmental management:

- The identification phase consists of the central routines: *recognition* in which opportunities, problems and crises are recognised and evoke decisional activity, and *diagnosis* in which management seeks to comprehend the evoking stimuli and determine cause-effect relationships for the decision situation.

- The development phase contains a *search* routine to find ready-made solutions, and a *design* routine to develop custom-made solutions or to modify ready-made ones.

- The selection phase involves a *screen* routine when search is expected to generate more ready-made alternatives than can be intensively evaluated, an *evaluation-choice* routine considering the three modes judgement, bargaining and analysis, and an *authorisation* routine to obtain approval throughout the hierarchy and from outside parties if necessary.

On basis of these principles and experiences from Danish and Swedish land-use planning cases a decision process for land-use planning can be structured and divided into the following seven steps (which are further described in chapter 3):

Formulation of the decision situation Description of the case	(Identification)
Specification of objectives Development of alternatives	(Development)
Assessment of benefits, costs and consequences Evaluation and choice Presentation and communication	(Selection)

The overall structure of the decision process is illustrated in Figure 1. The intention has been to prepare a simple framework for the land-use decision process which hopefully can be helpful in keeping an overview of the decision elements and problems.

As it appears from Figure 1, the procedure includes a straight forward line and possible loops between all steps. The delineation of steps in almost any decision process shows that there is not a steady, undisturbed progression from beginning to end; rather the process is dynamic operating in an open system where it is subjected to interferences, feedback loops, dead ends and other factors (e.g. new knowledge, interruptions, delays). The decision-making process is evoked by many stimuli, originating both inside and outside the organisation. The decision-making 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.

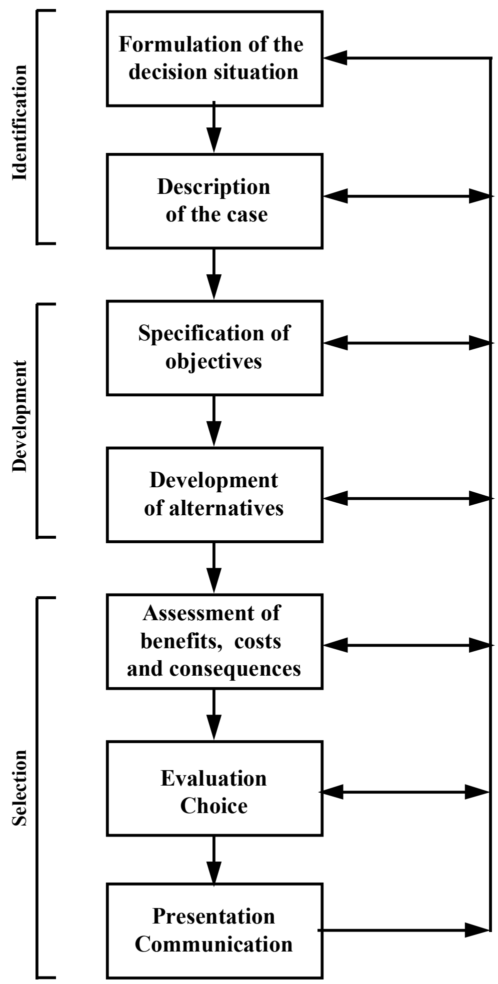


Figure 1. Overall structure of the decision process in land-use planning.

3 Description of the decision process

3.1 Formulation of the decision situation

The first part of the framework is characterisation of the land-use planning situation in question. This comprises three essential aspects: 1) description of the overall goal, 2) identification and involvement of the actors and 3) consideration of the appropriate knowledge and requirements.

The formulation of the overall goal shall describe the land-use planning problem (e.g. location/modification of a chemical site or development of land-use patterns in the area) and also address the origin of the decision situation, i.e. why did the question became important (e.g. application from industry, part of physical planning in the municipality in order to prepare or revise a district plan, national interests in the area).

In the first part of the decision process the planners and the decision makers must ensure that information concerning all types of constraints on the decision process are considered, this could be:

- legislative requirements (e.g. environmental protection law, safety standards, district plans, safety zones, preserved areas)
- touching upon tender spots (e.g. unwritten "laws", values, interests, popular or national traditions and habits)
- scheduling of the land-use planning process and allocation of resources
- identification and contact to actors and other key-persons
- identification and interpretation of opportunities, problems and troubles in the land-use planning environment.

As described in section 2.2 land-use planning is an iterative and cyclic process. During the whole process it is essential for the planner and the decision maker to know which values the actors consider significant. According to Stern & Fineberg (1996) a successful characterisation of a planning problem involving hazardous installations will depend on an analytic-deliberative process. Analysis uses rigorous, replicable methods, evaluated under the agreed protocols of an expert community to arrive at answers to factual questions. Deliberation is any formal or informal process for communication and for raising and collectively considering issues.

In the process leading to characterisation of the land-use planning problem, deliberation may involve various combinations of scientific and technical specialists, public officials and interested and affected parties. The deliberation process can be useful in considering conflicts of values and interests which can be important for the decision making. The deliberation aspect is important during the whole of the land-use planning process, and therefore in the first step of the process it shall be considered how to handle the deliberation process. Furthermore, deliberation can also strengthen a planner's and decision maker's reputation for trustworthiness by exposing decision assumptions to testing and verification by outside parties.

3.2 Description of the case

Factual information about the site and its surroundings shall be provided early in the decision process. This general information gives the basic facts that are needed for making the analysis work. The focus will be directed to description of the site or the area depending on the actual decision situation. Furthermore, the level of detail needed and the topics included will depend on the overall goal of the analysis.

Information and documentation about the site must be available for the land-use planners. The material shall include factual information about technical as well as managerial factors such as:

- intention: the chemical plant and the plans for siting/modification
- site and facility: name, address, products, capacity, codes, standards, permissions
- process and equipment: process conditions, control systems, supply systems, transport system, communication system, automation, containing systems,
- substances, mixtures and materials: raw materials, products, by-products, waste products, construction materials, auxiliaries, combustion products, physical and chemical properties, toxicological properties, ecotoxicological properties
- normal operation conditions: emissions, noise, waste, waste water, quantities of substances and materials, holding/storage conditions
- emergency preparedness: at the site/municipality/region
- review critical events: accidents or near misses that have occurred at the plant or at similar plants.

Maps are required to show the site lay-out and the location of the site in relation to local geographical features such as lakes, roads, railroads, towns. The maps shall be supplemented by description of the area including the following issues:

- demographic features and population density: residences, infrastructure, hospitals, schools, etc. It is important to consider static as well as dynamic features (e.g. is there in the neighbourhood a football stadium or residential area where a large amount of people can be present).
- topographic features: identification and description of dispersion routes (air, soil, water, subsoil water etc.), surface roughness (buildings, obstructions, vegetation etc.)
- meteorological factors: wind direction, wind speed, atmospheric stability etc.
- vulnerable objects: human beings, environment, property.

A land-use planning process can be carried out at different levels of details and the needed level of detail shall be considered during the first steps of the decision process. During the description step the following factors will have to be taken into account:

- access to information and data: search for information (systematic, memory), information sources available (internal, external)
- coverage of information: identification of internal and external factors influencing the decision.
- missing information: identify the need for supplementary information and data.

3.3 Specification of objectives and attributes

The development phase contains two steps “Specification of objectives” and “Development of alternatives” which are very closely connected. On one hand the objectives set the frame in which the alternatives are assessed and compared, and on the other hand the objectives cannot be selected without a clear reference to the developed alternatives.

An objective generally indicates the “direction” in which the decision makers should strive to do better and an objective can be characterised as a statement about the desired state of the system. Furthermore, the decision maker shall define the objective attribute(s) related to each objective. An attribute is a measurable quantity reflecting the degree to which a particular objective is achieved. There might be a formal relationship between objectives and attributes, but usually the relationship is informal and exists only in the mind of the people involved. In practice there is a considerable interplay in the creative process of generating objectives and selecting the associated attributes, and therefore it may be necessary to revise and update the objectives and attributes during the planning process (Keeney & Raiffa 1993).

Surveys may be useful in selecting objectives for public decision makers and planners. Individuals who will be affected by a certain decision can be asked what objectives should be included in the study. Such a process might identify many different kinds of objectives which have to be transformed into objectives manageable in the decision making process. Further, it may be useful to involve experts to identify the objectives in a problem area. Specification of objectives is a creative process which can be structured as follows (Keeney & Raiffa 1993):

- examination of the relevant literature
- analytical study, e.g. building a model of the land-use planning situation under consideration and identifying relevant input and output variables
- casual empiricism which includes observing people to see how, in fact, they are presently making decisions relevant to the problem.

The objectives to be used in a decision will often be identified by a more in-depth analysis leading to the determination of the evaluation objectives (root objectives). The planner and the decision maker has to carry out an identification and determination of significant objectives to adapt (extend and delete items) the generic list of objectives to the land use problem and to keep the number of items at an operational level. A proposal for objectives has been prepared which contains the following meta-objective, subdivisions and attributes:

- Safety and accidents (Table 1).
- Public distortion and health (normal operation) (Table 2).
- Environmental impact (normal operation) (Table 3).
- Cultural heritage (Table 4).
- Natural heritage (Table 5).
- Societal/economic aspects (Table 6).
- Company aspects (Table 7).

In the LUPACS project main emphasis has been laid on the development of objectives related to safety and the Seveso II Directive, but it has also been of importance to develop a methodology which can be adjusted to fulfil the different national interests and requirements and approaches in land-use planning. The following tables contain a brief description of the seven meta-objectives. A detailed discussion of specific quantitative objectives and attributes related to safety can be found in chapter 4 and chapter 5 contains considerations concerning economic relationships and objectives.

Table 1. Safety and accidents (Meta-objective).

Subdivision	**Attribute**
Potential Loss of Life (PLL) - acute or latent.	Minimise PLL onsite (staff) and offsite (neighbours, passers-by etc.).
Injuries and diseases - chronic or temporary.	Minimise injuries and diseases onsite (staff) and offsite (neighbours, passers-by etc.).
Impact on marine and terrestrial recipients - permanent or temporary.	Minimise impact on soil, water, groundwater and air. Minimise impact on flora and fauna.
Impact on property and infrastructure - permanent or temporary.	Minimise impact on private and public property and infrastructure.
Accident escalation/propagation.	Optimise access to rescue services. Maximise distances between objects.

Table 2. Public distortion and health (normal operation) (Meta Objective).

Subdivision	**Attribute**
Noise and vibrations.	Minimise noise and vibrations from industrial activities, traffic etc.
Smell/odour.	Minimise odour-concentrations in industrial and residential areas.
Dust.	Minimise dust in industrial and residential areas.
Air quality, e.g. VOC.	Minimise emissions of carcinogens, mutagens, allergens etc.
Drinking water (ground water, surface water).	Minimise pollution of sources for drinking water.

Table 3. Environmental impact (normal operation) (Meta-objective).

Subdivision	**Attribute**
Emissions affecting global warming and climate.	Minimise CFC, CO_2, CH_4, N_2O etc.
Emissions affecting acidification.	Minimise SO_2, NO_x, NH_3, P, HCl etc.
Emissions affecting eutrophication.	Minimise release of nutritive salts
Impact on marine and terrestrial recipients.	Minimise impact on soil, water, groundwater, air. Minimise impact on flora and fauna.
Resources and consumption.	Minimise energy, raw materials etc. Optimise recycling.
Waste and disposal.	Minimise landfilling. Optimise re-use.

Table 4. Cultural heritage (Meta-objective).

Subdivision	**Attribute**
Historical and preserved monuments and places.	Minimise loss or change of historical monuments/places.
Religious monuments and places.	Minimise loss or change of religious monuments/places.
Places, locations and areas of cultural or aesthetic quality.	Minimise loss or change of cultural or aesthetic views.
Attractive recreative landscapes and areas.	Minimise loss or change of attractive recreative areas.

Table 5. Natural heritage (Meta-objective).

Subdivision	**Attribute**
Preserved areas.	Minimise changes.
Attractive landscapes, areas, forests etc.	Minimise loss or change of attractive natural areas.

Table 6. Societal/economic aspects (Meta-objective).

Subdivision	**Attribute**
Employment.	Improve local employment.
Benefits to society.	Optimise benefits to society.
Society expenses/investments, e.g. infrastructure, public supply and transmission facilities.	Minimise societal expenses.

Table 7. Company aspects (Meta-objective).

Subdivision	**Attribute**
Net economic results.	Optimise net economic results.
Benefits to company, e.g. staff qualification, access to harbour.	Optimise company benefits.

To assign an attribute (or set of attributes) to a given objective, two properties should be satisfied: comprehensiveness and measurability (Janssen 1992). An attribute is comprehensive if, by knowing the level of an attribute in a particular situation, the decision maker has a clear understanding of the extent that the associated objective is achieved. An attribute is measurable if it is reasonable both (a) to obtain a probability distribution for each alternative over the possible levels of the attribute - or in extreme cases to assign a point value - and (b) to assess the decision maker's preferences for different possible levels of the attribute, for example in terms of a utility function or, in some circumstances, a rank ordering (Keeney & Raiffa 1993).

A problem which the planner and the decision maker often has to face is the difficulty finding reasonable attributes for some of the root objectives. In many of these situations it will be possible to surmount the problem by use of proxy attributes (Keeney & Raiffa 1993). A proxy attribute is one that reflects the degree to which an associated objective is met without directly measuring the objective itself.

The determination of objectives is a step in the decision process which forms the frame for the subsequent steps. Benefits, costs and consequences are assessed for each alternative in terms of the selected objectives and the alternatives are compared within this frame. Therefore, the set of attributes shall be (Keeney & Raiffa 1993).:

- complete, so that it covers all the important aspects of the problem and if it is adequate in indicating the degree to which the objectives are met
- operational, so that it can be meaningfully used in the analysis supporting the decision makers to understand the implications of the alternatives and facilitating explanations to others
- decomposable, so that aspects of the evaluation process can be simplified by breaking it down into parts of smaller dimensionality
- non-redundant, so that double counting of impacts can be avoided and the interdependency between the attributes is as low as possible
- minimal, so that the problem dimension is kept as small as possible.

3.4 Development of alternatives

The preparation of alternatives can be a complex, iterative process, where the planner and the decision maker begins with a vague image of some ideal solutions. First, the space from which alternatives can be developed has to be described, taking into account political, cultural, legislative conditions and restrictions. According to Janssen (1992) decision processes including the development phase can be divided into seven types:

- Simple decision processes which involve no development activities but may involve interrupts that complicate the process.
- Political decision processes which are more complicated since they involve extensive design activities and meet frequent and difficult interrupts. Design activities are mostly political design activities initiated to change the power structure within the decision process.
- Basic search decision processes where relatively clear guidelines for alternatives can be established at the outset. Development consists simply of finding the best available ready-made alternative.
- Modified search decision processes which are characterised by development activity in which ready-made alternatives are modified through limited design activity. These processes entail extensive cycling in development.
- Basic design decision processes which is the most common type of decision process. This type involves extensive design activity which typically leads to complex custom-made alternatives.
- Blocked design decision processes which are identical to basic design decision processes until the selection phase. In the last stages the final authorisation and implementation can be blocked through external interrupts leading to a demand for development of new alternatives.
- Dynamic design decision processes which are the most complex of the decision processes. These processes involve complex search and design cycles and encounter multiple interrupts.

A successful development of alternatives will depend on both analytic and deliberative processes. Both analysis and deliberation are processes for increasing understanding about existing problems and estimating future conditions (Stern & Fineberg 1996). Analysis has often provided the first news that a hazard may exist, and it can supply much useful information about the nature of the hazard, as well as about the feasibility and likely consequences of different alternative solutions of eliminating or mitigating it. Deliberation sometimes elicits ways the problem could be redefined, as well as insights about acceptance of the alternatives defined for solving the land-use planning problem The deliberation implies an iterative process that moves towards closure, and it considers each aspect of an issue and it may revisit earlier discussion on the basis of new knowledge and insight. Deliberative processes are important for developing the understanding required to inform decisions. Appropriately structured deliberation complements analysis by adding knowledge and perspectives that improve understanding.

A key question is to identify and select actors (persons) to be involved in the development of alternatives. On one hand it is important that the different interests and viewpoints are considered and that all good ideas are discussed but on the other hand involvement of too many actors may result in a very costly and long process. It is obvious that the authorities and the decision maker, e.g. the politicians, shall participate to ensure that the developed alternatives are in accordance with the legal requirements. Furthermore, in case the land-use planning situation includes a siting or modification of a chemical site, also representatives from the enterprise shall contribute to avoid that unrealistic alternatives are assessed and evaluated. The open question is to which degree experts and interested and affected parties shall participate. Some times a minimum of public participation in the land-use planning process is clearly prescribed in the legislation, for example public hearings, but in some cases it may be an advantage to extend the number of actors participating in the discussions about alternatives. Involving a broad spectrum of interested and affected parties makes the process leading to the developed alternatives more democratic and informative. This is attained in several ways: improving the formulation of the land-use planning situation, providing more knowledge to go into the process, determining appropriate uses for controversial analytic techniques, clarifying views and attitudes, and making the decision process more acceptable for the decision participants.

It is not possible to specify exact guidelines for development of alternatives as each land-use planning situation needs a thorough investigation of its specific aspects, conditions and requirements. Development of alternatives is a creative process with no clear starting and ending point, and the result of the process depends on the fantasy and experience of the participants. The development of alternatives can be carried out as follows:

- systematic combination and use of existing elements from the actual case, e.g. changing position, dimensions, processes, equipment
- preparation and use of new information
- modification of already developed alternatives
- use of experience from other land-use planning cases
- use of lessons learned from accidents and near misses.

For each alternative - in order to make them comparable - the next step is to assess the benefits, costs and consequences and therefore it can be appropriate or necessary (e.g. due to limited resources) to limit the number of alternatives considered.

3.5 Assessment of benefits, costs and consequences

For each alternative the benefits, costs and consequences are assessed and the assessment shall comprise all alternatives including the "zero"-alternative. The assessment shall be carried out in the same way for all alternatives using the selected frame of objectives and attributes (see section 3.3).

To compare the alternatives it is important to describe them in a uniform and systematic way, and consequently a crucial part of the decision process will be the selection of methods and principles used to characterise the objectives and attributes. Some attributes can be measured quantitatively but in a variety of units, scales or dimensions (e.g. economy, risk profiles, decibel, emissions), and some are normally expressed in qualitative or semi-qualitative terms (e.g. cultural and natural heritage, aesthetics). Many attributes are intuitively considered to be objective (as opposed to subjective) in nature, which means that there already exists a commonly agreed scale for that attribute and its levels are objectively measurable. However, there are objectives for which no objective index exists and, in such cases, a subjective index must be constructed. There are, of course difficulties in using subjectively defined attribute scales, and depending on context it may be necessary to go to creative, or even fancy extremes in order to get an objective base.

The discussion about advantages and limitations of qualitative or quantitative evaluation criteria is not new and is often raised in connection with assessment and evaluation of risk and safety issues. A well-known example is the discussion about the value of life and the aversion to express human life and health in terms of money. Many lay-people, public officials and public planners prefer for some objectives a qualitative evaluation of alternatives instead a quantitative one.

In the assessment of alternatives and fulfilling the frame of objectives and attributes the following issues can be relevant to consider:
- overall identification (screening) of hazard sources
- overall assessment of accident consequences
- potential exposure (humans, environment, property) - in case of accidents
- potential exposure (humans, environment, property) - normal operation
- emissions
- waste, disposal and recycling
- raw material and energy consumption
- expenses and profits to society and company
- expected future effects of the activity on the development patterns in the area.

Any limitations in the assessment of benefits, costs and consequences should be described and taken into consideration, such as lack of available resources, time limits and lack of data or information. This may be necessary in order to balance the complexity and size of the problem, on one hand, with the scope, ambitions and accuracy of the risk analysis, on the other hand. Further, the uncertainties related to the calculations and assessments should be carefully evaluated and described

3.6 Evaluation and choice

In general terms essential aspects of the evaluation process are: to maximise net land development benefits and to minimise various categories of costs and unwanted consequences. The evaluation-choice step may be considered to use three modes (Mintzberg et al 1976):
- in judgement, one individual makes a choice in his own mind with procedures that he does not, perhaps cannot, explain
- in bargaining, selection is made by a group of decision makers with conflicting goal systems, each exercising judgement
- in analysis, factual evaluation is carried out, generally be technocrats, followed by managerial choice by judgement or bargaining.

An evaluation method is any procedure that supports the ranking of alternatives using one or more decision rules. It is often the case that no dominant land use alternative will exist, that is better than all other alternatives in terms of all the selected objectives. Perhaps some of the alternatives can be eliminated, but generally speaking it is not possible to maximise several objectives simultaneously (Keeney & Raiffa 1993).

The elements of an evaluation method are the decision rule (DR), the set (X) of alternatives (x), and the set of rules (f_1 .... f_j) by which the value of each attribute is evaluated for a given alternative x. In essence, the decision maker is faced with a problem of trading off the achievement of one objective against another objective. If there is no uncertainty in the problem and if the multiattribute consequences are known for each alternative, the essence of the issue is: how much achievement of objective "a" is the decision maker willing to give up in order to improve the achievement of objective "b" by some fixed amount ? Weights are used as a representation of the relative importance of the objectives. Direct estimation of this relative importance by assigning a value to each objective proves to be a very difficult task for the decision maker. There may be no right or wrong answers to these value questions and different individuals may have very different value structures. If the trade-off issue requires deep reflection, there are two possibilities for resolving the issue: 1) the decision maker can informally weigh the trade-offs in his/her mind, or 2) he/she can formalise explicitly his/her value structure and use this to evaluate the contending alternatives. Of course, there are mixtures of intermediary possibilities between these two extremes (Keeney & Raiffa 1993).

Further, to make the objectives directly comparable they must be transformed into a common dimension or into a common dimensionless unit/measure (Janssen 1992). A common practice of many analysts is to “price out” - that is, bring down to a standard level - all the nonmonetary attributes into a (single) monetary attribute. A comparison of alternatives is then made only in terms of the “adjusted” levels of the monetary attribute (Keeney & Raiffa 1993).

In the evaluation process it can be useful to identify those objectives having a high impact on the decision and to carry out a sensitivity analysis of the analysis. If possible, it can be advantageous to group objectives according their scale of impact on the land use situation. Furthermore, it is important to assess the extent of open-ends and unsolved problems.

Industrial location and the determination of optimal land development patterns have long been issues of basic and applied academic research. Since the 1960s, urban and regional land-use models proliferated, the four modelling directions being spatial interactions, econometric. mathematical programming and simulation models (Briassoulis & Papazoglou 1994, Papazoglou et al 1998). In LUPACS a methodological approach developed by the National Centre for Scientific Research “Demokritos” has been used in order to evaluate the developed alternatives. The approach adopted by this system, is to find the subset of non-dominated solutions or the so-called efficient frontier. Then, the value function, if it has been assessed, can be used to determine the most preferred alternative among those belonging to the efficient frontier. Alternatively, the decision maker can directly determine the most preferred alternative of the efficient frontier without going through a formal assessment of a value function or a weight (Keeney & Raiffa 1993) (Briassoulis & Papazoglou 1994).

As mentioned, the different interested and affected parties have their own set of objectives and their own viewpoints on weights and value functions. When the solution to the land-use planning problem is to be chosen, it might be of interest to assess to which degree the solution in question will comply with the interests of the different parties. The preparation of a table as illustrated below can provide an overview of interests and fulfilment of objectives:

	Interested and affected parties concerned
Alternative 1	
. . . .	
Alternative n	

3.7 Presentation and communication

In the decision process it is significant that the possible solutions are visualised in an appropriate way to support the actors and key-persons involved in the understanding of how the solution will influence the area and society in question. All results and information shall be disseminated to the actors and key-persons involved in the decision process. When the solution is selected it has to be described and presented to the interested and affected parties.

In the presentation and communication step it is important to identify the interested and affected parties. The number and types of interested and affected parties will depend on the particular context of the land-use planning situation. They may include people from diverse geographic areas, ethnic, or economic groups and organisations, such as companies and local governments. The parties may include interest groups, such as trade associations, labour unions, environmental and consumer groups, and religious groups. The parties' concerns may focus on various possible forms of harm, not only mortality and morbidity, but also physical, social, economic, ecological and moral effects. Parties sometime do not know that they are interested or may be affected by land-use planning decision unless they are informed. The interested and affected parties can often be identified answering to the following questions (Stern & Fineberg 1996):

- who has been involved in similar risk situations before ?
- who has wanted to be involved in similar risk situations before ?
- who may be affected but not know they are affected ?
- who may be reasonably angered if they are not informed ?

3.8 Discussion of the overall framework

The intention has been to prepare a simple framework for the land-use decision process which can support an overview of the decision elements and problems in order to prepare a comparative analysis of land-use planning alternatives involving chemical sites. The methodology has been developed in parallel with the preparation of two Danish land-use planning case studies (see Chapter 6 and 7) and the experience indicates that the framework supported the structuring of the case studies very well.

An essential element of the framework is the determination of objectives and attributes. One aspect is the objectives setting the frame for the decision but also the associated attributes can be chosen in more than one way resulting in different solutions to the decision problem. The relationship between objectives and attributes and the influence of the selection of objectives and attributes on the final solution are areas that need further research.

The framework can be used to provide a common platform for a focused discussion of the land-use planning problem between the involved actors and interested or affected parties. It can support the identification of the central and/or conflicting elements of the decision problem and clarify differences in values and attitudes.

4 Discussion of objectives and attributes related to safety

Safety is concerned with safeguarding the conditions of human life. Safety is thus concerned with preventing injury, fatality and damage to private and community property. This points at the following natural types of possible attributes to express safety:

- probability for fatality (acute or delayed)
- probability for injury, with different levels according to seriousness, acuteness and possibility for recovery (see e.g. Soby et al. 1993)
- probability of damage, with different levels of amounts of damage.

From this small list, it is already clear that there are different possible detailed definitions. In the following sections, adequate definitions for the first two types of attributes will be discussed, as well as redundancy between the attributes.

We will not consider "damage" in detail in the remainder. It is common practice to express the amount of damage due to "natural" causes, like fire and earthquake, by means of monetary units, although some property might be invaluable for the owner itself. We will assume that "money" is an adequate attribute variable for assessing damage.

4.1 Attributes for fatality

With respect to fatality, 3 different ways of expressing the risk for fatality appear:

- The probability of total fatality in the whole area of concern, the Potential Loss of Life (PLL). This attribute is a single number and therefore it can be easily assessed.
- The Societal Risk (SR) for the whole area of concern. This attribute describes the probabilities for accidents leading to more than n fatalities for n=1 to (in principle) n=∞ and it consist therefore of a series of numbers for each n: SR(n). It can be used to account for the society's averse of accidents with catastrophic dimension (i.e. involving many casualties).
- The distribution of Individual Risk (IR) over the area of concern. The IR at a specific location represents the probability of fatality of a person that is present at that position all the time without any protection nor evasive action. By its nature, the IR is a function of x and y: IR(x,y).

It is noted, that these attributes include both acute and delayed mortality. There is a strong relationship between these three attributes. Any quantitative risk assessment usually results in the determination of the Individual Risk IR(x,y), normally presented by risk contours (curves that show points with the same IR) on a map. By combining IR(x,y) with the local population density d(x,y), the PLL for the area of concern A can be calculated:

$$PLL = \iint_A IR(x,y) \cdot d(x,y)dxdy$$

Assessment of the Societal Risk requires a direct analysis of different accident scenarios in conjunction with the local population density and cannot be derived directly from the distribution of Individual Risk. However, the Societal Risk SR(n) can be considered as the cumulative distribution of a discrete density function sr(n), which gives the probability for an accident with just n fatalities:

$$SR(n) = \sum_{i=n}^{\infty} sr(i)$$

It should be noted that the functions SR(n) and sr(n) contain the same amount of information. The total number of fatalities can now also be described as (Styhr Petersen, 1984):

$$PLL = \sum_{n=1}^{\infty} n \cdot sr(n)$$

We will now discuss the suitability of each of these variables in the definition of objectives in the framework of land-use planning.

Potential Loss of Life

The PLL is a straightforward attribute which is both comprehensive and measurable. The corresponding objective is "minimise the Potential Loss of Life in the area of concern". However, one can wonder whether individual safety is covered sufficiently well by this area-averaged quantity. It does not directly deal with aspects of equity, in other words, one can imagine that low levels of overall PLL can be achieved by exposing small groups of people to high levels of individual risk. A measure of risk variance is the standard deviation of PLL over the area of concern. With D the total population in the area of concern, we define:

$$\sigma_{PLL} = \sqrt{D \cdot \iint_A (IR(x,y) - \frac{PLL}{D})^2 \cdot d(x,y)dxdy}$$

Aspects of equity can now be taken into account by changing the objective to "minimise the sum of PLL + $\varepsilon \cdot \sigma_{PLL}$", where ε is an "equity index". This will be illustrated using 4 fictive different population distributions A, B, C and D within the risk contours, as in Table 8. The range of individual risk (4 orders of magnitude) is typical for land-use planning problems around single industries.

All four distributions apply to the same number of people. The distributions A, B and C have the same PLL, but there is a difference in how risk is distributed over the population. Assuming for simplicity that Individual Risk is inversely proportional to the distance squared to the industrial site, distribution B corresponds to a uniform population density over the whole area. For distribution A, the majority of the people are exposed to a low risk, but a small group is exposed to a high risk. For distribution C, no people are exposed to much-higher-than-average risk. The standard deviation of PLL - σ_{PLL} - is an order of magnitude smaller than for alternatives A and B. Now in practical situations, if C would be an alternative to B, D would probably also be an acceptable alternative to B, because it has the same number of people (4000) in the lowest risk area as B. The PLL for D is half of the PLL of C, and the standard deviation σ_{PLL} is also lower.

Table 8. Four fictive population density distributions for the same distribution of Individual Risk and corresponding Potential Loss of Life (PLL) and standard deviation of PLL. The distributions A, B, and C lead to the same PLL, but in distributions A and B small groups of the population are exposed to relatively high Individual Risk, which can be expressed by the standard deviation of PLL, σ_{PLL}*.*

	Population (number of people)			
Individual risk (per year)	A	B	C	D
$1\cdot10^{-8}$	4432	4000	3158	4000
$1\cdot10^{-7}$	0	400	1286	444
$1\cdot10^{-6}$	0	40	0	0
$1\cdot10^{-5}$	12	4	0	0
PLL (fat./year)	$1.6\cdot10^{-4}$	$1.6\cdot10^{-4}$	$1.6\cdot10^{-4}$	$8.4\cdot10^{-5}$
σ_{PLL} (fat./year)	$2.3\cdot10^{-3}$	$1.4\cdot10^{-3}$	$1.8\cdot10^{-4}$	$1.2\cdot10^{-4}$
	$PLL + \varepsilon\cdot\sigma_{PLL}$			
ε=0.03	$2.3\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.7\cdot10^{-4}$	$8.8\cdot10^{-5}$
ε= 0.1	$3.9\cdot10^{-4}$	$3.0\cdot10^{-4}$	$1.8\cdot10^{-4}$	$9.6\cdot10^{-5}$
ε= 0.3	$8.4\cdot10^{-4}$	$5.8\cdot10^{-4}$	$2.2\cdot10^{-4}$	$1.2\cdot10^{-4}$
ε= 1	$2.4\cdot10^{-3}$	$1.6\cdot10^{-3}$	$3.4\cdot10^{-4}$	$2.0\cdot10^{-4}$

This example demonstrates that in general it can be expected that the use of the simple objective “minimise the PLL” will tend to favour solutions with a reasonable degree of equity, because small groups of people exposed to high risks contribute a lot to the total PLL. Only in extreme cases, where the solution space would not include alternatives between e.g. A and C, σ_{PLL} can enforce equity. With an equity index in the order of 0.1 to 0.3, a reduction of the number of people exposed to the highest level of risk in alternative A by a factor of 15 would lead to the same “score” as alternative C.

Societal Risk

As Societal Risk is not a single number, an objective like “minimise the Societal Risk in the area of concern” can only be assessed subjectively (by comparing graphical presentations of the functions SR(n)) if the objective is not rephrased in more detail. A possible rephrase allowing a qualitative ranking of two alternatives A and B might e.g. use the following rule:

SR_A “is better than” SR_B if for all i>0: $SR_A(i) \leq SR_B(i)$

Alternatively, the function SR(n) (or sr(n)) can be integrated or summed to a single number, using a weight function. A natural weight function would be based on the number of fatalities n, i.e.

$$SR_\alpha = \sum_n n^\alpha \cdot sr(n)$$

With α=1, this number is equal to the PLL. This implies, that n accidents with 1 fatality have the same weight or “accept” as a single accident with n fatalities. If, however, one wants to express the aversion of large accidents, one can choose α>1. Reasonable weighting is obtained with α=3 (Styhr Petersen, 1984).

With α>1, the objective “minimise SR_α in the area of concern” is not strictly redundant with “minimise the PLL”, but the benefit of using both objectives will be negligible in most practical situations where other, more conflicting, issues play a role.

Individual Risk

Individual Risk is a single number neither, but a spatial distribution and an objective like "minimise the Individual Risk" can only be assessed subjectively without further detailed definition how to assess the overall Individual Risk.

Legal restrictions are often based on individual risk. Within multi-objective decision terminology, this means that individual risk is used as a goal, e.g.: "no population may be exposed to an Individual Risk higher than a stated value X". This can be restated as an objective: "minimise the number of people exposed to an Individual Risk higher than X". These objectives/goals are straightforward and fit well to the existing legal framework in a number of countries. There are however two drawbacks:
1) If the goal is reached, no further optimisation of safety will be enforced.
2) The objectives/goals minimise risk neither beyond nor (more important) within the "X"-risk contour. In other words, if only one objective with one limit value X is used, exposure to individual risk levels much higher than X will not be accounted for.

This type of objective/goal is therefore preferably used together with another objective related to safety, typically based on the PLL.

Alternatively, Individual Risk can be integrated over the area, using a weighting function. The most logical weighting function is the population density:

$$IR_{\beta\gamma} = \iint_A IR^{\beta}(x,y) \cdot d^{\gamma}(x,y)dxdy$$

With $\beta=\gamma=1$, this reduces to the PLL. With $\beta=2$ and $\gamma=1$, this reduces to the variance of the PLL over the population, weighting higher risks more heavily, see the discussion of σ_{PLL} in the section about the PLL. Functions with $\gamma>1$ weight high population densities more heavily, representing the (doubtful?) accept that in less dense populated (rural) areas risk may be higher than in dense populated residential areas. This way of weighting is not recommendable. Firstly, it is questionable whether this will lead to results that are much different from using the PLL. Secondly, the outcome might depend on data resolution, as data resolution affects the presentation of local variations in population density.

Discussion of attributes for fatality

Use of the Potential Loss of Life as the attribute variable to express safety concerns will be a reasonable choice in most cases. Concerns of equal distribution of risk can be addressed by including the standard deviation of the PLL over the population or by including a goal reducing the number of people exposed to individual risk higher than a certain value.
If prevention of large accidents is a major issue, the PLL can be replaced by or complemented by the number SR_3.

4.2 Attributes for injury

In the majority of cases of risk analysis, results are presented in terms of the probability of fatality. One may question whether this is actually the most relevant parameter. Normally one may expect that the number of injured people in an accident is at least an order of magnitude larger than the number of fatalities (e.g. the Bhopal accident lead to about 2500 fatalities and 200,000 injured, Fthenakis 1993). For emergency management, an estimation of the total amount of people needing medical care in case of an accident might be more relevant than the number of fatalities. Also, incidents leading to (temporary) health problems outside the site or requiring evacuation, occur quite regular compared to fatal incidents, and might present therefore a better frame of reference for the lay public with respect to their understanding of "risk".

However, "injury" is more complex to describe compared to fatality, which is a well-defined state. This is probably one of the reasons why injury is used seldom in risk assessments. One can think "injury" of having three independent dimensions; i.e. injury can be classified using three variables:
1. Amount of medical care required;
2. Time required to recover; and
3. Amount of permanent disability.

Normally, only limited information is available on these different aspects in, e.g., chemical accident reports. If at all, information about seriousness of injury is often limited, e.g., whether or not "requiring hospitalisation for more than 24 hours", (this is used in the French classification for accident severity, Amendola & Chaugny 1994). Some more detailed classifications are used in the area of occupational safety and traffic safety. The Annual report of H.M. Chief Inspector of Factories 1974 (Lees 1980b) distinguishes 26 different types of injuries ordered in 3 groups depending on severity. The UK regulation on reporting injuries (HSE, 1986) distinguishes 2 levels of injuries to be reported. The highest level includes, among other specifically described injuries, "any injury which results in the person injured being admitted immediately into hospital for more than 24 hours". The second level is described as being incapacitated for work for more than 3 consecutive days. Soby, Ball and Ives (1993) describe a division of traffic injuries in 8 classifications. These classifications cover 2 independent factors, viz. medical care and time to recover on one hand and permanent disability on the other.

As it is difficult to define the level or severity of injuries, it is also difficult to relate exposure to, e.g., toxic material directly to a quantified level of injury. Lees (1980) mentions some approximate Probit functions for injury due to overpressure (eardrum rupture), impact, flying objects and chlorine. "Injury" here means hospitalisation without permanent disability. Furthermore, the relation of heat radiation intensity levels and different types of burn injuries is relatively well known (Lees 1980, American Institute of Chemical Engineers 1989, Torvi & Dale 1994).

We took accident scenarios from the refinery case (see section 6.5) in order to obtain some idea about the relative importance of considering injury compared to fatality. Three accident scenarios were used, viz. scenario 1 (were the HCl-release is replaced by a chlorine release), scenario 4 (BLEVE from a LPG tank) and scenario 5 (flash fire due to a release from a LPG tank). The number of fatalities and the number of injured people were compared. We assumed that the population distribution is uniform over the area around the refinery. The Probit function for injury (defined as hospitalisation with or without lasting impairment of health) due to chlorine are from Lees (1980). A Probit function for injury due to heat radiation (defined as the onset of second degree burns) was constructed based on experimental data presented also by Lees (1980). The result shows that for a chlorine release, the ratio of the number of fatalities to the number of injured is 1 to 5. This ratio is strongly dependent on the duration of the exposure (according to the Probit functions used, injury is independent of the exposure duration, in contrast to fatality. In our scenario, the exposure duration is 5 minutes). For injury due to heat radiation, the ratio is 2 to 1; in other words, there are twice as many fatalities as injured people!

In order to obtain more insight in the possible variation between the number of injured and the number of fatalities, a comparison was made between an exposure limit (IDLH, "Immediately Dangerous to Life or Health"[1]) and the LC_{50} (based on rat-data and 30 minutes exposure) (Sonnich Thomsen 1997). The idea is that a small ratio (i.e. a larger difference) between the IDLH and the LC_{50} indicates that the ratio of injured people to the number of fatalities might be large, see the following table, which contains a selection of substances, in decreasing order of the ratio $IDLH/LC_{50}$:

Substance	$IDLH/LC_{50}$
Hydrogen fluoride	0.0078
Carbon disulfide	0.015
Methyl-hydrazine	0.019
Ammonia	0.03
Chlorine	0.043
Acroleine	0.087
Methyl-isocyanate	0.273
Hydrogen cyanide	0.312
Phosphine	2.268
Malathion	14.273

The table indicates a large range of ratios. However, one can not draw clear conclusions from this table. The ratios larger than 1 for Phosphine and Malathion indicate that this table suffers from the problems related to the extrapolation of animal data to humans, especially in case the toxic causes systematic effects, like in the nerve system. Concentrations of malathion that will kill almost all rats within 30 minutes, will not impair healthy humans from escaping the hazard. Furthermore, the actual ratio of injured people to fatalities in the Bhopal accident, involving methyl-isocyanate, was about 80, whereas we calculated a factor of 5 for chlorine while chlorine has a smaller ratio of $IDLH/LC_{50}$

Discussion of attributes for injuries

Although the number of injured might be a more relevant parameter than the number of fatalities, the lack of a systematic and practical classification of injury as well as the lack of knowledge about the relation between exposure and injury for the majority of toxic substances, prevents "injuries" from being a routinely used attribute for risk characterisation as by now.

If exposure-effect relations would be known (as e.g. for heat radiation), similar types of injury-related attributes can be defined as for fatality:

- Distribution of individual risk of injury;
- Potential number of injured people, equivalent to the PLL;
- Societal Injury Risk, equivalent to SR.

One will have as many of these numbers as one distinguishes between different classes of injury (depending on medical care, severity and permanency). As for fatality, the potential number of injured people will probably serve as a good attribute. Compared to fatalities, the societal injury risk might be somewhat more relevant, as it is related to the capacity of the local emergency response.

1 The IDLH represents the maximum concentrations from which, in the event of respirator failure, one could escape within 30 minutes without a respirator and without any escape-impairing (e.g. severe eye irritation) or irreversible health effects.

An important question concerns the redundancy between attributes based on fatality and those based on injury. For fire radiation hazards, where our estimate is that the number of fatalities will be of the same order of magnitude as the number of injured, the attributes are likely to be mutually redundant.

For toxic hazards, the extent of the area exposed to concentrations leading to injuries might be several times larger than the area exposed to fatal concentrations. The land-use patterns (i.e. the local population density) in these different areas will affect the outcome of both types of attributes in a different way, and the attributes are not necessarily redundant in a strict sense. But if one strives for a minimum size of the set of attributes (Keeney & Raiffa 1993), only one of these attributes will be sufficient in practice.

5 Socio-economic relationships and objectives

Any land-use planning problem has impacts on different aspects of life: safety, environment and economy. The LUPACS project focuses on aspects of external safety. However, land-use planning requires an integrated approach of all relevant aspects. It is beyond the scope of LUPACS to develop guidelines how to consider all relevant 6-7 types of meta-objectives (section 3.3), but as socio-economic considerations are often in strong conflict with aspects of safety and environment, it will be attempted to provide some guidelines how socio-economic aspects can be incorporated in the Multi-Criteria Analysis (MCA). We will focus on the economic aspects only, e.g. “employment” will only be considered from a point of view of the economic implications, and the sociological aspects will not be covered here.

The socio-economic effects of a business expansion depend on the relationship between this business and the (local) society. One can distinguish effects due to cash flow (e.g. salary, tax income, expenses) and effects due to the use of what we will call natural resources, which are reflected by actual changes in market value, e.g. land that will be restricted in use, will drop in value. Note that we do not consider monetary valuation of resources, for which there is not an actual economic market. These aspects can appear in the MCA as single objectives, or, if a Cost-Benefit approach is chosen as one way of carrying out such an MCA, a separate monetary valuation is required. In this chapter, we will consider the cash-flow relations (see section 5.2) and valuation of natural resources (section 0).

We will adopt the principle that for those objectives, for which it is possible to find attributes that can be expressed by monetary values and which express the interest of a more or less homogeneous group of stakeholders, we will use this monetary valuation and add the individual contributions. In other words, we will not pursue to apply MCA for different objectives that can all be expressed in monetary units, but these objectives will be collected into a single economic (or monetary) objective. The rationale in this approach is that we expect that the monetary valuation has already accounted for the trade-off between the different (sub-) objectives. Of course, this approach can only be followed, if there is no ambiguity in the monetary valuation. If actors involved in the land-use-planning process disagree on the valuation, one should consider incorporating the objective in question as a separate objective in the MCA. The condition that such a monetary attribute should represent homogeneous groups of stakeholders will cause that different objectives are used for, e.g., the industry's interests and the local community's interests.

5.1 General considerations

Extent of the socio-economic analysis

The economic activities within a society are highly linked. This means that relatively small changes have an influence on a wider scale than the scale where the original changes take place. As such, one can distinguish between direct effects (or 1st order effects), 2nd order effects, and so on. The first order effect of someone earning more money is that he personally has a higher budget to spend. The second order effect is that another person earns more money due to the increased expenses of the first person, etc. There can be several different types of 2nd order effects such as the increased consumption due to increased labour income but also due to increased deliveries from the local contractors and businesses to the industry in question. In economic models multiplicative relationships between different types of cash flows are used to simulate these 2nd order effects. This requires highly sophisticated models in order to obtain sufficiently accurate results. It depends on the type of industry (especially the differences in occupational effects of operation, maintenance, local contractors, etc.) how large the 2nd order effects will be. In case of the example that will be presented in section 5.2 the 2nd order effects are estimated to be of the order of 10%. In this report we limit ourselves to 1st order effects as suggested by the Danish Ministry of Finance's guideline for socio-economic evaluation of projects (Finansministeriet 1990), and we don't account for the increased local consumption by the local community. We suggest however, that local income generated by direct deliveries or services from local businesses to the industry is accounted for, and is included similarly as the income of employees.

An economic evaluation of a project needs to address the effect of the investment, the effects of normal operation as well as the costs related to demolition and clean-up of the site at the end of the life time of the project.

The domain of interest

Note that, in contrast to e.g. risk or noise levels, economic value does not vanish at the borders of the domain of interest. The definition of the borders of the domain of interest determine the amount of "import" and "export" of labour, services and goods to or from the area of interest, which are items that determine the socio-economic status in the domain of interest. Thus the assessment of the socio-economic consequences depends on the definition of the domain of interest. One should make a thorough assessment what the actual domain of interest for the relevant decision-maker is. Conflicts between different authority levels (municipality-county-national-European) originate often from different domains of interest.

The Net Present Value

Economic properties appear as a value (as on a balance sheet), expressed in a monetary unit, or as benefits or costs (cash flows), expressed as monetary unit per unit time (normally years). Value of natural resources and capital goods are normally expressed as a value (rather than a cash flow property), whereas the economic activities (sales, salaries, etc.) are cash flow properties. In order to compare both effects, one is forced to transfer the cash flow effects to values. Normally use is made of the Net Present Value (NPV) that represents a method to sum present and future cash flow effects together:

$$NPV = \sum_{t=1}^{n} \frac{x(t)}{(1+r)^t}$$

Here x(t) is the benefit (or cost) in time period (year) t, n is the planning horizon and r is the discount rate. The discount rate can represent the preference of consumers for present rather than future consumption, or can represent the cost of capital. Typical values of r are between 5 and 10%. If one considers the discount rate as a subjective preference, then one should be prepared to accept that different stakeholders might ask for different discount rates.

The time horizon

From the formula for the NPV, it becomes clear that the definition of the time horizon is extremely relevant in case NPV is selected as the relevant attribute. Land-use planning decisions can have long lasting consequences (note that the Avesta steel works were established at their present location some 200 years ago). On the other hand, the economic lifetime of equipment might actually determine the timespan of impact: When equipment in due time will be replaced, new land-use-planning decisions may turn up.

For a correct comparison of alternatives and consequences, it is in any case important, that the time horizon is selected the same for all (economic) consequences. The Danish Ministry of Finance (Finansministeriet 1990) recommends to use the economic lifetime as the project’s time horizon. Also in this case, different stakeholders may have different ideas about the relevant time horizon.

5.2 The cash flow relation between industry and local society

In order to assess the local economic consequences of any initiative, hereafter called the “industry” (new plant, expansion, etc.) due to the expected increased activity, we will consider the local relationships between the industry and the society (Figure 2).

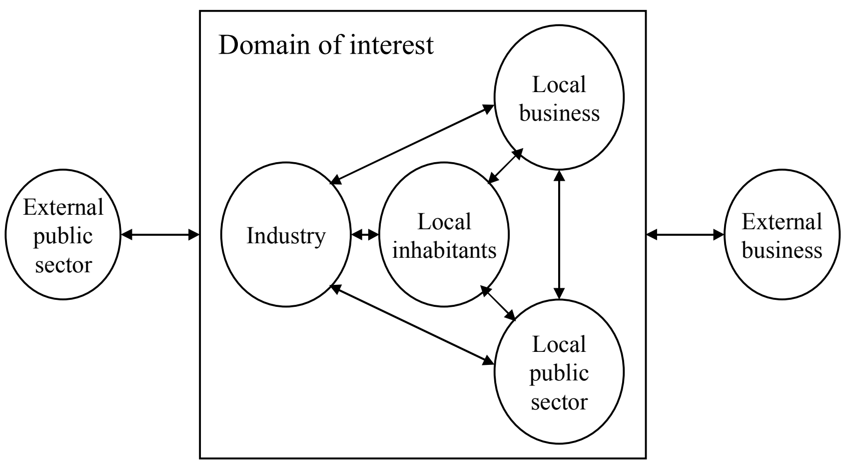


Figure 2. Cash flow relations between industry and local society.

We discern the following actors or societal sectors

- The industry itself.
- The local inhabitants, mainly through their role as local workforce.
- The local public sector, as collector of part of tax money and provider of services. Depending on the definition of the domain of interest, this can be municipality, a combination of municipalities (e.g. in a region), a county or province board, or a national government. Institutions providing social security (especially unemployment payments) are also considered to be part of the public sector. We assume that neither tax is collected nor services are implemented by supranational institutions.
- The external public sector, i.e. the public sector up to the national level outside the domain of interest (e.g., if the domain of interest consists of a municipality, the external public sector consists of the county or province board and the national government).
- The external business, i.e. all institutes or businesses outside the domain of interest that have an import/export relation with the domain of interest of goods, workforce or services. Import and export denote goods, services, etc., which pass the borders of the domain of interest.

If one is interested in evaluating secondary effects of economic activity within the domain of interest, one need to include a 6th actor:

- The internal business, i.e. the business that provides services and requires workforce within the domain of interest.

Now for each of the actors, relations with the other actors within the domain of interest can be defined, which are presented here in tables or matrices. Negative numbers (costs for the actor in question) are between brackets. Table 9 and 10 show how the costs are spent and where the benefits come from, all the factors in these columns are less than 1. Note that the tables indicate the change of the economic activity, without taking care of indirect (2nd order) effects (we have therefore left out the "internal business" as an actor). Table 9 considers the industry's situation during operation.

Table 9. Distribution of costs and benefits for the actor "Industry" during operation

Industry (C)		Local inhabitants (P)	Local public sector (L)	External public sector (N)	External business (E)
Salary	(CS)	cs_p (≈ 100%)			$1-cs_p$
Import	(CI)				100%
Capital costs	(CR)	$1-cr_e$			cr_e
Industry taxes	(CT)		ct_l	$1-ct_l$	
VAT	(CV)		cv_l	$1-cv_l$	
Turnover/ sales	CC	$(1-cc_e)$			(cc_e)
(Sum = Net Benefit)	"profit"				

The new initiative or investment is expected to improve the turnover or sales of the industry (inclusive of VAT) by a yearly amount of CC. These sales will be partly realised locally, but often (in case of a large industry producing bulk chemicals) only by sales outside the domain of interest: $cc_e \times CC$. This turnover will be balanced by a number of costs:

- salaries CS, spent mostly locally (note that this should include salaries paid by local businesses that render services to the industry),
- import of services and goods from outside the domain of interest, CI,
- capital costs (interest) CR related to the investments, which are spent outside the domain of interest unless a part of the capital is provided locally,
- industry taxes CT, typically a percentage of the profits,
- VAT, a fixed percentage of the turnover CC minus the import CI. How these taxes are shared between the local and external public sectors depend on the national tax system.

The "Net Benefit" or profit of the industry is the sum of the turnover and the above cost elements. Note that from an industry point of view, "profit" is a cost element, either transferred to the industry's own capital, or paid to the owners, which may be living within or outside the domain of interest. In this context we will not consider this second order effect. Table 10 shows the position of the local inhabitants during operation.

The inhabitants receive an increased salary PS that equals $cs_p \times CS$. There can also be income from interest if (part of) the inhabitants provide capital for the industry. This income is denoted with $PR=(1-cr_e)\times CR$. For simplicity, we assume that there is some unemployment in the domain of interest[2]. That means that the local community will receive less social security money after the industry has employed extra personnel. This budget PU has to be subtracted from the income PS. Furthermore, the income will be balanced by income taxes PT. What remain are an amount that can be spent (consumption) and an amount that can be saved[3]. This can be considered the inhabitants' net benefit.

Table 10. Distribution of costs and benefits for the actor "Local inhabitants" during operation

Local inhabitants		industry	local public sector	external public sector	external business
Salary	PS	(100%)			
Social security	(PU)		pu_l	$1-pu_l$	
Interest share	PR	(100%)			
Income tax	(PT)		pt_l	$1-pt_l$	
(Sum = Net Benefit)	Savings plus Consumption				

For the other actors similar tables can be set up, but all interactions between the actors are already included in Table 9 and Table 10.

2 If there is full employment in the domain of interest, the demand for extra workforce can lead to extraction of workforce from other duties, to import of workforce from outside the domain as well as to an increase of the level of salaries. These aspects are difficult to predict. A conservative approach would be to neglect the net extra salary in the domain of interest. This means that there would not be a net benefit for the inhabitants in the domain of interest.

3 The difference between consumption and savings is only of interest in case one wants to account for 2^{nd} order effects, i.e. the effect of consumption on the local economy.

An example

As an example (Table 11), we have set up a situation using more or less representative numbers for Danish tax ratios, showing the effect of an investment of 1 million DKK (or whatever other monetary unit one wants to look at) during the operational phase.

It is assumed that this will lead to a yearly turnover of 1 million (inclusive of VAT). The interest rate is 7%, salary costs consume 40% of the turnover, and raw materials ("import") are 10% of the turnover. Industry tax is 30% on profit and income tax in total is about 43% (local tax includes municipal and county taxes). In Denmark, the national authorities collect industry tax and VAT. Social security (unemployment money) is also paid by national institutions, so the savings on social security (assumed to be 250,000 DKK) are to the benefit of the external public sector. In this example, we assume that the industry produces products that are sold outside the domain of interest. Capital providers live also outside the domain.

The two lines at the bottom of Table 11 show some numbers that can be used as attributes: "net benefits" for the different actors as well as the NPV of these net benefits. For the industry, the net benefit is probably equal to the profit (although profit is paid to the owners, here incorporated in "external business"). For the inhabitants, it is the expendable and saved budget and for the public sectors it is the increased tax income. The "local payment balance" (local export minus local import) is the sum of the net benefits for the inhabitants and the local public sector.

Table 11. The effect of an investment of 1 million DKK during the operational phase.

	Industry	Local inhabitants	Local public sector	External public sector	External business
Investment	**1,000,000**				
Salary	-400,000	400,000			0
Import	-100,000				100,000
Capital costs	-70,000	0			70,000
Company tax	-61,500		0	61,500	
VAT	-225,000		0	250,000	-25,000
Turnover/sales	1,000,000	0			-1,000,000
Social security		-250,000	0	250,000	
Local taxes		-25,200	25,200		
External taxes		-13,500		13,500	
Net Benefit	**143,500**	**111,300**	**25,200**	**575,000**	**-855,000**
NPV (25 year/7%)	**1,815,789**	**1,408,344**	**318,870**		

Table 12 is an example of an analysis for the effects of the investment itself. It is assumed that half of the investment requires local workforce and the other half is import. For simplicity, we assume that the investment is depreciated in the first year. Therefore, the investment-related costs and benefits appear only in the first year, so the net benefit can be added to the NPV's for the "operational phase".

Table 12. The effect of an investment of 1 million DKK during the investment phase.

	Industry	Local inhabitants	Local public sector	External public sector	External business
Investment	**1,000,000**				
Salary	(500,000)	500,000			0
Import	(500,000)				500,000
Capital costs	0	0			0
Company tax	0		0	0	
VAT	0		0	125,000	(125,000)
Turnover/sales	0	0			0
Social security		(250,000)	0	250,000	
Local taxes		(49,000)	49,000		
External taxes		(26,250)		26,250	
Net Benefit (equals NPV)	**(1,000,000)**	**174,750**	**49,000**	**401,250**	**375,000**

Note that some industry investments require public investments as well (roads, wastewater treatment, etc.). These expenses can also be included in the scheme, leading to lower (or even negative) benefits for the local public sector. Maintenance costs for these public investments need to be included in the scheme for the operational phase.

A third table would also be required to account for decommissioning and clean up of the site at the end of the lifetime. This can be included in the "Investment table" (Table 12) using the NPV's of the costs and benefits of these activities.

Taking operation and investment together, the NPV's calculated over 25 years in this example will be:

- For the industry: 815,789 DKK;
- For the local inhabitants 1,583,094 DKK;
- For the local public sector 67,870 DKK.

5.3 Other economic values

In the previous section, effects of the changed economic activity directly due to the siting or expansion of an industry are described. However, there may be other effects on economic values in the domain of interest.

Capital goods

The investment associated with the industry's expansion will normally lead to production capacity (capital goods) with equivalent value. However, as we have depreciated the investment in the first year (or otherwise during the economic lifetime) there will be no value remaining after the time horizon. The value of the investment should therefore not be included in the economic valuation of the project.

If there are some investments that have not been depreciated over period of the time horizon (e.g., bridges and similar infrastructure will often have longer economic lifetimes), then the value at the end of the time horizon can be accounted for after transferring this to an NPV.

Real estate

The land-use planning decision may pose restrictions on the use of some real estate property, e.g., the establishment of a safety zone or the extent of a noise contour excludes some land to be residential. As the (market) value depends on the land-use restrictions, it is possible to transfer the restrictions in land use to changes in the total capital value (which can directly be added to an NPV for another economic aspect). It is highly recommended to define a base-line situation, preferably the existing situation that is also used to determine the other economic impacts. Changes in capital value are expressed as changes to this base-line situation. This will prevent that results become very dependent on the definition of the domain of interest.

Evaluation of the local value of real-estate property should only account for property that is owned locally. In most cases, this will mean that the industry's property should not be accounted for.

Compensation

A land-use planning decision may include the necessity of people or businesses to move to other locations. Minimising the amount of people that need to move can be a socio-economic objective as such (as the sociological consequences not necessarily can be expressed by monetary values). But normally, these people or businesses will get financial compensation as well. These compensation costs can be included in the scheme for the investment phase, counting the benefit both for the category that will receive the compensation (this may well be outside the domain of interest if people move outside), as well as the category that will provide the compensation (normally, this will be either the industry or the public sector).

Environmental costs

We mentioned the costs for decommissioning and clean up in the previous sections. One may argue that costs for repairing damage to the environment also should be included. The principle is that only cost and benefits are included in the tables introduced above which actually take place and can be anticipated. This means that e.g. environmental taxes that are agreed between authorities and industry in connection to regular pollutant emissions and the like can be included in the socio-economic evaluation. However, as described in the introduction to this chapter, we suggest to consider effects on the "value" of natural or cultural environments and resources as independent objectives.

5.4 Relevant attributes for the socio-economic objective

Each one of the net benefits presented in the above tables for the relation between industry and local community can be used as adequate attributes to express the effects of the initiative for the corresponding sector or actor. The local benefit (the sum of the benefits for the local inhabitants and the local public sector) might be a very adequate attribute to express the benefit of the community without considering the industry's profit. Only if the industry is owned locally (i.e., the profits of the industry return to the local community), the industry's benefit should be included in the local society's benefit. Otherwise, the industry's benefits need to be treated as a separate objective under "company aspects". The financial socio-economic consequences thus can be expressed as the total sum of the following contributions:

1. The local benefit of the investment phase (year 1);
2. The Net Present Value corresponding to the local benefits during the operational phase during the economic lifetime;
3. The cumulative change of commercial value of real estate property in the domain of interest;
4. Any net effects of compensation in the domain of interest (considering local inhabitants as well as the local public sector and to the extent that this has not been included in the investment costs and benefits);
5. If appropriate, the Net Present Value of any locally owned infrastructure that still represents a value at the end of the time horizon.

Of course, sociological objectives like "minimise the unemployment in the domain of interest" can be added to the above economic objectives.

6 Case study - expansion of refinery

6.1 Formulation of the decision situation

The refinery is covered by the Seveso Directive. In 1991 the refinery submitted an application to the county concerning the establishment of a new process plant and storage facilities. The reasons for the application was a significant resource of condensate found in the Sleipner Field in the North Sea in connection with the exploitation of natural gas. The land-use planning situation can be characterised as an expansion of an existing hazardous installation where only minor changes of the land-use patterns around the site are possible.

The decision to allow the expansion was based on an Environmental Impact Assessment following EU requirements (Directive 85/337) including an assessment of the impact on environment, property and human lives during normal operation and in case of an accident.

The decision process involved the following actors:

- the municipality (officials and politicians)
- the county of Vestsjælland (officials and politicians)
- the Danish Emergency Management Agency: approval according the emergency legislation and on the extent of safety zones,
- the Working Environment Service and the local office: adviser on safety level, safety zones, approval of safety levels
- the company staff
- the public and citizens, during the planning period two public hearings were arranged with invitations to the public and the NGO's 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.

6.2 Factual information about the case

The refinery

The refinery is situated south of Kalundborg 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. About 300 are employed at the refinery and about 100 of the jobs were created by the expansion.

The refinery was established in the early '60s. Until 1991 the capacity was approximately 3 mill. tonnes crude/year. The products are oil products as e.g. gasoline, gasoil, light and heavy fuel, kerosene, propane, butane. After the expansion also a natural gas condensate is produced increasing the throughput capacity to 5 mill. tonnes/year. In 1995 the production was 3.928.000 tonnes. The refinery occupies, the expansion included, approximately 750x850 meters. The refinery consists of: process area (on site), the crude tanks (off site), propane and butane tanks, truck facilities and pier facilities (about 1 km from the refinery). High risk storage includes 3 spherical tanks with propane and butane. The expansion comprised a new process area, a new condensate storage tank, a new LPG storage tank and new petrol storage tanks. Totally, there are 7 spherical and 2 cylindrical tanks. The two largest butane tanks have a capacity of approximately 2830 m^3 each. The pressure is 4 bar.

The first risk analysis was delivered in 1989. According to the authorities the safety level is high and the plant was approved with some minor exceptions and recommendations. The company uses a number of improvement tools and methods, such as ISRS (International Safety Rating System), LCA (Life Cycle Analysis), ISO 9000 and 14000, EMAS (Environmental Management and Audit Scheme) and Synergy (accident reporting and follow-up system).

The area

The neighbourhoods around the refinery can be described as follows (distance from refinery in brackets):

- closest school (750 meters)
- local roads bordering the refinery
- public ferry terminals (1.5-2 km)
- an assembly of residences with about 25 houses (500 meters)
- residential area with 250 houses (1.2 km)
- a small village with 25 houses (200 meters)
- a privately owned castle (750 meters)
- 10 employee refinery owned residences bordering the refinery fence
- a power plant, 1467 MW (250-500 meters)
- high voltage lines and pylons run across the field east of the refinery.

6.3 Objectives and attributes

In this section a list of possible objectives are listed. It shall be stressed that this list was not the basis for producing the conditions for the expansion. Only a few of the objectives were actually defined and used back in 1991 when the decisions about the expansion were made. The expansion of the refinery has been used in LUPACS as a test case and therefore most of the objectives have been invented for this purpose.

The structure of the list of objectives presented in section 3.3 has been used in the development of the following list. First, a gross list was prepared containing all the issues that might be considered, described and discussed in a refinery case. The meta-objectives are presented in Table 13, and for each meta-objective the relevant issues are described.

Safety and accidents

- Harm to human beings: The most severe hazards for human beings onsite and offsite the refinery will probably be a BLEVE (Boiling Liquid Vapour Cloud Explosion) caused by a release of LPG from a storage tank. The consequences can be injuries and deaths (burns, blast, missiles).
- Environmental impact: Release of oil products can cause harm to vulnerable recipients such as: ground, ground water, wetlands, meadows, streams, coast lines, the fjord. Release causes can be: leakage at refinery, ship collision, failures at waste water treatment plant.
- Impact on property: Explosions and fires at the refinery can cause damage to property onsite and offsite.
- Safety zones: In connection with the approval procedure, a safety zone of 300 m around the refinery was defined. Within this zone residential, institutional nor industrial constructions are allowed without prior approval by the Emergency Management Agency.

Table 13. Meta-objectives for the refinery case study.

Objective	Description
Safety and accidents	The risk from production, transport and storage shall be minimised.
Public distortion and health (normal operation)	The life quality and the health of the public should be as high as possible.
Environmental impact (normal operation)	A negative impact on the environment from normal operation is not acceptable beyond the levels defined in the county objectives and national guidelines.
Cultural heritage	Influence on cultural heritage must be minimised. No risk of irreversible damage is accepted.
Natural heritage	Influence on natural heritage must be as little as possible.
Societal/economic aspects	The existing planning basis should be respected if possible. Net societal economic impact should be maximised.
Company aspects	According to the company policy and with as few investments as possible.

Public distortion and health (normal operation)

- Air quality: Emissions from refinery processes can be NO_x, SO_2, soot, VOC (Volatile Organic Compounds). As part of the permission given by the county it was required that a recovery plant was constructed to keep the ambient concentration of benzene in the air at an acceptable level. Further, the transportation of raw materials and products will contribute to the air pollution.
- Noise: Boiler, compressors pumps etc. cause noise at a relatively high level. Further, noise problems can arise due to heave vehicle traffic.

Environmental impact (normal operation)

- Air quality (regional and global): The refinery will contribute to the emission of the so-called green house gases (e.g. CO_2) which might cause climate change. Further, SO_2 and NO_x are released, which contribute to acidification.

Cultural heritage
- Grave mounds, archaeological objects, castles and cultural buildings: Protection zones are defined in the local or regional plans.

Natural heritage
- Nature protection: Nature protection zones concerning birds, wet lands, forests, streams, lakes and coasts.
- Visual disturbances: Light, equipment, flare etc. will have an impact on the visual impression of the area.

Societal/economic aspects
- Occupation: The refinery expansion created approximately 100 new jobs.
- Public costs: The expansion of the refinery required an expansion of the harbour facilities, an increase of the capacity of the waste water treatment plant together with the sewer system and changes in the emergency preparedness. Further, it was necessary to move some high voltage pylons and some wind turbines.
- Public benefits: Increase of industrial activity will contribute to the development of the city and the region.

Company aspects
- Investments: Keep the investments as low as possible using existing staff and facilities as much as possible.
- Interests: Easy access to qualified personnel, access to harbour, reliability of supply systems (energy, cooling water, fresh water etc.).

6.4 Alternatives

This section contains description of the alternatives. It shall be remarked that some are real alternatives which were used during the land-use planning process in 1991 while others are invented only for LUPACS purposes.

Given a significant recourse of condensate found in the North Sea in connection with the exploitation of natural gas the company pointed out 5 possible solutions for refining the condensate:
- Selling the condensate to another company directly from the terminal.
- Contracting with another company to refine the condensate.
- Refining the condensate at a refinery abroad.
- Refining the condensate at the company's Danish refinery.
- Create new capacity at one of the company's refineries.

The last two of the solutions imply production in Denmark. There are 3 alternatives for the refinery case (see Figure 3):

1. No expansion within the county (code B).

2. Expansion at the Kalundborg site - here there are 4 possibilities as presented in Figure 4:
   - south of refinery, within the fence (code K1, the solution chosen in 1991).
   - east of refinery (code K2)
   - west of refinery (code K3)
   - south to the refinery and south of the road (code K4).

3. A completely different alternative could be to build the new refinery capacity at another location in Denmark. For LUPACS purposes a suitable location in the county could be at Stigsnæs (code S) where a large coastal area has been designated for industrial activities. Here there is a deep water harbour, facilities for waste water treatment and a large distance to the closest city.

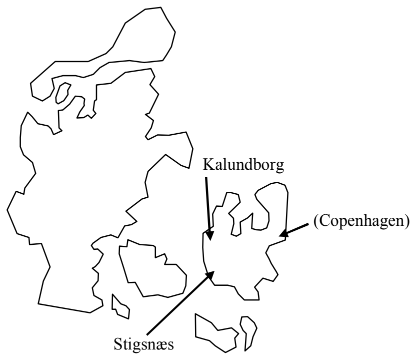


Figure 3. Location of the refinery in Denmark.

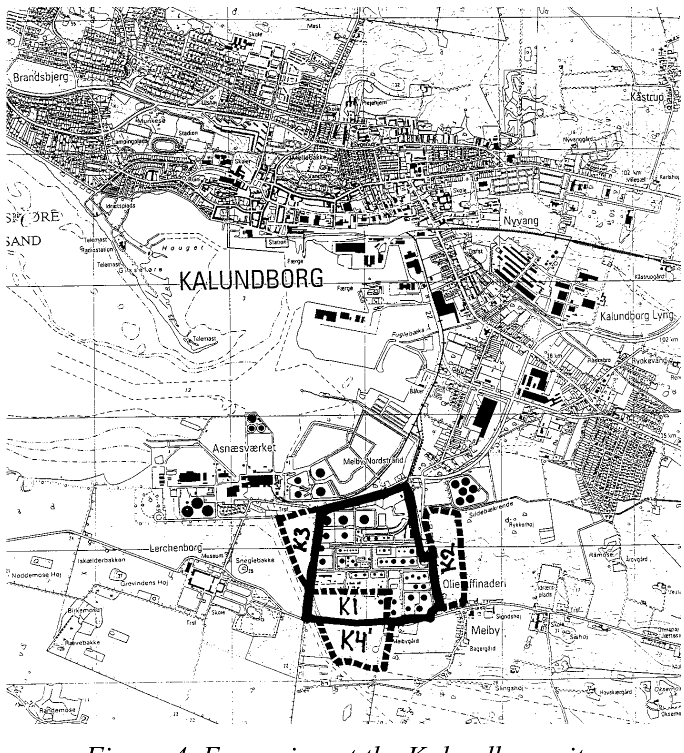


Figure 4. Expansion at the Kalundborg site.

6.5 Assessment of consequences

In this section the assessment of consequences is shortly summarised. Due to the limited resources in the project emphasis has been laid on risk objectives and the other objectives presented in Table 13 have only been treated to a minor extent.

Accident scenarios

Accident potential exists which can cause impact and harm to human beings, the environment and the property. The refinery has carried out the detailed risk analysis (Vestsjællands Amt 1997). The following 10 scenarios were considered:

- Scenario 1 : HCl release from Powerformers
- Scenario 2 : Hydrocarbon release from new process installations with fire ball formation
- Scenario 3 : H_2S release from new process installation
- Scenario 4 : BLEVE from LPG tanks
- Scenario 5 : Flash fire from LPG tanks
- Scenario 6 : BLEVE from LPG tank car ("old" facility)
- Scenario 7 : BLEVE from LPG rail tanker ("old" facility)
- Scenario 8 : Fire in crude oil tanks
- Scenario 9 : Fire in condensate tanks
- Scenario 10 : Fire in petrol tanks

Risk profile input

In Table 14 the contributing hazardous installations are described. In this table, the probability of the event is given. The probability in the risk profile is the conditional individual risk provided the event happens. The (normal) individual risk is the product of the conditional individual risk and the probability of the event. It should be mentioned that the basis alternative B always is present. Thus for the Kalundborg alternatives K1 to K4, the risk profiles for the basis alternative and the expansion should be overlaid and added (risk may be added), for the Stigsnæs alternative (S), the effects in the Kalundborg area and the Stigsnæs area should be added (e.g. the PLL (Potential Loss of Life) in both areas).

In preparing this part of the input, use has been made of available effect-calculations and indications of probabilities for a number of accident scenarios. This needed to be completed with Probit-functions (Lees 1980) to calculate individual risk and in cases of dispersion, the effect-distances needed to be completed with cloud width and wind direction probability. Individual risk contours were centred around the equipment under consideration: alternative location of this equipment involved a shift (linear translation in geometrical terms) of the contours.

Table 14. Risk profiles refinery expansion.

Scenario	Alternative	Frequency of occurrence
S1: HCl release Powerformer	B	2e-8 per year
S1: HCl release Powerformer	K1, K2, K3, K4	1e-8
S1: HCl release Powerformer	S	1e-8
S2: C_nH_m release new process/fire ball S2: C_nH_m release new process/fire ball	K1, K2, K3, K4 S	1.6e-6 1.6e-6
S3: H_2S release new process S3: H_2S release new process	K1, K2, K3, K4 S	4.8e-5 4.8e-5
S4: BLEVE LPG existing tank	B	1e-6
S4: BLEVE LPG existing tank	K1, K2, K3, K4	1e-6
S4: BLEVE LPG existing tank	S	1e-6
S5: Flash fire from existing LPG tank	B	3.5e-5
S5: Flash fire from existing LPG tank	K1, K2, K3, K4	3.5e-5
S5: Flash fire from existing LPG tank	S	3.5e-5

S6: BLEVE from LPG tank car	B	1e-7
S7: BLEVE from LPG rail tanker	B	1e-7
S8: Fire in crude oil tank	B	9e-6
S9: Fire in condensate tank S9: Fire in condensate tank	K1, K2, K3, K4 S	9e-6 9e-6
S10: Fire in petrol tank S10: Fire in petrol tank	K1, K2, K3, K4 S	9e-6 9e-6

Basis for calculation of risk contours

For the calculation of the dispersion of HCl and H_2S, some assumptions were used to extrapolate the information from the available effect-calculations. Plume width and plume height increase both with distance with about $x^{0.8}$, thus maximum concentration at plume centreline decreases with about $x^{-1.5}$. Within one wind direction sector (30 degrees), the probability of being hit by the maximum concentration is equal to sector width divided by plume width, i.e. this will decrease by $x^{0.2}$ (i.e. top hat profile assumed). The probability of wind within a wind direction sector is determined by meteorological statistics. Data based on D5 (neutral atmospheric conditions, 5 m/s wind speed) and F2 (stable atmospheric conditions, 2 m/s wind speed) statistics is combined according to presented release frequencies from the available report. No correction for real wind speed was carried out, therefore the calculations are conservative). The wind direction rose for Stigsnæs is assumed to be the same as for Kalundborg.

In order to transfer calculated exposure concentrations to fatalities, Probit functions are used. For HCl this reads: $Pr=-16.85+2\ln(Ct)$, and for H_2S: $Pr=-31.42+3.008\ln(C^{1.43}t)$, t in min., C in ppm (AIChE 1989).

Assumptions for the calculation of effects from BLEVE and fireball are that the thermal radiation decreases with distance x from the centre of the fire as $1/x^2$. The duration t is 30 sec for BLEVE, Scenario S4, 10 sec for Scenario S2, and 7 sec for Scenarios 6 and 7. The assumed Probit function to relate thermal radiation to fatalities reads: $Pr= -14.9+2.56\ln(tI^{4/3}/10^4)$; I intensity in W/m^2 (AIChE 1989).

Assumptions for the calculation of flash fire (Scenario S5) are equal to those for dispersion. The concentration 0.42*LEL (corresponding to the refinery's safety distance for F2) is interpreted as the contour for 375 kJ/m^2 impact, using the Probit function for heat radiation mentioned for the BLEVE and fireball calculations.

Assumptions for the calculation of crude oil/condensate/petrol tank fires are equal to those for BLEVE calculations, with the same probit function but exposure over 5 minutes (time to find shelter).

Land use options

There are already detailed community plans and regulations regarding allocation/position of existing and future land-use patterns. In other words, there is little freedom in defining new land-use patterns, and therefore it has been assumed that there can be no or little change in the existing land uses. Possible options are to propose restrictions on population densities in the direct vicinity of the plant and to suggest to move the population from a nearby village. The economic benefit of both land-use pattern and plant extension have been determined in terms of capital gain (net present value). This includes: value of land (mainly based on the marked value of houses and industrial estate, if necessary this includes the costs of alternatively moving people to elsewhere); capitalised gain of employment (roughly estimated to be 300 million DKK over a period of 30 years, based on 100 extra employees earning 100 000 DKK a year) in the region; extra company investment costs for certain alternatives (e.g. acquisition of land use or extra cleaning facilities).

Other quantified objective scores

The noise contours were determined, in order to determine the number of people affected by too high noise levels. To prepare this part of the input, use was made of measured noise-levels and expected increases for one alternative at 3 positions. From this, the additional noise intensities were estimated spatially, to be centred at the processing area of the extension. Again, the noise contours shift with the location of this processing area.

The increased risk for tanker accidents in the Kalundborg Fjord has been estimated on basis on accident theory (Fujii & Tanaka, -, Macduff 1974), existing traffic intensity (including high speed ferries: velocity differences between ships are input to the accident model) and expected increase of tanker movements.

Table 15. Probability of oil spills in Kalundborg fjord.

	B per year	**K1-K4** per year	**S** per year
Number of collisions involving tank-ships	0.125	0.177	0.125
Number of groundings involving tank-ships	0.41	0.54	0.41
Number of oil spills (10% of collisions)	0.013	0.018	0.013

6.6 Evaluation and conclusion

As mentioned in section 3.6 a methodological approach developed by the National Centre for Scientific Research “Demokritos” has been used in order to evaluate the developed alternatives (Papazoglou et al. 1998). The approach adopted by this system, is to find the subset of non-dominated solutions or the so-called efficient frontier, which can be used to determine the most preferred alternative among those belonging to the efficient frontier. For the evaluation the underlying objectives can be formulated as follows:

1. minimise the potential loss of life
2. maximise the economic benefit
3. minimise the risk for oil pollution in the Fjord
4. minimise the number of people annoyed by noise

Efficient frontier curves were calculated for each site alternative, having land-use pattern as variable. For each site alternative, one efficient frontier curve includes a large number discrete alternative land-use patterns. In Figure 5. the efficient frontier is presented for alternative K4 (expansion south to the refinery and south to the road). It should be noted that in Demokritos’ system there is a direct link between the presentation of the efficient frontier and a map showing the alternatives (by pointing at a point on the efficient frontier, the corresponding land-use pattern is shown).

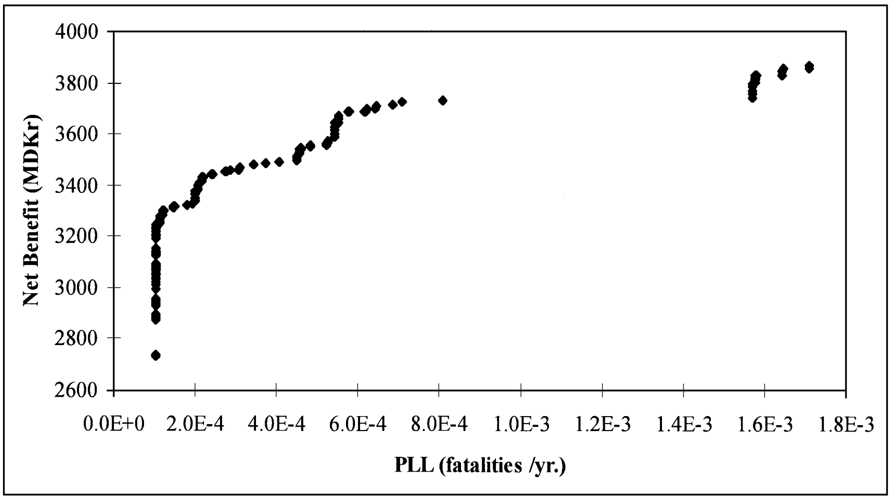


Figure 5. Efficient frontier of K4 - effect of surrounding land-use patterns. Result from the Demokritos's system.

For the refinery expansion case the use of this approach resulted in having 6 efficient frontier curves in one plot. The joint efficient frontier for all alternatives together is the curve that follows/combines the curves which are upper-left most at any PLL-value. It should be noted that the present land use allocation plans are in these graphs somewhere at the highest (upper-right) ends of the curves, because the available options are restricted to diminishing the amount of people nearby the refinery, thereby creating safer and less economical profitable solutions.

If we consider that in the refinery case changing the land-use patterns is not a real option, we have only 5 alternatives: changing the location of the extension around the site (K1, K2, K3, K4), the zero-alternative (B) together with the Stigsnæs alternative (S). They are represented (approximately) in Figure 6.

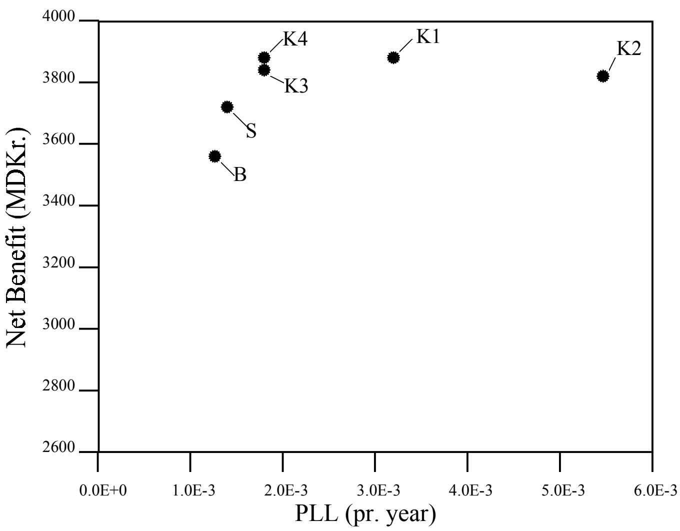


Figure 6. Evaluation of alternatives with no change in land-use pattern. K1 and K2 are not part of the efficient frontier.

From this it is clear that alternatives K1 and K2 (South and East of refinery) are not optimal. K3 and K4 (West of refinery and South of and south of the road, respectively) are very close together. It is obvious why these 2 alternatives are better: the distance to the residential areas is larger than for K1 and K2. The efficient frontier exists of the existing situation (B). The final decision depends on whether one accepts an increase of PLL of about 25% (from about 1.5 10^{-3} to 1.8 10^{-3} per year) for an increase in value of about 300 million DKK.

6.7 Lessons learned from the refinery case study

The refinery case is one out of four in the LUPACS project. The purpose of bringing land-use planning cases into the project is to support the development of the methodology by introducing problems and experiences from real life. The refinery case study has been used with a high degree of freedom compared to the actual treatment and approval of the refinery expansion back in 1991, and alternatives and objectives have been invented for the LUPACS project.

The refinery case study has been essential in the description of the overall structure of the decision process in land-use planning and in the development of objectives. The refinery case study has been carried out in close cooperation with the authorities involved in the planning process and their experiences have been a very important contribution to the work.

From the refinery case study the following specific observations have been made:

- It is important that the overall goal and level of detail of the land-use planning process is discussed and determined in the beginning of the course.
- In the planning process environmental aspects are normally emphasised, but also economic aspects are considered by use of the BATNEEC principle (best available technique not exceeding excessive costs). The planning problem is seldom only a question about how to optimise safety issues, and therefore it is essential that different types of objectives can be taken into account, e.g. protection of ground water. In Denmark the planners consider land-use planning as a process with public hearings which have to be carried in accordance with the requirements described in environmental impacts assessment directive.
- For the time being the competent authority prefers a qualitative evaluation of the alternatives and not a quantitative.
- The Danish planners found the approach using efficient frontiers very difficult to understand, and they recommend that the results must be presented and visualised in an appropriate way. They suggest to perform a more detailed test of the approach before a thoroughly evaluation can be prepared. Furthermore, the approach needs several calculations based on data that might not always be easily accessible. Often the decision process will have more than two dimensions which makes it hard to explore the optimum solution by means of this approach.
- In the development of alternatives the most critical point is to decide if all relevant alternatives have been taken into account. In the refinery case it has been discussed if all possible solutions in Denmark and abroad to the refinery expansion problem should be evaluated, and it was concluded only to include alternatives within the county.
- Having established alternatives at different locations (e.g. Stigsnæs and Kalundborg) a question arose concerning how to compare the alternatives. High weight objectives for one alternative (e.g. noise) might not have the same weight for the other alternative. Further, a general topic was discussed concerning how to determine the set of objectives and how to put the objec-

tives in order of priority. It can be difficult to determine if all relevant objectives are included and evaluated in the right way.
- Finally, it has been difficult to provide all the information and data necessary for the evaluation of alternatives. An example is the economic impact of the refinery expansion on the community's future development.

7 Case study - ammonia pipeline

7.1 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 Fredericia 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.

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.

7.2 Factual information about the case

The ammonia pipeline

The pipeline is transferring ammonia from the storage facilities owned by Ny Nitrogen situated in Lyngsodde south of Fredericia to the fertiliser plant owned by Kemira Danmark A/S situated in Fredericia (see Figure 7 and Figure 8).

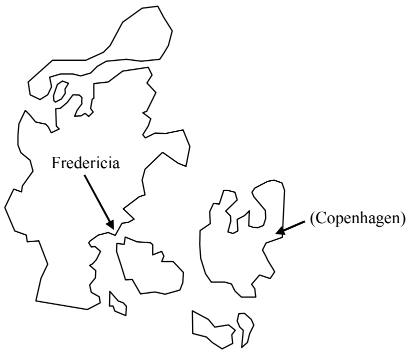


Figure 7. Location of the pipeline in Denmark.

The subterranean pipeline is about 7,3 km long placed in a 1,2-1,5 m deep re-filled ditch. The pipe is made of an insulated steel pipe with an exterior jacket pipe of PEH (polyethylene high density). The pipe diameter is 168,3 mm with a wall thickness of 12,7 mm. The insulation is PUR (polyurethane foam) with a thickness of about 36 mm. Three cryogenic ammonia storage tanks with capacities of 40000, 25000 and 18000 tonnes, respectively, are located at Ny Nitrogen A/S each one equipped with a separate pump station. The ammonia is transferred at -33°C with a capacity up to 60 tons per hour by a maximal pressure of 25 bar and a normal operation pressure on minimum 10 bar. At Kemira the ammonia is warmed up in heat exchangers, which are also used for process cooling purposes, and transferred into two pressurised tanks at a drift pressure of 6,5-7 bar prior to consumption.

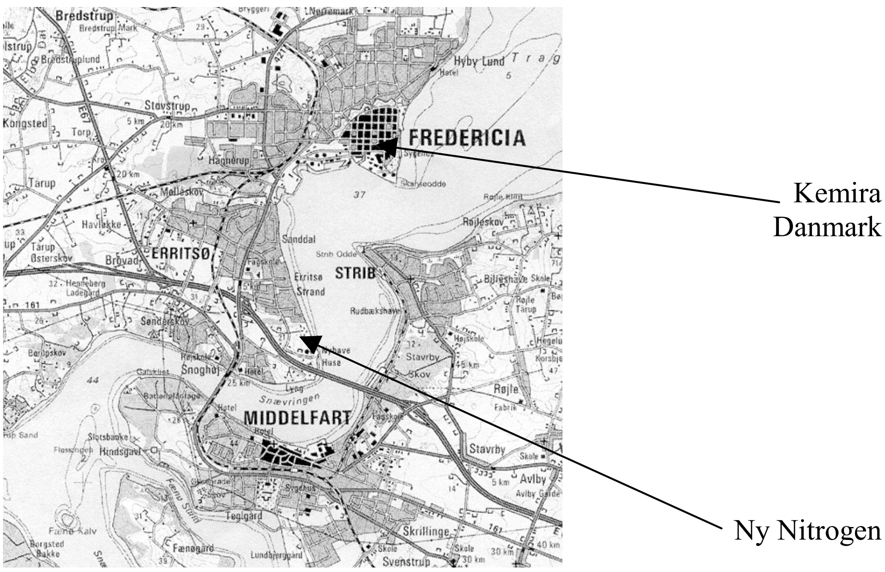


Figure 8. Location of Ny Nitrogen and Kemira Danmark.

The area

The neighbourhoods around the pipeline can be described as follows (distance from pipeline in brackets)

- closest school (50 meters)
- local roads (0 meters)
- residential areas (50 meters).

The pipeline track crosses primarily areas owned by the public, Ny Nitrogen A/S or Kemira Danmark A/S. The largest part of the track is situated in a traffic corridor following the main road. The pipeline passes residences and public buildings (e.g. a school). The areas affected by the pipeline are enjoined by a restrictive covenant to prevent pipeline damage.

7.3 Objectives and attributes

In this section a list of possible objectives are listed. It shall be stressed that this list was not the basis for producing the conditions for the expansion. Only a few of the objectives were actually defined and used back in 1992 when the decisions about the pipeline were made. The ammonia pipeline has been used in LUPACS as a test case and therefore most of the objectives have been invented for this purpose.

The structure of the list of objectives presented in section 3.3 has been used in the development of the following list. The meta-objectives for the ammonia pipeline case study are presented in Table 16, and for each meta-objective the relevant issues are described.

Safety and accidents

- Harm to human beings: The most severe hazards for human beings onsite and offsite the refinery is release of ammonia. The probability for a large leak in the pipeline is very low, but the pipeline can be damaged by e.g. foreign contractors, corrosion, leaks due to defects in welding, not following the start-up and shut-down procedures.
- Environmental impact: Gaseous releases of ammonia will cause harm to human. Possibly, the vegetation might be damaged up to 100 m from a leakage. Ammonia is very water soluble and might be leached with rain into the ground water or will be washed into surface waters, where it might harm fish. Soil pollution is unlikely as ammonia has a high vapour pressure and gaseous to ambient temperatures.

Table 16. Meta-objectives for the ammonia pipeline case study.

Objective	Description
Safety and accidents	The societal risk from transport, storage and handling of ammonia shall be reduced significantly compared to previous technical configuration.
Public distortion and health (normal operation)	The life quality and the health of the public should be as high as possible.
Environmental impact (normal operation)	The environmental impact shall be low.
Cultural heritage	Influence on cultural heritage must be negligible.
Natural heritage	Influence on natural heritage must be minimised.
Societal/economic aspects	The existing planning basis should be respected if possible. The public cost to establish the new pipeline and for the emergency response should be a minimum.
Company aspects	Reduction of the resources spent on provision of ammonia to the fertiliser plant. Maximal pay-off.

Public distortion and health (normal operation)

- Air quality: The most important emission is expected to be ammonia located at the end points of the facility at Ny Nitrogen and Kemira. Gas emissions shall pass through a scrubber system.
- Noise: Compressors pumps etc. cause noise at a relatively high level but no residencies are situated close the equipment.

Environmental impact (normal operation)
- Ground water: To protect the ground water a procedure shall be available for protection of the ground water with respect to handling, collection and pumping of ammoniacal water.

Societal/economic aspects
- Occupation: Establishment of the ammonia pipeline reduced the staffing requirements for ammonia sea transport with about 5-10 jobs.
- Public costs: The ammonia pipeline reduced the public income from harbour charges with about 2 mill. DKK. per year
- Public benefits: Continued industrial activity will contribute to the development of the city and the region.

Company aspects
- Investments: Cost of construction for the ammonia transport facility was about 50 mill. DKK.
- Savings: About 2 mill. DKK. per year in harbour charges and about 1,2 mill. DKK per month for transport by ship. In total about 15 mill. DKK per year.

7.4 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 by keeping the ammonia storage tank in the centre of the Fredericia and transporting ammonia 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 following 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 dunes 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.

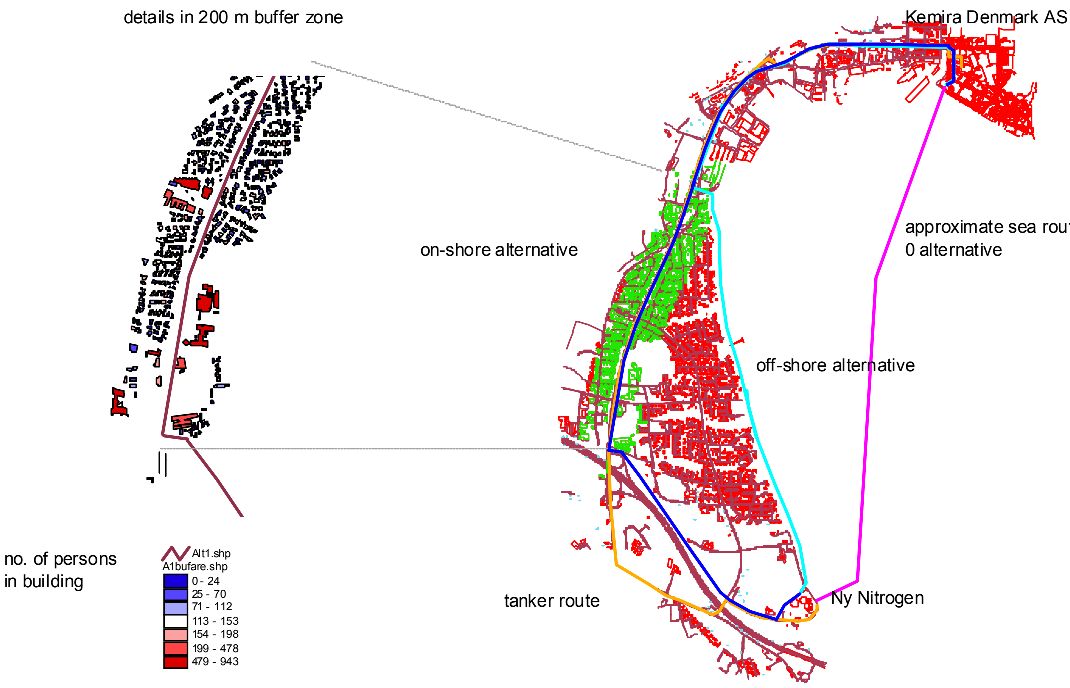
7.5 Assessment of consequences

In detail the on-shore line following the traffic corridor through Fredericia and the off-shore shallow water alternative to the marina were discussed. The risk assessment for these alternatives gave no remarkable difference for the societal risks and both are close to the acceptance criteria of 10^{-6} fatalities per year recommended by the Danish Environmental Agency. This is an improvement compared to the shipping solution. The accident frequency for both was about the same. Nevertheless, it was concluded that the consequences for the off-shore pipeline would be greater, but as the population density on the sea side is zero the calculated societal risk was only slightly higher compared to the on-shore line. The only difference was the expected time for maintenance and repair, as such work off-shore was expected to take about 3 weeks, much longer than for the on-shore pipeline. During that period trucks have to transport ammonia to the chemical plant inducing a high societal risk not acceptable under the criteria adopted by the municipalities. Further, there have been many concerns on littoral drifts along the coast and the possibility of pipeline damage due to ice packing along the coast by the plot owners near the planned pipeline.

The main discussion was the application of the GIS system (Geographic Information System) to support the decision makers and planners (Brazier & Greenwood 1998). The maps of the area browsed by the GIS system makes it easy to select the relevant areas and to visualise the isorisk curves. But, GIS system has a much wider potential of applications as it helps to combine the different information needed, keep track on these information, combine databases and helps by allowing spatial database requests, e.g. to find the number of buildings in a 200 m buffer around the pipeline (see Figure 9). It is e.g. also possible in a GIS to combine data from administrative databases with a distribution model like the Danish Operational Street Pollution Model (OSPM) to facilitate exposure to traffic air pollution using GIS (Jensen 1998) and make statistics on the extracted database information. To calculate the societal risk is a rather time consuming work as a number of population densities and wind direction probabilities have to be calculated for a number of areas. This would be greatly supported using a GIS, as it calculates very easily population densities in different areas and can combine meteorological data into it to find the wind direction probabilities. Of course, to be able to make such calculations, a large amount of data are necessary and it might be very time consuming just to find the data for each new risk assessment and planning case. On the other hand, these basic data for a region are also of interest for other tasks e.g. maintenance of technical installations, as e.g. telephones, electric power supply, streets, routing of public services and many others. Therefore, a good strategy would be to establish a central GIS server system to provide topographic, meteorological and geological maps, demoscopic and emergency data (location of fire stations, number of rescuers available, beds in hospitals etc.) which can be easily accessed by the planners.

Once the planner has collected and integrated the data in the "case" GIS database, it is easy to go through different alternatives comparing them and make presentations to inform the public and politicians. Another aspect is that the GIS could help to order and track all the huge amount of documents, photographs, maps, demographical data and models, as it is possible to establish a database and to link the photographs and documents to the objects they describe. An example on the combination of the presentation and structure of maps and their linked attribute tables is shown in Figure 9.

Figure 9 presents the alternatives, which have been taken into account in the LUPACS discussions. The maps are partly imported and converted CAD drawings and partly (i.e. the routing of the alternatives) have been prepared by using the GIS tool 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 also 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 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 or using on average a certain building according to the database information. The table with the database information is shown just below the map. From the thematic map, the red coloured buildings indicating the highest number of persons in a building are readily seen. Further a table with statistics based on the data extracted for the buffer zone is shown. The shown data (prices and persons) have been invented 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. 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 that is to identify objects which might damage the pipeline in emergency situations.



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
T_000_BYGVAERK
T_000_BYGVAERK
T_100_BYGNTAG
T_100_BYGNTAG
T_100_BYGNTAG
T_100_BYGNTAG
T_100_BYGNTAG
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_SILO_TANK
T_100_BYGNTAG

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 9. Structure and application of a GIS database.

7.6 Lessons learned from the ammonia pipeline study

The ammonia pipeline case study has been used with a degree of freedom compared to the actual treatment 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 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.:
  - public emergency institutions
  - industries and other installations (pipelines, sewer systems, public supply systems etc)
  - population density
  - present land use
  - ground water reservoirs
  - recreational areas
  - natural and cultural heritages.

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

- Possibilities for link 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.:
  - physical, chemical and health properties of chemicals
  - meteorological factors (wind direction, atmospheric stability etc.)
  - demographic information (time for public arrangement, e.g. open air concerts, sport matches)
  - actual photographs of technical installations and surroundings.

- Disadvatanges: The application of GIS system needs a certain infrastructure to provide compatible and reliable digital data and maps to support the planner/decision maker
  - such a infrastructure is not fully implemented in all countries
  - using the system requires specific training.

8 Discussion and conclusion

A methodology for land-use planning involving chemical sites has been developed for making decisions in local and regional administrations. It has been the intention to seek a model, that combines decision logics with the flows in the administrative process. Real life decisions seldom result from considering one or two objectives and performing a few logic operations, rather they are complex situations with actors struggling to find their ways through decision space towards applicable solutions. Where chemical substances are processed, produced or stored, land-use planning must check risk parameters, in order to protect people and environment, but economy and a series of other parameters also influence the outcome of planning decisions, either as formalised inputs or as parameters in judgements and bargaining.

The work frame or methodology presented treats the planning process as a multicriteria decision. The development draw on two initial approaches, one signifying the planning decision, the other signifying the planning process, and it progressed in close connection with two application cases. As the project team is made of both scientists and experienced physical planners, these cases acquired a central role as "test sites" for decision and as representatives of real life planning. With a computer tool their own construction Demokritos was able to calculate and present the efficient frontier for the first Danish case, thus demonstrating a means for presenting the choice with two parameters.

By giving both a decision model and the objectives-and-attributes set, one stages the background for the development of decision support tools. The method can basically serve regulators with different national practices, but at a later stage of development, where actual tools can be detailed and decision space actually is constructed and presented to decision-makers, the resulting tools may look rather differently.

The refinery case study has been essential for the development of the overall structure of the decision process in land-use planning and in the development of objectives. The framework was subsequently applied in the ammonia pipeline case study and the general list of meta-objectives supported the description of the decision process very well although not all the meta-objectives were relevant for this case. It will be of interest to test the list of objectives on other cases involving establishment or modification of chemical sites to verify the completeness and coverage of the framework.

The land-use planning process has the following characteristics:

- risk parameters are active in (nearly) all such decisions
- other objectives can be activated in the decision
- inventing new alternatives during the decision process can be a positive side effect
- the process is more circular than linear.

One of the central issues of the decision process is to evaluate and rank the objectives, and to compare alternatives with respect to advantages and disadvantages. For this purpose, it is essential - but not necessarily sufficient - that the alternatives are described in a uniform and consistent way. A key objective for one alternative might not have the same weight for other alternatives and a main issue is therefore how to choose the set of objectives and how to order the objectives after priority.

The work reported above dwelled with difficulties that are often met with multicriteria decisions, namely the matter of selecting proper objectives and of finding adequate measures for meeting these objectives. It has been discussed to which extent it is possible or reasonable to express the attributes in quantitative, qualitative or semi-quantitative terms. Examples on quantitative objectives and attributes related to fatalities and injuries have been collected together with considerations on socio-economic relationships and objectives. The open question is whether this type of attributes will be used and accepted when the authorities present the results for the politicians, the company and other actors involved in decision process. Risk questions and decisions are often characterised by differences in knowledge and values among the actors, which can lead to difficulties in reaching consensus about objectives and attributes for the decision. Furthermore, different views on ranking of objectives may influence the final decision.

For some planning objectives it is awkward or even impossible to specify quantitative representations - for instance about aesthetics, about the value of "nature", about cultural relations - and efforts on circumventing that problem were not large in this project. Mostly, this is assumed to be covered through the hearings etc., i.e. through contacts by the planner to interested parties and key persons as well as through the contacts, where other actors take on the decision maker's role.

Development of alternatives is a complicated task. There are at least two significant questions:

a) How can it be ensured that all relevant alternatives are considered ?
b) Which limitations and restrictions are set on the decision situation by political attitudes, company interests and viewpoints from other actors ?

In Denmark land use decisions concerning chemical sites are often taken at local or regional level and in practice it may be difficult to include alternatives involving other areas of the country or solutions affecting other countries. For the ammonia pipeline case study it was only of interest to consider alternatives at the local level, but with the refinery case study also alternatives at national level could in principle be taken into account.

The collection of data and information is a critical point in the decision process. One problem which the planners often have to face is the limited resources allocated for the land-use planning task and the time restrictions on the decision process. From a user point of view it is of interest to have a decision support tool to structure and schedule the planning process which also deals with tasks closely related to the decision process like suitable presentations, guidelines, procedural support, documentation templates etc. A second problem is to provide the necessary data and information. In many cases it can be very time consuming and expensive to collect the needed data and information or to carry out investigations and calculations producing input data to the decision process. It shall be emphasised that in several parts of the planning the authorities and other actors prefer a qualitative assessment to a quantitative one, this has to be considered when an actual decision is planned.

Probably the most viable result of the efforts presented is the investigation of planning practice governed by the multicriteria decision view and by the intent to construct a supportive frame for the planning decision. The cases together with two Swedish cases were useful also for developments of presentations of the Demokritos tool. Land use planning can be supported through methodologies, specific tools and education of planners, but investigations like the one reported here throw light on society's planning problems in general. It is definitely demonstrated, how measurements are mixed with inputs, that are sometimes difficult to measure, sometimes difficult even to detect, but in one end, land use planning has many parameters that indeed are measurable: geography, risk, economy etc.

9 Glossary of terms in relation to multi-objective decisions

Actors. Persons involved in the decision making process or interested or affected by the decision (Berrogi 1996).

Affected parties. People, groups or organisations that may experience benefits or costs as a result of a decision about land use (Stern & Fineberg 1996).

Alternative. A possible solution. Each alternative is fully and uniquely described by the set of available *decision variables*, such as land-use pattern, location of the site, etc. An alternative is only considered valid if its decision variables or implications do not violate a *restriction.*

Attribute. Variable used to quantify the implication of an *alternative* with respect to an *objective.* The attribute provides a scale for measuring to what degree its respective objective is met. An attribute needs to be <u>comprehensive</u> (i.e. provide sufficient information to assess to what extent the associated objective is met) and <u>measurable</u> (if necessary on a <u>subjectively</u> defined scale) (Keeney & Raifa 1993).

Consequence. The consequence (singular) is the complete set of implications associated with an alternative. In other words, the consequence (according to (Keeney & Raifa 1993)) is determined by the whole *consequence vector*. NB. It might be more appropriate to define the consequence as the single implication for a single objective (Keeney & Raifa 1993).

Consequence variable. See *attribute.* Also used as numerical evaluator or descriptor for an attribute (Keeney & Raifa 1993).

Consequence vector. Set of *attributes* associated to an *alternative.* The dimension of the vector (number of elements in the set) is equal to the number of *attributes* (Briassoulis & Papazoglou 1994).

Decision maker. Person who has the competence and the responsibility for a decision, e.g. director of an enterprise or politicians.

Decision variables. The parameters and factors under control by the decision maker, each set of decision variable values constitutes an *alternative* (Briassoulis & Papazoglou 1994).

Deliberation. Any process for communication and for raising and collectively considering issues. In deliberation, people discuss, ponder, exchange observations and views, reflect upon information and judgements concerning matters of mutual interest, and attempt to persuade each other. Deliberation about risk often includes discussions of the role, subjects, methods, and results of analysis. Bargaining and mediation are specific deliberative processes, as are debating, consulting, and commenting (Stern & Fineberg 1996).

Dominate. One *alternative* dominates another alternative when all *consequence variables* (numerical evaluators) for the first alternative are at least equally preferable to those of the other alternative <u>and</u> when also for the first alternative at least one consequence variable is preferable to that of the other alternative (Briassoulis & Papazoglou 1994), (Keeney & Raifa 1993).

Efficient frontier. Set of alternatives which are *optimum solutions,* i.e. alternatives which are not dominated by other alternatives (Briassoulis & Papazoglou 1994), (Keeney & Raifa 1993).

Evaluation criteria. See *attribute.*

External factor. Relations, parameters or events that do not have a direct impact on the problem but can have a strong influence on the solution, e.g. energy crises. External factors are difficult/impossible to regulate (Sørensen 1995).

Goal. Wish to achieve a predefined level of performance, e.g. "less than 5% of the population should be exposed to noise levels higher than 50 dB(A)". In contrast to *objectives*, one can only determine whether the goal is met or not met. Thus the *attribute* associated to a goal can only have two (logical) values: true or false. It is preferable to interpret or enforce goals as *restrictions*, except if *alternatives* for which the goal is not met are still acceptable solutions (Keeney & Raifa 1993).

Interested parties. People, groups or organisations that has to be informed about and involved in the characterisation of the land-use problem or decision making process. Interested parties may or may not also be affected parties (Stern & Fineberg 1996).

Internal factors. Relations, parameters or events having a direct impact on the problem which can be used in the regulation and planning process (Sørensen 1995).

Objectives. Set of wishes that is pursued by the decision maker. An Objective is a statement about the desired state of the system. Objectives may be organised in a hierarchy, such that an objective is subdivided in lower-level objectives. The lowest-level objective is associated with a single *attribute.* Objectives have to be formulated in terms of "minimise ..." or "maximise ...". The objectives should not be *redundant* (Keeney & Raifa 1993).

Optimum solution. *Alternative* for which one can not find another alternative for which at least one *consequence variable* (numerical evaluator) is better (=preferable) while the other consequence variables are the same (Briassoulis & Papazoglou 1994).

Proxy attribute. A proxy attribute is one that reflects the degree to which an associated objective is met but does not directly measure the objective, and thus indirectly measures the achievement on a stated objective (Keeney & Raifa 1993).

Redundant. *Objectives* are redundant if they express the same aspect. Redundant objectives do not add new information to the problem. In other words, neglecting redundant objectives will not change the conclusions of the analysis. E.g.: if the dispersion pattern of NO_2 and SO_2 is exactly the same, then the objective to minimise NO_2 concentrations at residential areas is redundant to the similar objective for SO_2. Note that, if the (type of) health impact of NO_2 is completely different than for SO_2, then the two objectives to minimise the health impact from both substances are not necessarily redundant (although the two impacts may possibly be combined into a single objective with respect to health) (Keeney & Raifa 1993).

Restriction. A restriction prohibits or enforces certain implications (e.g. "No inhabitant may be exposed to an individual risk larger than 10^{-5} per year") or *decision variables* (e.g. "at least 100 ha in this area need to be residential area"). In practice, restrictions reduce the number of the acceptable solutions (*alternatives*). Some "restrictions" may not turn out to be so strict after all, thereby hiding "hidden agendas" by some actors. Therefore one might sometimes prefer to use the term '*goal*', allowing alternatives in the evaluation for which certain 'goals' are not met.

Root objectives. The *objectives* to be used in the decision process can often be identified by a more in-depth analysis leading to the determination of the evaluation/root objectives.

Trade-offs. How much of objective "a" is a decision maker willing to sacrifice for the benefit of objective "b". Weights are used as a representation of the relative importance of the objectives. Direct estimation of this relative importance by assigning a value to each objective proves to be a very difficult task for the decision maker (Janssen 1992).

Utility function. A function transforming the *consequence vector* to a single value: the utility. The function includes the trade-offs between different levels of consequences as well as between different types of consequences (i.e. different *objectives*). (Keeney & Raifa 1993).

10 Acknowledgement

The authors wish to thank the work performed in the frame of the LUPACS project by our partners at Swedish Rescue Services Agency, Göteborg University (Sweden), Joint Research Centre (Ispra), National Centre for Scientific Research "Demokritos" (Greece), Université Paris VI Laforia (France) and County Board of Södermanland (Sweden).

Furthermore, we wish to acknowledge the CEC Environment and Climate programme for sponsoring the LUPACS project.

11 References

Amendola, A., Chaugny, M., (1994). *Gravity Scales for Classifying Chemical Accidents*, ESReDA Seminar on Accident Analysis, Ispra, Oct. 13/14 1994.

American Institute of Chemical Engineers (1989). *Guidelines for Chemical Process Quantitative Risk Analysis*, Center for Chemical Process Safety, New York, 585 pp.

Berrogi, G.E.G. (1996). *Visual interactive decision modeling in regional safety management,* ESREL-96/PSAM III, pp. 1971-1976.

Brazier, A.M. Greenwood, R.L. (1998). *Geographic information systems: a consistent approach to land use planning decisions around hazardous installations,* Journal of Hazardous Materials, vol. 61, pp. 355-361.

Briassoulis, H., Papazoglou, I. (1994). *Determining the uses of land in the vicinity of major hazard facilities*, Computer Support for Environmental Impact Assessment, B-16, p.177-186.

Cristou, M.D. (1997). *An overview of the approaches followed across Europe in support to land-use planning decisions concerning industries handling hazardous materials*. Joint Research Centre of Ispra, ISIS/SMA 3211/96, 102 pp.

Cristou, M.D., Porter, S. (editors). (1999) *Guidance on land use planning as required by Council Directive 98/82/EC (Seveso II).* Joint Research Centre, European Commission, EUR 18695 EN, 58 pp.

Diamond, J.T., Wright, J.R. (1988). *Design of an integrated spatial information system for multiobjective land-use planning,* Environment and Planning B: Planning and Decision, vol. 15, pp. 205-214.

Finansministeriet (1990). *Vejledning i samfundsøkonomisk projektvurdering.* Statens Informationstjeneste (Guidelines for societal economic project assessment), 88 pp, (In Danish).

Fthenakis, V.M. (1993). *A review of accidents, prevention and mitigation options related to hazardous gases.* Brookhaven National Laboratory, Upton, Long Island, NY 11973, BNL-49192 Informal Report, 17 pp.

Fujii, Y., Tanaka, K. *Traffic capacity. Studies in Marine Traffic Engineering.* Journal of Navigation, Vol. 24, no. 4, p543-552.

HSE (1986), *A guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985 (RIDDOR),* Health and Safety Executive, Health and safety series booklets HS(R)23, St Hugh's House, Stanley Precinct, Bootle, Merseyside, L20 3QY, UK.

Janssen, R. (1992). *Multiobjective Decision Support for Environmental Management,* Kluwer Academic Publishers, The Netherlands 230 pp.

Jensen, S.J. (1998). *Mapping human exposure to traffic air pollution using GIS.* Journal of Hazardous Materials, vol. 61, pp. 385-392.

Keeney, R.L., Raiffa, H. (1993). *Decisions with multiple objectives. Preferences and value tradeoffs.* Cambridge University Press, 569 pp.

Lees, F.P. (1980). *Loss Prevention in the Process Industries*, Butterworths, London, ISBN 0 408 10604 2, 1316 pp (2 volumes).

Macduff, T. (1994). *The Probability of Vessel Collision*. Ocean Industry, Sept. 1974.

Malmén, Y., Nissilä, M., Rasmussen, B., Rouhiainen, V. (1992). *Nordic Experiences and Future Trends for the Preparation of Safety Reports*, Nord 1992:46, Nordic Council of Ministers, 178 pp.

Mintzberg, H., Raisinghani, D., Théorêt, A. (1976). *The Structure of "Unstructured" Decision Processes,* Administrative Science Quarterly, June 1976, Volume 2, pp. 246-275.

Papazoglou, I.A., Nivolianitou, Z.S., Bonanos, G.S. (1998). *Land use planning policies stemming from the implementation of the SEVESO-II Directive in the EU.* Journal of Hazardous Materials, Vol. 61, pp. 345-353.

Rasmussen, B., Grønberg, C.D. (1997). *Accident knowledge and emergency management.* Risø-R-945(EN), 223 pp.

Soby, B.A., Ball, D.J., Ives, D.P. (1993). *Safety Investment and the Value of Life and Injury*, Risk Analysis, Vol. 13 No. 3, pp 365-370.

Sonnich Thomsen, E., Written communication, December 1997.

Stern, P.C., Fineberg, H.V. (1996). *Understanding risk. Informing decisions in a democratic society*, National Academy Press, Washington , 249 pp.

Styhr Petersen, H.J., (1984). *Acceptabel risiko* (Acceptable Risk), Dansk Kemi 1, pp 4-6, 1984 (In Danish).

Sørensen, L. (1995). *Multikriterieanalyser - Multikriteriemetoders anvendelse i energiscenarieanalyser (*Multi Criteria Analysis - Usage of Multi Criteria Methods in Energy Scenario Analysis*),* Risø-R-836 (DA), 86 pp. (In Danish).

Torvi, D.A., Dale, J.D. (1994). *A Finite Element Model of Skin Subjected to Flash Fire*, Transactions of the ASME, Vol. 116, pp 250-255.

Vestsjællands Amt (1997). Information and material from the County Board of West Zealand.

Walker, G. (1995). *Land-use planning, industrial hazards and the "COMAH" Directive,* Land Use Policy, Elsevier Science Ltd. vol. 12, no. 3, pp. 187-191.

Zhu, X., Aspinall, R.J., Healey, R.G. (1996). *ILUDSS: A knowledge-based spatial decision support system for strategic land-use planning*, Computers and Electronics in Agriculture, 15, pp. 279-301.

Bibliographic Data Sheet	**Risø-R-1106(EN)**

Title and authors

Multi-objective decisions in land-use planning involving chemical sites

Birgitte Rasmussen, Ib Bertelsen, Vibeke Burchard, Peter Christensen, Nijs Jan Duijm, Carsten D. Grønberg, Frank Markert

ISBN			ISSN
87-550-2523-4 : 87-550-2524-2 (internet)			0106-2840
Department or group			Date
Systems Analysis			May 1999
Groups own reg. number(s)			Project/contract No(s)
12100051			ENV4-CT96-0241
Pages	Tables	Illustrations	References
57	16	9	30

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 structures the planning process in seven steps, where one can loop through the steps as several times. Essential parts of the methodology are the specification of objectives and the development of alternatives where the objectives sets the frame in which the alternatives are assessed and compared. The list of objectives includes the following items: safety and accidents, public distortion and health, environmental impact, cultural and natural heritage, societal and company aspects. Focus is laid on the safety related items, and objectives and attributes related to safety are discussed in detail. An approach based on efficient frontier curves has been used for comparison of alternatives having land-use pattern as variable. In the development of the method case studies from Sweden and Denmark have been used, and essential topics and results from two Danish case studies are presented.

Descriptors INIS/EDB

Available on request from Information Service Department, Risø National Laboratory,
(Afdelingen for Informationsservice, Forskningscenter Risø), P.O.Box 49, DK-4000 Roskilde, Denmark.
Telephone +45 46 77 40 04, Telex 43 116, Telefax +45 46 77 40 13