Evaluation of the use of Advanced Information Technology (Expert Systems) for Database System Development and Emergency Management in Non-Nuclear Industries

Rasmussen, Jens; Pedersen, O. M.; Grønberg, C.D

Publication date:
1986

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

EVALUATION OF THE USE OF

ADVANCED INFORMATION TECHNOLOGY (EXPERT SYSTEMS)

FOR DATA BASE SYSTEM DEVELOPMENT

AND EMERGENCY MANAGEMENT

IN NON-NUCLEAR INDUSTRIES

REVIEW PROJECT FOR JRC-ISPRA
Contract No. 2605-84-12 ED ISP DK

Jens Rasmussen, O. M. Pedersen, And C. D. Grønberg

Risø National Laboratory
Dk 4ooo Roskilde, Denmark

LIST OF CONTENTS:

1. INTRODUCTION

The current trend in the industrial development is towards large, centralized production units and there is, consequently, an increasing potential for severe accidents. This in turn creates an increasing demand on methods for systematic risk analysis and - in case of release of the accident potential - means for effective emergency management. At the same time, there is a dramatic development within electronic information technology and, quite naturally, widespread efforts to exploit this technology in the design of systems for support of systematic risk analysis, decision support systems for operating crews during plant disturbances and accident control, and for support of the general emergency management organization. The topic of the present report is a feasibility study aiming at identification of the key problems in non-nuclear industrial emergency management for which the use of modern information technology at present appears to offer solutions, and to point to the lines of necessary development. The study will be divided into a number of sections, each having a specific focus:

First, a selective review has been made of the state of the art of decision support systems and "expert systems" with the aim of selecting a conceptual framework for the subsequent analysis and of identifying tools for promising system design approaches. From this review it appears that the present development of models of decision support systems based on the system theoretic point of view and the concurrent swing towards more cognitively oriented task analysis offer a suitable framework. Furthermore, AI-tools for data base design and for communication for distributed decision making should be considered carefully for a more detailed development.

An analysis of the specific problem domain of emergency management in more detail supports the proposal for use of a cognitive task analysis framework. In particular, the framework seems to be a very suitable tool for identifying the relationships between information sources, information users, as well as the content of the information needed in decision situations during emergency management. In addition, it will be effective for specification of the information formats to be used in risk analysis reports, inspection reports, and data bases of the various relevant services and authorities, in order to make the information accessible during emergency situations.

Finally, reports from a number of recent Danish industrial accidents have been reviewed, and key persons interviewed, to give a

preliminary basis for judging the feasibility of the theoretic discussion. In order to give a background for the use of Danish case stories, the organization of emergency management in Denmark is briefly described.

The result has been that there is a potential for development of a distributed data base for support of emergency management, if the information need of the actual task forces is studied carefully, and the proper formats of information and suitable retrieval attributes are derived from such studies. Tools for such studies are now available. In addition, the administration of the data bases of a number of services and authorities will have to be studied, and means for coordination developed.

The report ends with a number of recommendations to this effect.

2.REVIEW OF THE STATE OF THE ART OF DECISION SUPPORT SYSTEMS

The purpose of this review is a identification of the various lines of development of advanced information systems which are intended for support of distributed decision making, and for data base querying and consulting systems.

Design of advanced information systems is an activity in the intersection of the active interest of several professions such as management science, economics and organizational science, computer systems engineering, information and software science, operations research, etc., together with the professions of the different application domains. The approaches taken to the application of advanced information technology have consequently been from different points of view, and the emphasis has been different. What is taken for granted in one program of development, turns out to be a research issue in other programs. Therefore, to have a guide for a review of the vast literature, an overview of the characteristics of the different lines of approach will be useful.

2.1 Management Information and Decision Support Systems

Support of administrative and managerial activities in institutions and commercial organizations is the classical domain for development of information processing systems. In such organizations, a group of decision makers with different roles are interacting with and sharing a common problem domain, for which the state of affairs is represented in the data base of an information system. Several approaches have been made towards the introduction of decision support functions in this information system.

Until recently, the behaviouristic research paradigm has been in control of psychological and social studies and, consequently, the explicit study of the cognitive processes involved in decision making tasks has not been considered an acceptable approach. Development of managerial decision support systems has, therefore, been pursued separately in two schools, one based on a management science perspective, focusing on the formulation of rational, normative decision making strategies based on objective economic analysis of the problem domain, another based on a social science perspective and focusing on the social system considering the roles and needs of the people in the system. The two approaches considering what are generally labelled "management information systems" and "decision support systems", respectively, have been considered alternative paths to a solution, an attitude which has caused considerable controversy. However, due to increasing understanding of the cognitive aspects of decision making, a more integrated view of the system has recently been evolving. These lines of development will be briefly reviewed.

Management science approach. A major class of proposals for decision support systems has been based on decision making research rooted in economic theories, in particular the expected utility theory developed by economists and mathematicians. The approach focuses on decision making from a prescriptive point of view only. It is a logical structure for decisions and makes no claim that it represents or describes the information processing of human decision makers. The emphasis is not on what they do, but on what they should do. Modern theorists (Keeney and Raiffa, 1976) emphasize the mathematical modelling of subjective probability and utility and promote the use of the theory to aid decision makers to achieve logical consistency. Management scientists typically base their system design on the assumption that managers will be able to, and want to, apply formal, optimal decision strategies derived from economic theories, if supported by suitable information systems based on such theories. This means that decision makers should alter their practice when supported by the system. A general criticism of this approach has been that the formal models based on economic or decision theories fail to appreciate the complexity of the challenges under which real-world decision makers must operate. Critics of decision theory also argue that it is not useful as a guide because human beings do not behave in accordance with the fundamental assumptions of the theory.

In fact, management information systems based on such models have not been particularly successful for a number of reasons, such as:

- Higher level executives do not follow the normative decision models (Mintzberg, 1973, Dreyfuss et al., 1980).
- They do not take into account the intentional nature of the systems to be controlled (Rasmussen).
- They do not consider that needs and tools vary considerably with the role of the decision maker and his position in an organisation (Sutherland, 1983).

This does not, however, exclude the usefulness of the rational, normative decision models when implemented in consistent computer programs. Only well defined analysis tasks should, however, be allocated computers, and only in support of human users who can evaluate the necessary preconditions and data. The critique of the use of decision theoretic models for decision support systems is valid only for situations when the system forces a user to use normative procedures against his actual needs.

Social science approach. Whereas the management science approach is focused on the problem characteristics, the perspective of the social science is primarily concerned with the characteristics of the decision makers and their social roles. Contrary to a normative view of decision making, the aim is to match the support system to the immediate preferences of the decision maker in terms of cognitive style, personality, etc.(For a detailed review, see Sage, 1981).

Therefore, social scientists take the stand that decision support should be based on an analysis of the decision strategies preferred by the individual decision maker in a specific organisation, and designed in cooperation with the user. This means that there will be no formal basis for evaluating the performance of such a system; the only basis for judgement will be user-acceptance, and there will be no structured way to plan the functional systems design, which will be based on bottom-up integration of the requirements of the individual activities.

System science approach. Recently, a more integrated, top-down approach to the design of management decision support systems has been taken by system scientists. An illustrative example is the discussion presented by Sutherland (1983). He compares the approaches taken by the two schools based upon management science and social science, respectively. His conclusion is that both approaches are too schematic and drawn to unacceptable extremes, and that a more balanced view should be taken.

A formal system theoretic approach to design of decision support systems is necessary; but, on the other hand, it is necessary to take

into consideration that decision making in the different levels of an organization cannot be covered by one theoretical model, and will require different tools for effective support.

This means that formal models are needed for the functional organization of support systems, at the same time as it is realized that behavioural, cognitive, and sociotechnical factors are indeed critical determinants of managerial practice:

First, the system designer must "assess client properties against some sort of normative referent", i.e., it is necessary to define the role of the client company in the overall economic environment, to define the function at the level of purpose. Next, it is argued that rather than to consider the decision makers in terms of personality types (such as risk takers versus risk averters; theory X versus theory Y), it is necessary to apply some sort of taxonomy of decision functions to map decision technologies onto decision types.

Four levels of decision types are identified and correlated with decision processes and support models:

- Goal programming and long range planning at the highest level are related to sequential state model for heuristic problem solving procedures or structured decision making procedures. Support in this function is essential for executives who are responsible for development of the firm over the long run. At this level, development of a plan serves to define the trajectory an organization will be expected to take from some current position to an assumedly more favourable position in the future.
- Strategic analysis at the next lower level includes contingency planning related to stochastic-state techniques to provide for deductive techniques for problems the "state" outcomes of which are variable, such as game-theoretic models or logical analysis programs. This technique underlies most classic military contingency planning.
- The tactical programming, one level further down includes "equilibrium maintenance" mainly based on statistics-based decision and control instruments for dealing with probabilistic problems, such as econometric methods, parametric decision theory, etc. Instruments of this form dominate at the tactical level of most organizations, where the ambition is to try to keep the parameters of the organization in some sort of equilibrium position with the near term properties of the immediate operating environment by means of functions such as forecasting, logistical programming, budgeting, and financial control.
- The lowest level is concerned with operations management, based on discrete-state instruments which are primarily algorithmic and

analytical methods that allow optimal solutions of deterministic problems. This is the domain of methods of industrial engineering and operations research.

The basic idea of this system theoretic approach is that any properly conceived management support system should include tools for all of these levels. And, this is so, whether or not it is requested by the existing management authorities.

Sutherland emphasizises the need for a structured design methodology:

1. The first step is to identify "a population of decision requirements that is derived by examining organizations in aggregate in terms of universalistic (e.g., ideal-type or categorial) as well as context specific properties." The "population of decision problems can be abstracted from the particular organizational units or personalities without loss of technical integrity. This abstraction is indeed necessary, for macrosystem requirements should not be induced from a consideration of requirements associated with existing agencies or individuals." The "most essential implication of the abstraction of decision requirements from organizational agencies is that it allows the designer to carry through the mapping function to a different level of effect through formal decomposition analysis (compare the identification of control requirements in the cognitive task analysis discussed in next section).
2. The next step is an attempt to reduce a population of functionally abstracted decision requirements to their most fundamental constituents, i.e., to decompose into elementary operations or primitives.
3. Then, the set of all primitives is reduced into a prime set, in order to remove redundancies.
4. Given this prime set, attention shifts to the instrumental capabilities they imply in terms of a collection of decision aids. All integral decision aids or model base components are now decomposed into their lowest order transformational components - the microfunctions which are the basic elements of "any structured model-base".
5. Now a prime set of system facilities is generated, to have a mutually exclusive set which in aggregate should be able to perform all the functions associated with the set of decision aids from which they were derived.
6. Any of the higher-order decision requirements should thus be able to be met by synthesizing in effective real-time the functions pertinent to the integral decision aid.

Sutherland then discusses how modern information technology should be used to improve the quality of managerial practice. He argues that next generation support systems will tend to have the following provisions:

1. In those areas where technical default by humans has serious consequences, the authority of the support system will expand.
2. In areas where managerial issues are complex, well-articulated and consistently enforced check and balance procedures may be introduced via system facilities, i.e., an authority shift in balance between decision makers and decision analysts. (Note: an error recovery feature.)
3. The support systems will constrain the analytical and technical prerogatives of decision authorities along lines consistent with scientifically preferred decision methodology.

The prerequisite for this concept will be that the analytical procedures or techniques underlying a support system are congruent with the nature of the problem at hand. Therefore, the tools for the different levels in an organisation will be different. This congruence is discussed with reference to generic problem/instrument domain. Four levels of problems are considered: Deterministic, probabilistic, equifinal, and indeterminate problems. Also four instrument categories are used: Discrete state (operations research, industrial engineering, or AI algorithms), finite state (statistical decision theory, correlation, regression), stochastic state (contingency planning), and sequential state. Optimal tools are then to be found in the diagonal of the representation, while choice outside the diagonal will be either ineffective (insufficient) or inefficient (too sophisticated) for the purpose.

The rationale for this solution will be to ensure that organisational decision problems get all the precision and discipline they deserve, but no more.

The social decision support approach is met by Sutherland with the argument that "differences in decision "styles" are the reason why normative decision constraints are required in the first place, not a rationale for their neglect".

The approach to design of decision support systems proposed by Sutherland is nearly congruent with that developed for support of supervisory process plant control (Rasmussen, 1983, 1985) and reflects the use of cognitive concepts to bridge between characteristics of the problem space and the decision maker. In the present context, it is important to note the application for distributed decision-making in a social system.

2.2 Expert Systems, Artificial Intelligence Approaches

While the approaches to decision support systems mentioned above are predominantly problem driven, the solutions based on artificial intelligence approaches are by nature tool driven.

Expert Systems. The presently most visible category of advanced information systems is "expert systems". In particular following the Japanese "fifth generation computer" initiatives, the term seems to include all kinds of advanced information systems. In the present context, however, the term "expert system" is used in the "classical" sense to characterize a decision support systems based on heuristic rules derived from experts and intended to support a well defined decision maker having a uniform set of decision tasks within a bounded information context. The problem context has typically been chosen by AI research teams because they have formed "micro-worlds" being suitable for program development. The general idea has been to represent not the formal, "scientific" knowledge of professional textbooks (typically being structural knowledge related to laws of nature and "first principles"), but the know-how, and heuristic rules-of-thumb of highly skilled practitioners.

Recent reviews of the historical development of expert systems (Hayes-Roth et al., 1983) focus on expert systems for application in domains of very uniform characteristics, such as

- Dendral, for analysing mass spectroscopic, nuclear magnetic resonance, and other such data to infer molecular structures,
- Mycin, for medical diagnosis of infectious blood desease,
- Expert, Cadeus, for other domains of medical diagnosis,
- Prospector for geologic survey support, etc.

The present expert systems are laboratory "demonstration" systems, of which non are in actual, serious use. Several problems are to be expected from serious application of this approach to decision support systems:

- In order to be accepted by a user, advice from an expert system in a risky decision context will require a more elaborate explanation capability than is presently available (see, for instance, Rasmussen and Goodstein, 1985).
- The lack of well defined limits of the domain of expertise and the lack of ability to retract to arguments based on first principles. This problem is formulated in the following way by Hayes-Roth et al., 1983): "Today's expert systems typically show up badly when measured along a number of dimensions:
  - They are unable to recognize or deal with problems for which their own knowledge is inapplicable or insufficient.

- They have no independent means of checking whether their conclusions are reasonable.
- Explication of their reasoning process is frequently silent on fundamental issues.

In a review Buchanan (1982) concluded with the following limitations:

- Narrow domain of expertise,
- Limited language for expressing facts and relations, limited assumptions about problem and solution methods,
- Stilized explanations of lines of reasoning,
- Little knowledge of their own scope and limitations,
- Knowledge bases extensible but little help available for initial design decisions,
- Single expert as "knowledge czar".

In a discussion of control problems in expert systems, Barnett (1982) was concerned with the reliability of such systems. The symptom-based rules are derived from experts' experience rather than being model-based. Therefore, they are usually very effective and produce correct behaviour, but they also have the potential to produce inconsistent responses to unfamiliar information. "The rules are plausible and work a high percentage of the time, this is why experts use them. However, when they fail, the human expert will know enough to realize this fact and find out why. He retreats to a better grounded model (one based on more general principles.

These problem may not be prohibitive for the application in the domain where the classic expert systems are developed, because of the recurrent and uniform nature of the problems and the well structured set of action alternatives. In general these features are not typical for the decision situations for which data base or support systems are developed.

There is, however, some signs of activities to resolve the problem. Lehner et al. (1985) explore the relationship between AI and decision analysis. Decision analysis is found to be based on normative, or prescriptive, problem representations intended to guide users through an effective decision process. They continue: "Unfortunately, from the perspective of many types of practical decision-aiding applications, both normative decision aids and expert system technology have significant limitations. Particularly, in expert system development there is a lack of established techniques for problem structuring and knowledge engineering. This has led to time-consuming rule-based development efforts with limited success in domains where the knowledge required to solve problems is not already well documented." On this basis the paper considers the combination of

production systems and multi-attribute utility models; in a way, it proposes expert system support in operation on a model, i.e., support in operation at the knowledge-based level. The argument for this development supports the need for problem structuring in the present context of emergency management.

From this review, use of "expert-systems" for support of the decision making process "on-line" seems to be premature. However, AI tools for organization of the distributed data base available to emergency management may be feasible.

Other Artificial Intelligence Approaches. More differentiated approaches have been taken to the design of decision support systems, when AI techniques have been considered tools in a design effort based on analysis of the problem requirements.

A system oriented approach to design of a system for support of distributed decision making, based on the tools made available by artificial intelligence research has been proposed by Thorndyke et al. (1982). This proposal will be reviewed in some detail because distributed problem solving appears to be an important feature of emergency management:

Thorndyke et al. describe a system for model-based situation assessment and planning based on expert system architecture. Applications are described for military strategic planning, air traffic control, location and identification of hazardous chemical spills. To model the organization of time stressed situation analysis and planning, the "cooperating experts paradigm" is used.

Distributed problem solving is becoming increasingly important for the planning of support systems for a variety of domains such as battlefield decision making, air traffic control, etc., characterised by widely dispersed data gathering, time stressed decision making, and natural clustering of activities. Distributed problem solving uses separate processors to attack the problem at multiple points, exploiting parallelism for speed and power. Distribution frequently entails the decomposition into a set of loosely coupled subproblems.

A detailed description of the approach as used for air traffic control can be found in Stebb et al. (1981), who examine the use of heuristic methods for coordinating the cooperation among several decision makers having a common set of objectives. Focus is on development of system architecture for distributed situation assessment, planning, and control. Different experts share a common data base - the world model. The experts either sense the world and infer aircraft intentions, generate and evaluate plans, control and monitor execution, or communicate mutually.

Distribution of functions may be chosen in a variety of ways leading to different architectures:

- Space centered, based on geography.
- Function centered, based on aircraft function.
- Plan centered, based on planning approach.
- Hierarchical, based on level of abstraction.
- Object centered, based on autonomous self-planning.
- Object centered, based on communicating objects.

Goals to consider for air traffic control are the following:

- Error free routing, no collisions with obstacles or other planes.
- Uncertainty reduction, adapt to changing conditions (weather, etc.).
- Adherence to separation regulations.
- Resource (fuel) conservation.

Problem solving processes considered for air traffic control are:

1. Situation assessment.
2. Conflict recognition.
3. Plan generation.
4. Plan evaluation.
5. Message passing.
6. Bargaining.
7. Plan execution.

For the organisation of these activities the Hearsay-II paradigm is used (Erman et al., 1980). A number of experts are organised around a common data base, the "world model": a sensor, a plan generator, an evaluator, a communicator, and a controller.

They cooperate in the function mentioned:

Situation assessment involves updating of the world model by the sensor or the communicator. The evaluator takes care of conflict recognition , by trajectory projection, or by including planned manoeuvres received via communicator in projection. Plan generation depends on coordinated planning in all processors sharing the same airspace. Four types of coordination are considered: preplanned protocols, iterative local planning, asynchronous cooperative planning, and simultaneous global planning.

With preplanned protocols, each processor acts according to predefined rules, known to all processors. Assuming each processor

maintains accurate knowledge of the planning methods and protocols of the other processors communications are largely unnecessary. However, such rigid individual behaviour may lead to suboptimal global solutions.

In iterative local planning, all processors sharing a local region initially exchange goals and constraints. Such coordination may require time synchronisation of the planning activities. Each processor then generates plans only for aircraft under its control and communicates intentions to the other processors, who will then replan. Deadlocks and loops may occur.

In asynchronous cooperative planning, nearby processors also share goals and intentions, but, in addition, they share partial plans so that discrepancies are identified and acted upon quickly. Rather than iterating individually, the processors act as a committee, revising plans until an overall solution is found. This approach characterises Opplan, Hearsay-II, HASP, and has been successfully used in distributed applications (Lessser and Erman, 1980).

In simultaneous global planning, processors initially exchange their status and goals, then each autonomously works towards a single overall plan. Different plans are then generated, representing the different perspectives of the participants, and the ultimate plan is chosen through bargaining.

Plan evaluation depends on simulation of the execution of the candidate plan. It determines whether plans meet certain minimum standards and selects the best of the qualified. If none passes, reasons for the failures are posted.

Message passing is then initiated by communicator, requesting processors to amend their plans. The communicator is administrating the communication channels, based on an information value model, considering the needs and costs of transmission.

Bargaining may impose heavy communication requirements, and an arbitor may be assignsd, who willl use some social "welfare function" to resolve conflicts.

Plan execution involves the control of the plan and monitoring by the controller.

Architectures of organisation. Six distinct organisations are proposed:

Three distinct distribution methods, depending on association of processors with:

1) The objects they control and the data they gather. Two types, depending on on-board processors which are either autonomouos (a communication-free organisation in which each aircraft performs all control functions autonomously) or cooperative (aircrafts communicate to plan collectively by resolving conflicts. Both iterative local planning and asynchronuous planning can be supported).
2) Clusters suggested by the planning environment. Two types, depending on either regional grouping (each processor controls a region rather than an aircraft) or functional grouping (each processor controls a particular phase of a flight, or a particular type of crafts)
3) Subproblems defined by decomposition. Two types depending on either global solutions from different perspectives and bargaining or hierarchical decomposition (i.e., decomposition of the problem or of the problem solving system?).

The conclusion of this review is that the structure offered by the HEARSAY system concept for communication and coordination in a distributed group of decision makers appears to match the needs for data base support in emergency management, and should be considered in more detail for future developments.

2.3 Decision Support in Emergency Management

The present problem of information systems for emergency management in appears to be characteristic in the following respects:

- The problem domain is poorly defined. The system should support decision making related to a large variety of emergencies, caused by very different physical processes. The resources to consider in emergency control may belong to different technical service fields.
- The decision maker(s) are difficult to identify in advance, being dependent on the size and nature of the actual case.
- Several organisations and technical services may be involved, and decision making will have the nature of a cooperative effort in a distributed system.
- Support from the system may be relevant during dynamic emergency situations, as well as for planning purposes.
- The information needed for decisions may stem from a large variety of sources, such as engineering textbooks, laws and regulations, risk analysis, analysis of prior accidents, procedures, and instructions.

Key problems for system development will, therefore, be to consider:

- Organisation of large, inhomogenous data bases, information retrieval, requirements for analysis supplying data in order to have proper data attributes and formats compatible with user needs.
- Analysis of the organisation of the cooperative decision making, and the structure of the communication network involved.
- The nature, in general terms (covering typical situation scenarios), of the control and decision task, and the related information needs.

At present it appears very plausible that a coordinated data base and a consistent specification of the information needs of the various decision makers, as well as of the requirement to the information formats used by the information sources, will be an important area of development for advanced information technology.

4. A FRAMEWORK FOR ANALYSIS AND DESIGN OF DECISION SUPPORT SYSTEMS

In consequence of the discussion in the previous section, the approach to the design of a decision support system based on new technology should be taken from a cognitive point of view, and should include an analysis of the decision task and the information processing requirements in terms referring to human cognitive functions.

In general, when designing systems for support of decision making, the problem is to design systems which are also effective during situations which have not been foreseen during design, and which are not familiar to the user. In addition, such systems will be operated by a wide variety of users whose background and formulation of needs are poorly known. In such cases, the design cannot be based on a detailed quantitative model of the actual information process; instead a model or conceptual framework must be used which describes the interaction in terms of related categories defining the boundaries of a design envelope within which users can generate effective ad hoc tactics suiting their subjective preferences.

For design it is necessary to structure the great variety of real life work conditions into domains which correspond to design decisions. By the use of a multi-facetted description system it is possible to represent a great variety of conditions by a rather low number of categories in each domain, related to general features. From this point of view, the following dimensions of a conceptual framework for description of a cognitive task have proved useful for the analysis of cognitive tasks, and, hence, for design of decision support systems:

The problem domain. The first domain of an analysis which will serve to bridge the gap between the purely technical description of the

work content and the psychological analysis of user resources should represent the functional properties of the system in a way which makes it possible to identify the control requirements of the system underlying the supervisory task. This is an analysis in technical systems terms and will result in a systematic and consistent representation of the problem space.

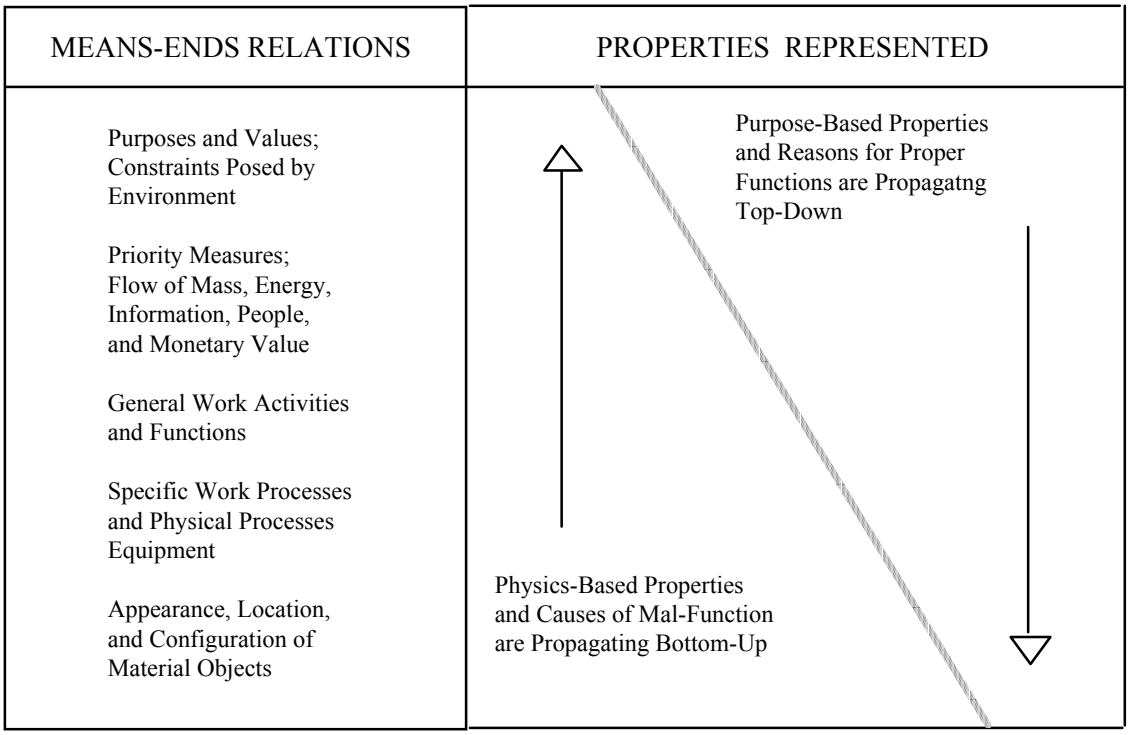

Figure 1. A means-ends abstraction hierarchy used for representation of the functional properties of a physical work environment.

Since decision making in emergency management, as in many other contexts, is a resource management problem, an appropriate representation of the problem space should reflect the varying span of attention in the part/whole dimension, and the varying level of abstraction in the means/end dimension (see figure 1). Change in representation along both dimensions is normally used by decision makers in order to cope with the complexity of a decision task (Rasmussen, 1985).

The decision sequence. The next domain of analysis to consider is related to the decision process which has to be applied for operation upon the problem space. It is generally accepted that the decision process can be structured into a fairly small number of typical decision processes representing the various phases of problem analysis and diagnosis, evaluation and choice of goal priority, planning of resources, and, finally, execution and monitoring, see figure 2.

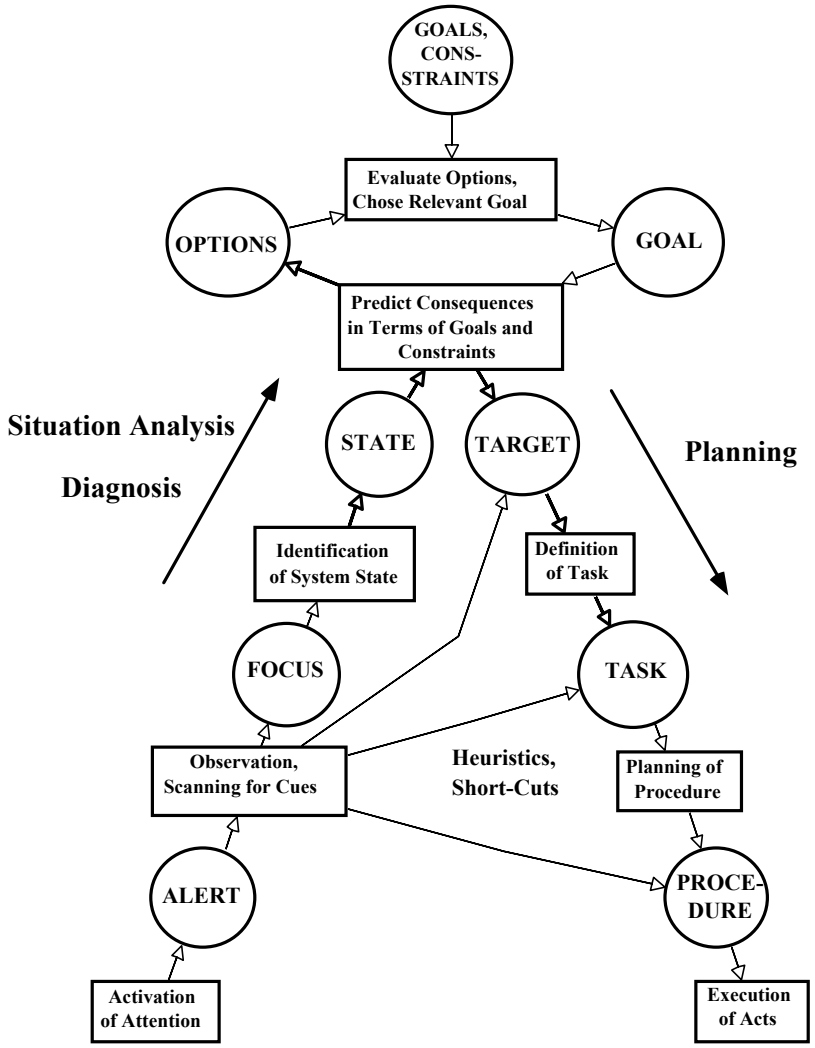

Figure 2. Schematic map of the information processes involved in a control decision. Rational, causal reasoning connects "states of knowledge" in the basic sequence. Stereotyped processes based on "know-how" can bypass intermediate stages.

Human mental economy can be achieved by the partitioning of a complex process in subroutines connected by more or less standardised key nodes representing states of knowledge useful for linking different processes, for bringing previously successful subroutines into use in new situations, and for communicating with cooperators in decision making. This is important since a decision task will be shared by the ultimate decision maker and the operations planner with the decision support system as the means of communication.

The decision task analysis will have to consider whether the decision is to be based on the planner's or the system designer's analysis a priori, and communicated to the ultimate actor by means of operational instructions and/or computer programs (in order to ensure proper treatment of, for instance, rare event risk

considerations), or whether the decision must be left for an "on-line" evaluation by the ultimate emergency manager.

At this level the task analysis will be in implementation-independent terms, and will include identification of the cognitive control mechanism required; i.e. which of the subroutines that can be preplanned routines called from memory, and which must be organised ad hoc.

Mental strategies and heuristics. An analysis in this problem domain can serve to identify the information processing strategies which are effective for the different phases of the decision sequence in order to identify the required data, control structures, and processing capacities. It is generally found that a given cognitive task can be solved by several different strategies varying widely in their requirements as to the kind of mental model and the type or amount of observations required (see, for instance, for concept formation: Bruner et al., 1956; for trouble shooting: Rasmussen et al., 1974; and for bibliographic search: Pejtersen, 1979). An analysis of the task is therefore important in order to identify the different strategies which may be used to serve the different phases of the decision sequence, and to select those which are considered effective and reliable.

This analysis, which is related to operations research rather than psychology, identifies the information processes required in implementation-independent terms as a basis for a subsequent human-computer task allocation based on demand/resource matching. It may be difficult to identify the useful, possible strategies by rational analysis, but since users are very inventive regarding identifying clever tricks, the strategies may be identified by empirical studies of user behaviour. This, of course, requires psychological as well as domain expertise.

An important part of the analysis is identification of the general resource requirements of the strategies in terms of data about the actual system state, about basic functional relations, the processing capacity needed, etc., and about the consequences of errors. The results will be the basis for matching these requirements with the resource characteristics of the designer, the support computer, and the final user for planning of their roles in the interactive decision task.

In highly structured, but complex decision tasks as, for instance, involved in supervisory process control, the analysis of mental processing strategies by techniques such as verbal protocols, can be very important as a basis for identification of information needs during rare situations and thus to select display formats. In the present application of emergency management it will be very doubtful

whether a systematic analysis of mental information processing strategies is possible or even particularly helpful. The decision situation will be rather unstructured and change from one situation to the next. However, the type of situation met will be rather uniform and frequent for an emergency task force, and the information needs and formats may be identified by analysing the actors' roles in the game, and from interviews and posterior analysis of cases, as has been done for information retrieval studies in public libraries.

Cognitive control domain. While the information content should be included in the messages from a decision support system from an analysis of problem space and mental strategies, the form of the displays should be selected from consideration of human cognitive control mechanisms. This is necessary in order to have a communication format which will lead future users to develop effective mental models and heuristic rules. The familiarity with a situation will determine the domain of cognitive control and, thereby, the nature of the information used to control the activity and the interpretation of observed information. Control may depend on a repertoire of automated behavioural patterns, a set of state-action production rules, or problem solving operations in a symbolic representation. And, consequently, the same display configuration may be interpreted as a pattern of signals for control of direct sensori-motor manipulation, as signs which may act as cues for release of heuristics, or as symbols for use in functional inference.

These aspects are important for decision support systems in supervisory control of invisible processes of a process plant from which only symbolic information is available. The domain is probably of less importance in the control of accidents accessible to direct observation and supported by verbal communication of information and advice.

4. IMPLEMENTATION FOR EMERGENCY MANAGEMENT SUPPORT

It follows from the preceeding section that the most important domain of analysis for emergency management will be the problem domain and the decision task, including the role and cooperation of several decision makers.

4.1. Problem Domain

The first aspect to consider will be the problem domain, i.e., the representation of the relationships controlling the state of affairs in the emergency management context.

A representation in terms of a means-end hierarchy has proved to be useful for supervisory process control as well as for problem solving in general (Rasmussen, 1985). For supervisory process control these relationships have been analysed and described systematically along the part-whole and the means-end dimensions in order to have a consistent framework for identification of the control requirements of a system and the content of the related decision task. Also emergency management is a resource management task in a purpose-function-equipment hierarchy and adequacy of decision support cannot be judged without an explicit description of the total system in terms of the configuration and the state of available resources at each level.

In the present case, the geographical location, physical resources and functions of various emergency management services as well as the physical characteristics of potential accident sources, can be described in terms of the lower abstraction levels, while their interaction can be represented at more general functional levels, and safety policies and regulations are expressed at the highest levels of abstraction. In the following sections, attempts will be made to illustrate the problem space of the various scenarios in this framework and to identify the information needed to analyse the control and coordination requirements at each level, and the resulting need for data, data integration, and communication. In the analysis will be included a description of the propagation top-down in the hierarchy from laws and regulations to procedures and instructions at the lower functional levels.

A difference in comparison with supervisory process control will be that in emergency management different decision makers will be active at the various levels in the hierarchy, while in supervisory control tasks in process plant control rooms, the same decision maker may serve several levels. This will influence the communication structure.

A sketch of the possible, typical content of the various levels may be useful in order to illustrate the use of scenario analysis, of structuring the description of rules and regulations, and of identification of the kind of information which should be collected by interviews. In this respect, it is important to realize a basic difference between the problem space of supervisory process control and emergency management: In process control, a decision maker is faced with a well structured, integrated system with well defined boundaries, and the task is one of resource management to compensate for disturbances by reconfiguration of the system. This means the disturbances originate from faults in the same system, from which components are

selected for compensatory actions, and the problem domain can be described as one coherent assembly, well-known to the decision maker.

For decision making in emergency control in general, outside plant boundaries, the situation is different. The problem space consists of two parts which are rather independent. One consists of the potential sources of accidents, industrial plants spread around a geographical area, occasional transport of dangerous substances, etc., and potential targets for damage in terms of people and groups, which may change dynamically, depending upon time of the day and the year, as well as upon major collective events as sport games - in short a dynamically changing set of sources and targets in a geographical map.

The other includes the resources for accident control, which may be called into use in case of an emergency. Again these resources do not add up to an integrated system, but present themselves to the decision maker as a distributed set of services which should be activated and integrated into an effective system, the size and configuration of which depend entirely upon the physical nature and size of the actual emergency and its geographical location.

A description of the problem space should be systematic identification of the elements in these two domains which basically constitutes sets of separate items in which only a subset will be selected for consideration as an active physical system when they are activated and interact during an accidental course of events. The descriptions will, therefore, have the character of a general data base including the relevant items together with all those physical and functional characteristics which may be necessary for control of the system which may emerge during accidents.

The two domains will have very different roles in the decision making during emergency control, and the information needed for their representation in a decision support system will be considered separately since they will depend on different analysis and data sources.

The discussion will be based on the abstraction hierarchy which has been found to be useful for decision making modelling, and a short description is included in the following section to support a more detailed discussion of the content of a systematic description.

4.2. The Means-End Abstraction Hierarchy

Emergency management can be considered a resource management problem in a means-end hierarchy representing the functional

properties of the environment. In this hierarchy, these properties are represented by concepts which belong to several levels of abstraction.

The lowest level of abstraction represents only the physical form of the system, its material configuration. The next higher level represents the physical processes or functions of the various components and systems in a language related to their specific electrical, chemical, or mechanical properties. Above this, the functional properties are represented in more general concepts without reference to the physical process or equipment by which the functions are implemented, and so forth.

At the lower levels, elements in the process description match the component configuration of the physical implementation. When moving from one level of abstraction to the next higher level, the change in system properties represented is not merely removal of details of information on the physical or material properties. More fundamentally, information is added on higher level principles governing the cofunction of the various functions or elements at the lower level. In man-made systems these higher level principles are naturally derived from the purpose of the system, i.e., from the reasons for the configurations at the level considered. Change of level of abstraction involves a shift in concepts and structure for representation, as well as a change in the information suitable to characterize the state of the function or operation at the various levels of abstraction. Thus an observer asks different questions to the environment depending on the nature of the currently active internal representation.

In other words, models at low levels of abstraction are related to a specific physical world which can serve several purposes or violate different goals. Models at higher levels of abstraction are closely related to a specific purpose which can be met by several physical arrangements. Therefore, shifts in the level of abstraction can be used to change the direction of paths, suitable for transfer of knowledge from previous cases and problems. At the two extreme levels of models, the directions of the paths available for transfer are in a way orthogonal, since transfer at one level follows physical, material properties, while at the other it follows purpose.

Decisions during emergency management are related to correction of the effects of disturbances and mitigation of accidents. Events can only be defined as disturbances or accidents with reference to acceptable states, normal function, or other variants of system purpose or functional meaning. The functional models at the different levels of abstraction play different roles in coping with disturbed systems. Causes of improper functions (disturbances) are depending

upon changes in the physical or material world. Thus they are explained "bottom-up" in the levels of abstraction, whereas reasons for proper or acceptable function are derived "top-down" from the functional purpose.

A task for which the use of representations at several levels of abstraction is of obvious value is design of technical systems and of operating procedures. Basically, design is a process of iteration between considerations at the various levels rather than an orderly transformation from a description of purpose to a description in terms of physical materialization of a solution. There exists a many-to-many mapping between the levels; a purpose can be served by many physical configurations, and a physical system can serve many purposes or have a variety of effects. The framework, should therefore be useful in the present context, since emergency management includes the ad hoc design of a mitigating system, and its subsequent control.

Not only reasoning in such causal, physical systems should be considered. For emergency management, not only prediction of the response of physical systems is important. Other persons and social groups will be part of the system an emergency manager has to control. As for technical systems, various levels of abstraction can be used to model human "functional" properties. What is of particular interest here is that, in ordinary working life, human interaction is based on a "top-down" prediction drawn from perceptions of other persons' intentions, motives, and on common sense representations of human capabilities, together with knowledge of accepted practice. Causal bottom-up arguments literally play no role, and the most important information to use for planning human interactions for unfamiliar occasions is therefore knowledge of the value structures and myths of the work environment.

Physical systems with known and invariate internal structure are responding to changes and to human acts according to basic laws of nature which can therefore be used to predict their behaviour. They are "causal systems", and their response to physical changes for which no experience is available for an observer can be explained or predicted by means of bottom-up reasoning in the abstraction hierarchy, i.e., by functional analysis.

This approach is not possible for all the environment in which humans have to make decisions. Systems with a high degree of autonomous internal functioning, with self-organizing and highly adaptive features, will change their internal functional organization continuously in order to meet the requirements of the environment and to suit their internal goals or performance criteria. Even though

such systems are basically controlled by laws of nature, their complexity in general makes it impossible to explain or predict their performance by functional analysis during real life decision making. The alternative is to consider such systems as "intentional systems" controlled by motives or intentions together with the constraints on performance posed by the environment - physically or in the form of conventions and legal requirements - and by the limiting capabilities of their internal mechanisms.

For emergency management systems, the information related to the decision space will be discussed for the two separate categories mentioned above, the domain of potential risk, and the domain of mitigation resources.

4.3. Domain of Potential Risk

This part of the data base includes information identifying the potential risk sources, their functional physical properties making it possible to predict the accidental propagation of effects of accident releasing mechanisms, and the possible higher level consequences in relation to social norms and legal rules. This part of the data base will supply the basis for the "upward" analytical part of the decision ladder, and the information will be available from risk analysis, technical manuals, and analysis of the technical features of prior cases. Examples of the information at the various levels can be (figure 3):

Level of physical form. The content will typically be related to identification of the elements of the total system, inventory descriptions, appearance, configurations, and locations. In particular this should include identifying information on location of special accident potential, explosives, major chemical storage facilities, etc. In general, information on geographical population densities and road maps classified according to transport capabilities (traffic density and speed, load capabilities, etc.) related to potential accident sources also belong to this level. Sources of such information will be design documentation from individual installations, statistical reviews, reports from road authorities, geographical and demographical institutes, technical support services of local government, etc.

Level of physical function. This level includes information on the functional properties and limitations of the elements identified in the lower level, i.e., information specifying what they can be used for, what can be done to them, what they can do in terms of damage, etc.

Domain of Potential Risk					
	National Overview and Patterns	**Emergency Classes**	**Companies and Installations**	**Specific Production Plants and Systems**	**Processes, Substances, and Components**
Goals, Purposes and Constraints	Risk pattern in terms of social and economic consequences with reference to features of established policies and public opinion				
	National pattern, geography and demography	Risk pattern as related to industrial branches	Risk pattern of individual installations and plants	Risk related to specific processes	Risk related to specific materials, substances and components
Priority Criteria, Economy, Risk, Man Power Flow	Risk measures in terms of economy, probability and other abstract measures suitable for setting priorities				
General Functions	Accident potential in general terms; fire, explosion, flooding, intoxication				
	Relation to geographical regions or population features	Relation to industrial activities or to population groups	Relation to specific process plants or installations	Functional and accidental mechanisms of specific processes	Risk classes related to categories of processes, substances, and material
Processes of specific Installations, Groups, and Equipment	Physical processes and mechanisms behind accidents, causation, propagation, potential for interaction with accident control measures				
	National and geographical patterns, meteorological data, water streams, other propagation characteristics	General data on industrial practices, processes and accidental mechanisms. Safety measures	Functional information on specific plants, accident potential and mechanisms, safety measures	Relation to specific manufacturing processes	Properties of substances and materials
Material Topography Locations, Configurations, Appearance	Locations, topography, physical design and appearance				
	National pattern of potential sources and population, propagation routes, road and barrier topography	Distribution according to branches and risk categories	Location of specific plants and installations. Drawings of buildings and access routes, maps of likely propagation paths	Location of specific process equipment, identification data, transport and access information	Information for identification and location of material, substances, and components. Personal data

Figure 3. Domain of potential risk.

This level identifies the functional properties of generally speaking two categories: Information necessary to identify accident mechanisms, to predict courses of events, and to judge effects of countermeasures. The category includes functional characteristics of hazardous installations and equipment, their typical behaviour during various categories of accidents, and their responses to possible means

of intervention; characteristics of chemical ingredients in terms of toxidity, fire and pollution characteristics, and their reactions to means for fire extinction, cleaning, and medical treatment.

The information in this category will to a large extent include data extracted from analysis of previous cases, derived by risk analysis, and the use of the characteristics of the means-end relations should be considered carefully when the formats applied to document the results of such analysis are chosen and the data bases are organised. This will be considered in more detail below.

Level of general function. At this level the description is in terms of requirements for general functions during the various circumstances without consideration of the underlying physical mechanisms or processes. At this level, general functions and consequences of, for instance, propagation of fires, explosions, flooding, etc., can be considered irrespective of their physical origin.

Information at this level is in general included in professional textbooks, it may be generalizations from analysis of previous cases, from laboratory experiments, or derived deductively from more basic scientific theories.

Level of abstract function. This level may be useful to represent abstract descriptions of the interrelation of various general functions in terms of material flow characteristics, economic properties, general polution characteristics, etc.

The level will include abstract measures which are without physical or causal dimension and which, can therefore be used to compare, prioritize, and coordinate lower level general functions. Such measures are for instance monetary values and flows; flow and inventory of (possibly unspecified) mass or energy; probability measures like risk, reliability; etc. These measures are all well suited to interrelate the effects of generic functions and to relate them to higher level goals and constraints.

A possible application of this level may be to represent the rule sets and regulations derived from primary laws by central organisations and the higher level institutional control and monitoring of activities and monetary expenditures as a reference for judgement and prioritizing regarding the potential for damage from different physical sources.

The level of purpose. This level specifies the basic purposes and restrictions for the decision making. For emergency management, it can be used to represent legal requirements, regulations on acceptable risk, limits of polution, economic constraints, as well as institutional goals and criteria. In addition, social and institutional goals and criteria, public opinion pressure, etc., whether implicitly or

explicitly formulated, should be considered for representation at this level.

Domain of Emergency Management Resources					
	National Overview and Patterns	**Activity Categories, Emergency Classes**	**Organizations and Institutions**	**Emergency Task Forces**	**Individual Agents and**
Values, Goals, and Constraints	National laws and government agency regulations	Goals and constraints for measures against; fires, floods, traffic accidents, etc.	Goals and targets for services and institutions; hospitals, fire brigades.	Goals and targets for groups and task forces	Exposure limits for individuals, regulation data
Priority Criteria, Economy, Risk,	Criteria and measures for priority setting Flow, accumulation, turn-over of funding, man power, and material				
		Risk Categories	Services	Task forces	Individuals and equipment
General Functions	Available resources for general emergency control functions; Fire fighting, medical care, transportation and evacuation, etc.				
		General overview of resources. General rules and heuristics for counter measures.	Resources specified with reference to organizations, institutions. General institutional rules and practices	Resources of identified task forces, groups, and operational units and institutions	Capabilities of equipped individuals and major tools
Processes of specific Installations, groups, and Equipment	Physical functioning, capabilities, and limitations of emergency control mechanisms;				
				Physical functions and capabilities of tools as available to task forces and groups. Instructions and procedures, standing orders	Physical Characteristics and limitations of tools. Information on possible, unacceptable interaction with media and installations . Procedures and practices
Material Topography, Locations, Configurations, Appearance	Locations, descriptions, identification of items, forces, groups.				
	Road system with data on traffic and load capacity.	Geographical location of services and institutions, access routes.	Drawings of premises of individual institutions. Drawings of buildings. Inventory lists of service stations	Inventory, locations, identifying characteristics of equipment, tools, and members of task forces	Drawings of equipment, with size and weight data

Figure 4. Domain of emergency management resources

4.4. The Mitigation Resource Domain

This domain includes the information about functions, processes, and equipment/personnel which is available to form the counteracting and mitigating force. It represents the problem space for the "downward" planning leg of the decision ladder. The information included at the various levels can for instance include (figure 4):

Level of physical form. The content will typically be related to identification of the elements of the total system, inventory descriptions, amount, numbers, appearance, locations. In particular this should include identification of geographical locations of services, such as hospitals, fire brigades, etc; with identification of resources in terms of types and amount of equipment and personnel; major mechanical tools (cranes, tractors, bus service (for evacuation); all items together with information about service availability and delays, road access, distances.

In general, information on geographical population densities and road maps classified according to transport capabilities (traffic densities and speeds, load capabilities) belongs to this level.

Sources of this information will be the description and drawings of the locations and inventories of the various rescue and mitigation services.

Level of physical function. This level includes information on the functional properties and limitations of the elements identified in the lower level, i.e., information specifying what they can be used for, what can be done to them, what they can do in terms of damage, etc.

This level identifies the functional properties and specification of resources which will enable planning of mitigation, such as the capability of all the equipment and tools available, the professional abilities of the personnel categories listed for the various services and groups. Also the organisation of this part of the data base should be based on a careful analysis of user needs in terms of means-end relations.

The information at this level specifies the accidental mechanisms which the emergency management has to face and the functions available for coping. The mapping onto the lower level identifies the physical possibilities of events and availability of physical resources.

Level of general function. At this level the description is in terms of requirements for general functions during the various circumstances and the availability of resources without consideration of the underlying physical mechanisms or processes. Functions at this level may be the functions of and available resources for alarming, fire-fighting, transport, evacuation, cleaning, medical first aid, communication, etc.

At this level, the integrated activities and requirements for various categories of major events are described in order to evaluate requirements for coordination of the individual functions and for prioritising and allocating of activities to operational units. The context at this level is suited for allocation of authority and for coordination of activities from units of different organisational origin.

Level of abstract function. This level may be useful to represent abstract descriptions of the interrelation of various general functions in terms of material flow characteristics, economic properties, general polution characteristics, etc.

A possible application of this level may be to represent the rule sets and regulations derived from primary laws by central organisations and the higher level institutional control and monitoring of activities and monetary expenditures related to various services and activities. The level may be the focal level of setting priorities of resources for various aspects of purposes and constraints, being in abstract terms not relating to specific purposes or implementations.

The level of purpose. Information at this level specifies goal and constraints for industrial safety in general, and the same kind of information will be basis for the planning of emergency management, and for constraining industrial risk potential.

It is interesting to note that the representation of the potential risk domain and the mitigation domain in a way joins at the level of purposes and goals. At this level the general policy and value judgement take place, and from here the implications propagate top-down through the potential risk and the mitigation resource domains. The policy and goal level is determining the acceptable risk and, therefore, both the acceptable content of the potential risk landscape, and the funding and strategy for resources made available for emergency management.

4.5. The Use of Problem Representation

This representation of the problem space will be a multi-level representation in terms available/required equipment-process-function-purpose elements, and decision making in a specific situation will be a resource management task aiming at a proper relationship in the potential many-to-many mapping between the levels. A property of the total emergency management system considered at an individual level can be characterised in three different ways, (1) "what" it is, i.e. its causal properties in interactions at that particular level, (2) "why" it may be chosen, i.e., its role at the next higher level, and (3) "how" it may be implemented by resources at the next lower level. This means that the data element in a data base

should be characterised from at least three different points of view. Decision making in a particular situation will be an iterative consideration of the resources at the various levels until a satisfactory relationship through the levels has been identified, connecting the various, possibly conflicting, goals and constraints with the available physical resources. This will involve the task of keeping track of a many-to-many mapping in a complex net, and the use of information technology should be considered not only for advice giving à la expert system, but also for support of the decision process itself (for instance by alerting the user to consider other relevant means-end mappings than the one behind an actual information request). The relevance of this depends, however, on the extent to which activities are stereotyped and rule-bound, and judgement will depend on the practical experience obtained from the analysis of some more complicated cases stories (who will have access to a computer in the whole process? Somebody in a command center with radio link to a data centre? For which category of accidents will that be realistic?

The nature and the related sources of information to be included in a data base should be specified for each of the cells in the domain abstraction/decomposition matrix (figures 5 and 6).

Domain of Potential Risk: *Information Sources*					
	National Overview and Patterns	**Emergency Classes**	**Companies and Installations**	**Specific Production Plants and Systems**	**Processes, Substances, and Components**
Goals, Purposes and Constraints	Generalizations in terms of policies and goals				
Priority Criteria, Economy, Risk, Man Power	Generalizations from accident and risk analysis and overviews; in terms of economic and risk level terms for setting priorities				
General Functions	Statistical reports and overviews	Overviews from branch organizations, safety authorities, journals, etc.	Company overviews and safety records. Risk analyses and consequence prognoses.	Risk analysis, consequence prediction. Incident and accident reports. Textbooks and journals	Chemical, technical textbooks and journals. Risk and work safety handbooks
Processes of specific Installations groups, and Equipment	National summaries and overviews	Summaries over branches and emergency classes	Technical manuals, emergency and safety plans and procedures. Overall production, transport, and management manuals and reports.	Technical equipment manuals, process specific accident research and event reports. Inspection reports; maintenance logs.	Toxicological and pharmacological handbooks. Incident analysis reports and data banks. Hospital rules and data
Material Locations, Configurations Appearance	National summaries and overviews	Geographical overviews for emergency classes from branch organizations and authorities	Drawings, maps, manuals on sites, buildings, and configuration of installations and supply/waste piping	Drawings, manuals, descriptions of plants and equipment. Installation and handling manuals. Inspection reports. Inventory lists.	Reports from companies, suppliers, inspection reports. Inventory lists

Figure 5: Domain of Potential Risk: *Information Sources*

Domain of Emergency Management
Information Sources

	National Overview and Patterns	**Activity Categories; Emergency Classes**	**Organizations and Institutions**	**Emergency Task Forces**	**Individual Agents**
Goals, Purposes and Constraints	National laws and regulations		Statutory instruments. Authority regulations. Institutional constitutions	Institutional derivation of laws and regulations	Worker protection regulations. Union agreements
Priority Criteria, Economy, Risk, Man Power Flow	Accounting Systems				
General Functions	Resources and capabilities; reports from institutions and services				
		General strategies; text, generalizations from incident, accident, and risk analysis. Generalizations from drills, exercises, and experiments			
Processes of specific Installations, groups, and Equipment		Functional information from accident and risk analysis, exercises and manuals for equipment. Derived procedural information and empirical know-how			Equipment manuals, data from research, textbooks, accident and risk analysis
Material Locations, Configuration Appearance	Road authorities, statistical institutions	Descriptions, architectural drawings and maps, equipment inventories, and staffing information			Equipment manuals and specifications

Figure 6. Domain of Emergency Management: *Information Sources*

Data types to consider together with their sources will be:

•orders (in terms of goals), intentional statements, etc. (from preplanning or from level above),

•procedural information (from preplanning or from cooperators at same level),

•state information in actual situation (from communication sources),

•models (structural, causal information, from textbooks, risk analysis, incident analysis).

A specific problem to consider is the interface between risk analysis, incident analysis, equipment manuals and data bases for emergency mangement, with respect to formats for reporting

assumptions, and intermediate results. The importance of proper specification of the explicit format of assumptions, models, and results of risk analyses, has been discussed in detail by Rasmussen and Pedersen (1984). This discussion also has implications for risk management.

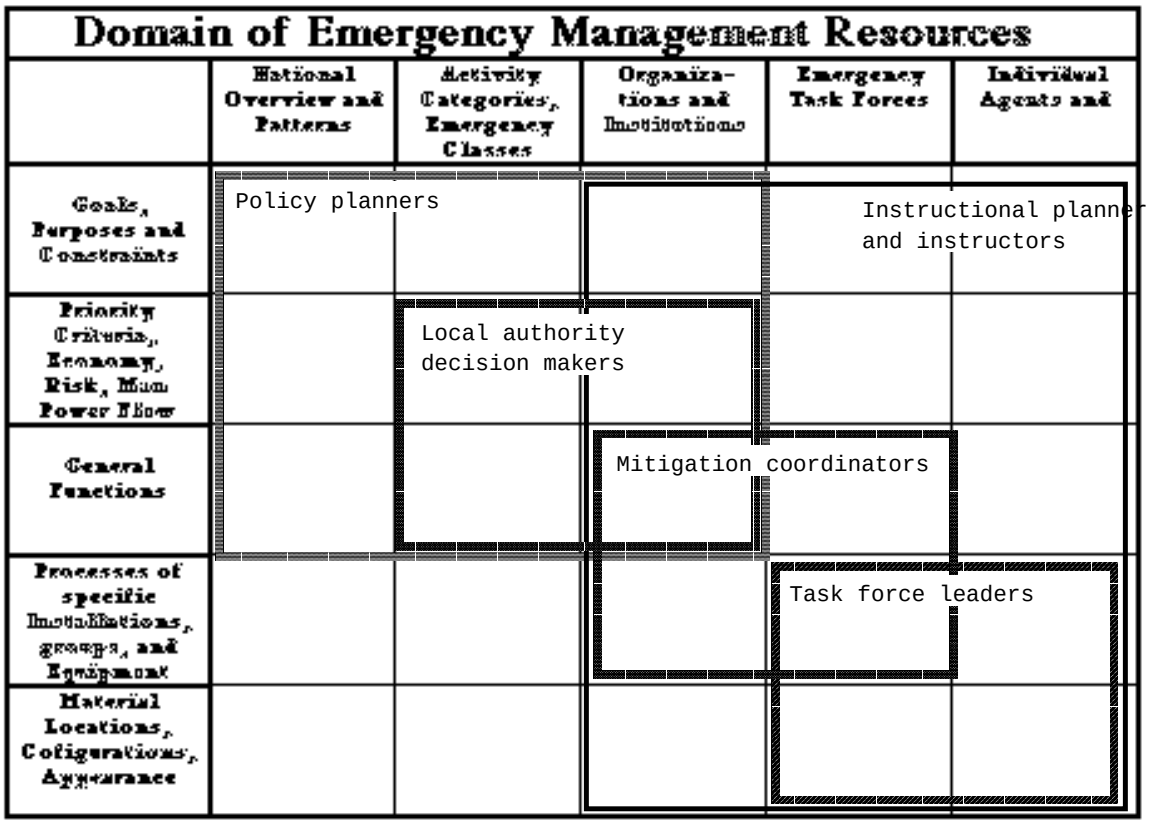

Figure 7.

The form in which the information should be stored in the data base depends entirely upon the users' formulation of their problem and needs (cf. Pejtersen's work on information retrieval in libraries). This, in turn, depends on the identity of the actual decision maker, and the boundaries of his information needs in terms of location in the problem space chart (see figure 7), as well as upon the hierarchical structure of the operating organisation. Will, for instance, the organisation be strictly hierarchical, as a military command organisation in which each person is clearly related to a function in the hierarchy, and (ideally, at least) only communicates orders downwards in the form of goals to achieve, not the ways to do it. In this kind of system, the information to be communicated between persons, and the kind of information they will seek in the data base can be identified. However, in normal, civil organisations, people do not stick to their roles, and the same individual will probably be

moving between levels. This may give ambiguity in the search phrases for data from the data base, and communication between levels may be through a person shifting levels, rather than by person-to-person exchange, (i.e., will a person look after information at the level he at the moment cognitively will be at, or will he look from levels above and below?). The perception of the task by the individual participants in a case should be carefully studied, together with the way the task and information need is expressed, in particular, the redundancy in the verbal terms with reference to the problem space characteristics should be considered. In the analysis it may be a help to compare situations or activities which were considered particularly successful or the opposite by the participants. Is there a difference in the distribution of these cases in the problem space? Considering the assistance needed, the support systems to consider may be different for different persons, and consequently be depending on the localization in the problem space.

Another aspect of a strict hierarchical structure which should be considered in the analysis of cases is the (theoretical) lack of contact between groups at the same level. Does a problem appear if the rescue company "Falck", the public fire brigades, and the civil defense corps, cooperate in firefighting, and the hierarchical structure is respected?

For the effective use of information, it should be considered that the selection and formulation of information to present should reflect and distinguish the different alternatives of action. The number of action alternatives are decreasing down through the levels. In this respect the information should be clearly operational, and the implications in terms of action alternatives, and in constraints on their choice, should be represented in a way that can be used in search terms. Frequent errors are related to not using an action alternative, rather than to doing something wrong.

It should be carefully considered that the amount of information and the complexity/diversity (in a specific, dynamic situation, at least) will increase downward through the hierarchy. This will probably be reflected in the organisational structure if it is assumed that the evolution will have aimed at equal complexity for the individual decision makers.

The data base representing the problem domain in terms of risk potential and emergency management resources will include structural information about functional properties and causal relationships which must be transformed into procedural information in order to be operational in the actual accident situation. This transformation can be based on heuristics derived from prior experience or deductions based on state information from the case

actually present. If procedural transformations are incorporated in the data base, it will have to be rather general rules, or very specific retrieval attributes must be defined. If the procedural information have to be generated on-site, it will either have to be done by the decision maker himself, or information on the actual state of affairs will have to be transmitted to the advisor in possession of the necessary general background knowledge or the intermediary working on the available data bases. See figs. 8-9. This advisor can be a human domain expert or a n "expert system inference machine" attached to the data base.

The conclusion of this preliminary analysis is that the means-end hierarchy is well suited to structure the information content of the data base which is underlying emergency management decisions, during preplanning as well as during the actual situations. Thus structured, it will be possible in a consistent way to identify the proper search terms to use for retrieval design, and to specify the format in which information should be supplied by the numerous data sources, such as risk analysis, incident analysis, plant design, operations planning, and inspections. The analysis of actual cases will serve to make such rules explicit by means of selected examples.

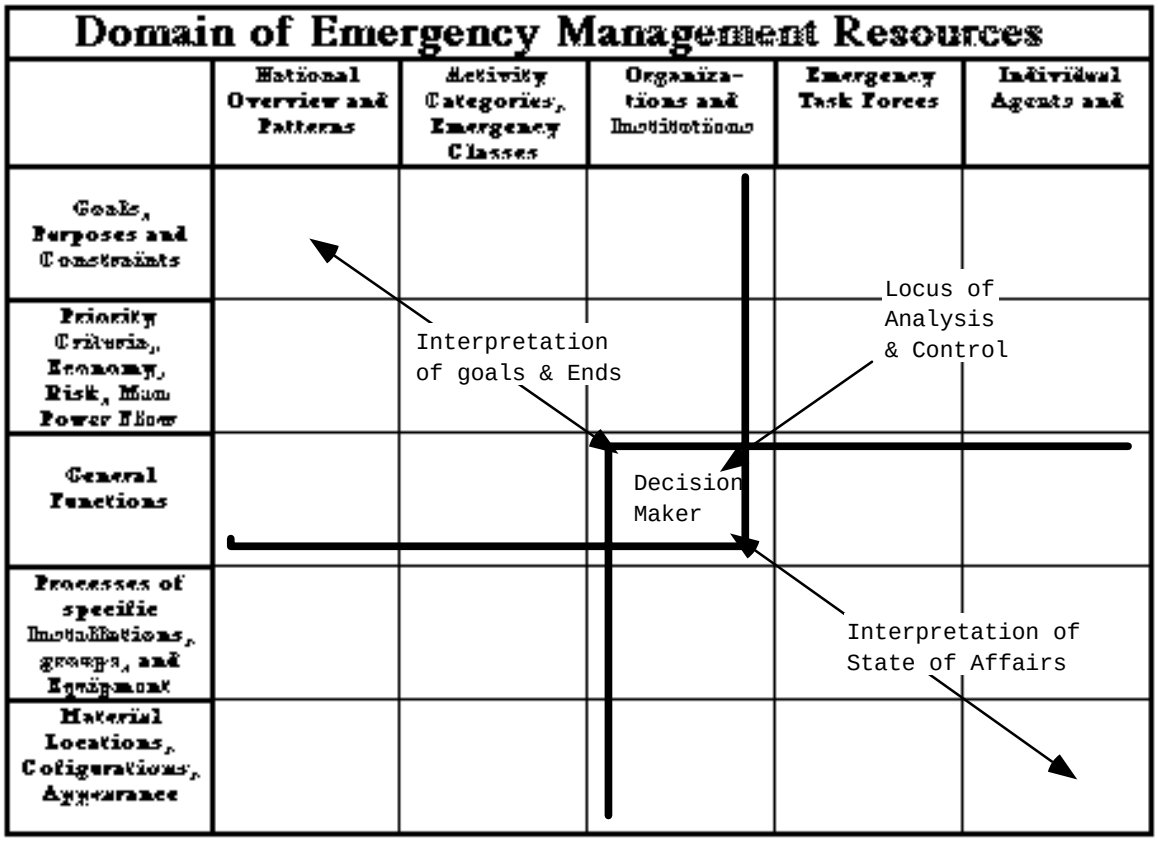

Figure 8. Locus of control.

4.6. The decision process

Another dimension in the modelling framework to consider is a description of the decision process. A preliminary analysis indicates that the "decision ladder" used for systems control will be useful for the present purpose, structuring the decision in terms of situation analysis, evaluation and goal identification, activity planning, and execution. In particular the ladder should be useful for the representation of the interaction between preplanned decisions , their implementation in rules and standing orders, and on-site decision making. An important part of the analysis of specific cases will be to evaluate the degree to which activities are rule-based, and to identify the relevant rules and their origin (formal or heuristic?).

In addition, the cooperation between several decision makers can be represented, in particular the cooperation across the levels of the means-end hierarchy which, in the present context, will also be levels in the lines of command. This means it will be necessary to identify the person in charge of the different data processing functions of the "ladder", and the content and form of information needed for communication during cooperative decision making. During planning, the sequential consideration of different goals and constraints by different decision makers should be considered (cf. the analyses of Cyert and March, 1963). Are the decision makers in accident control cooperating, or are they sequentially solving the problems as they appear? For instance, do the fire brigade people just try to put out the fire, or do they consider the problem of restauration which they leave for the demolition team in terms of water and mechanical damage? Analysis of case stories should include a description identifying decision makers in the overall organisation and the content of their decisions in the means-end hierarchy.

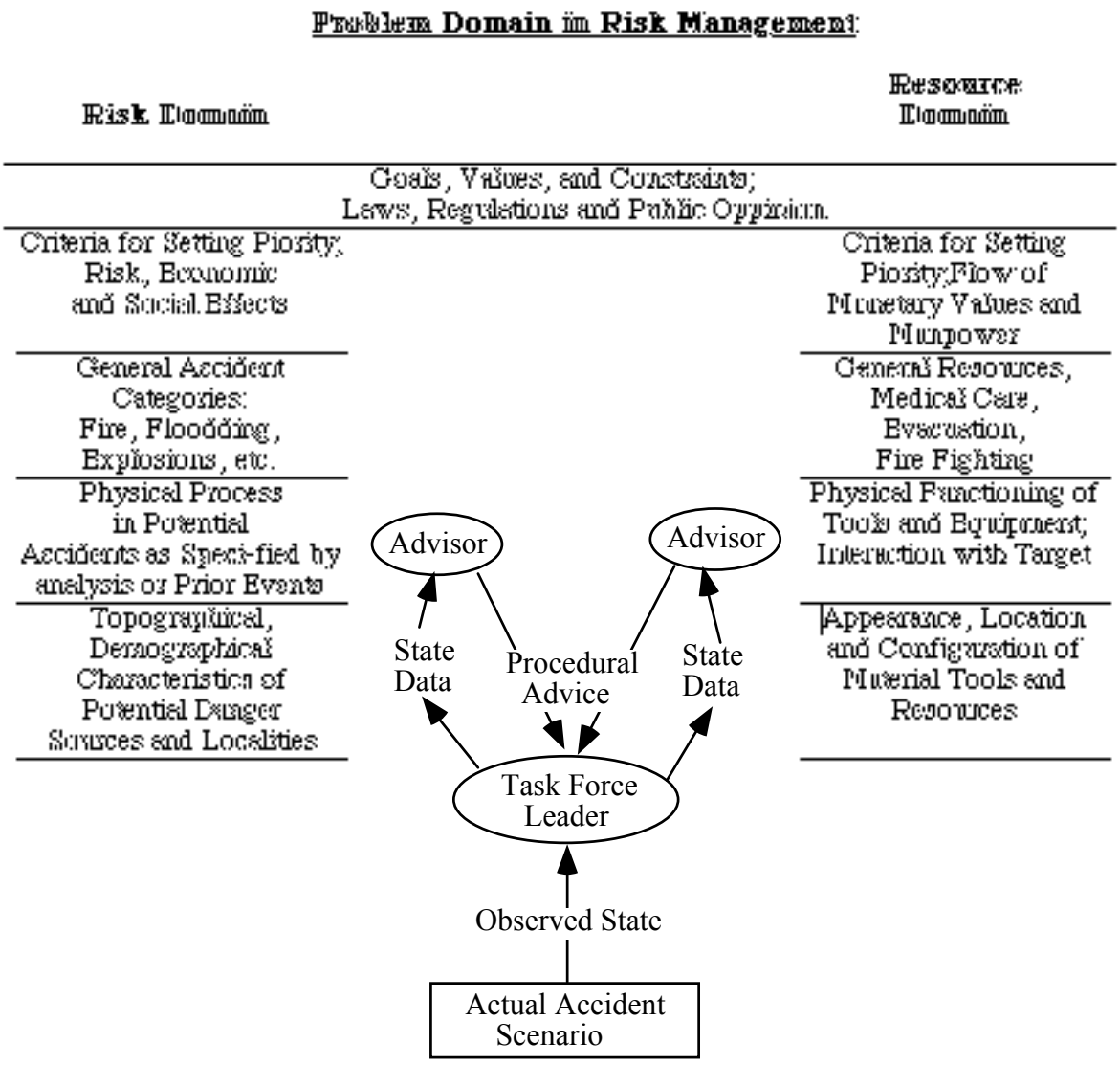

Figure 9.

In order to specify the information need, at least three different decision scenarios should probably be considered:

1. Long term planning of mitigation resources and procedures,
2. alarming and task force selection and organisation in case of emergency, and
3. situation analysis and control during action.

For each of the subprocesses of the ladder, it should be specified:

- who is the performer?
- when is the decision made (preplanning or in situation)?
- what information is needed (source and category (state, structural, procedural, or itentional))?
- where is it in the problem space matrix?
- who is the reciever?

4.7. Decision strategies

In order to identify information needs, the effective strategies for the different phases of the decision process should be determined. Material for diagnosis is already available, but situation analysis, more broadly, and planning should be reviewed. Strategies for higher level control of distributed decision making, in particular, should be considered. Some correlation between the planning strategies in emergency management and the strategies behind current expert system support should be made possible.

4.8. Information Retrieval Strategies

Finally, the question of organisation of information retrieval in data bases is being considered. In supervisory control of process systems, the information needed for resource management within the means-end hierarchy is typically configuration data for a rather well structured and stable system, together with data derived from measured physical variables in that system. Characteristics of the data base involved, therefore, pose no basic problem.

For emergency management, the situation is different. The physical system underlying the courses of events is badly structured and its constituents and properties will be unfamiliar to the decision makers. Important information will depend not on measurements and analysis but on judgements based on experience from previous "similar" cases. Design of data bases which make data from previous technical analysis, design information, data from previous cases in the form of heuristic rules, will require a systematic taxonomy with retrieval attributes compatible with a user's changing needs during the decision task.

Taxonomies already developed for human error classification and information retrieval in libraries (Pejtersen, 1980) are being considered for adaptation to the present project, to gain a taxonomy compatible with the structure of the means-end hierarchy. The long-range aim is guidelines for analysis of incident reports and design of retrieval systems. The experience with the existing data bases on properties of characteristics of potentially hazardous chemical substances has been that too much information is returned from queries (see the following sections for more details). Therefore, systematic attempts must be made to transfer the know-how from library systems in terms of proper formulation of search terms and language control of synonyms and related terms before the data base entry.

The elements in a data base should be characterised along all the dimensions of a user's needs, and, therefore be compatible with the

concepts used by users. Several different categories of relationship among concepts will be used for different purposes. The most typical categories we have met in protocols and interviews are mentioned here:

•Of basic importance are relations along the means-end dimension, i.e., the relation between the levels of the problem space. Along this dimension information is found what functions or objects can be used for, or about how they can be realised. This dimension is of primary importance in resource management.

• To label or name objects, answering questions like: what is this?", set membership relations of a generic hierarchy will be used. This kind of category will be familiar from biological classification, a technical example could be: process plant component - pump - centrifugal pump - specific type of pump. This dimension will be important, for instance, to classify chemical substances into generic categories which have in advance been characterised with respect to toxidity, explosiveness, etc.

• To discuss what a given piece of equipment is composed of, consideration is structured according to whole-part relationships in a decomposition hierarchy, such as: Diesel generator - oil supply system - injection pump - pump bearing. Information of this category may be useful to infer presence of certain equipment, or substances from more general characterisations, for instance to identify the equipment resources available when calling a specific rescue team.

• In order to identify or describe objects or substances, categories in terms of descriptive attributes are used, frequently, however, represented by prototype members, is there anything similar to XXX which caused us problems at the incident at --?

• To predict the course of events during an accident and the effects of intervention, cause-and-effect relationships are used to predict the propagation of changes through a system.

• It should be mentioned here that relationships are frequently found which cut across these more formal categories, being episodic relationships referring to the context of prior experience. In the present context, this point of view will be important to characterize the previous cases which may be the primary source of data for the expert system.

The conclusion of this discussion is that the question of the systematic identification of subjective formulation of roles and information needs will be an important topic. The interviews in the present feasibility study will only serve to scratch the surface but,

hopefully, good examples can be found for formulation of the need for more detailed studies.

5. ORGANIZATION OF EMERGENCY MANAGEMENT IN DENMARK

5.1. Laws and Regulations

5.1.1. Fire service and fire commander

The duties and responsibilities of a chief fire officer, as well as the organization of emergency forces at the scene of an accident have been settled through the Fire Services Act. Danish law has been consulted, as this forms the basis for the following case studies.

Information needs will very much depend on the user situation and his background. The case study in a following section is based on firemen's reports, and interpretation in terms of information handling therefore requires one to have some knowledge about the job, the organization, and the educational background.

The basic education of the fire brigade personnel is supposed to be broadly identical to common European practice, but the organization of fire services and of emergency operations is known to differ somewhat. Therefore, the present section is reviewing relevant Danish laws.

It is characteristic that a fire officer will be the leader on the scene of the accident in most types of accidents, including cases involving hazardous chemicals, no matter if there is a fire potential involved, too.

The Fire Services Act (Brandloven, 1976) requires every local authority to arrange a fire organization covering both inspection of buildings, etc., and emergency service. Concerning the last matter, the local authority can have this job done by the neighbouring authority, or by a private firm. Requirements to education and training, equipment, etc., are defined by the Ministry of Justice which is the ministry governing fire as well as police organizations.

Chapter 3 of the Fire Services Act describes measures in case of fire, covering alarm, immediate actions, fire service operations, police assistance, and assistance from neighbouring forces and civil defense forces or military personnel. In this chapter it is stated that command on the fire site during fire mitigation and rescue operations is exercised by the chief fire officer or his representative. The chief fire officer is the person responsible for both the fire inspection work and the fire service arrangement of the local authority. Fire commander will be used below to title that member of the group of chief fire officer

and representatives, who is on duty and is controlling the actual emergency operations on the scene of the accident.

When an emergency occurs, the job of a fire commander is more thoroughly laid down in the ministry's "Chief Fire Officer Instruction" (Instruks, 1983): Section 8 of this instruction reads (unofficial translation):

> "In case of fire, explosion, accident with dangerous substance, building collapse, train accident, aircraft accident on land, and ship accident at the pier, the fire commander controls all technical emergency operations at the scene of the accident. ... During very large peacetime accidents, the head of police will coordinate all emergency operations. ... The command structure is shown in Fig. 10 adopted from (Instruks, 1983).

During the inspection work, the chief fire officer is obliged to reduce the fire risk in hotels, industry, storage areas and any other place with more than average fire risk. Through this work he is able to collect information on such objects that may one day be significant fire locations. The Fire Services Act does not specify emergency plans to the made for the principal fire objects, but the Chief Fire Officer Instruction requires the chief fire officer to develop "meeting plans" for such objects where significant risks can be foreseen in case of fire. A meeting plan may cover:

- specification of first force and perhaps second force
- preferred route station to site
- preferred access points
- preferred start positions on the site, water supplies, etc.

Extensive emergency plans are presently not required by the Fire Services Act, but such plans are worked out in special cases, including oil refineries for example.

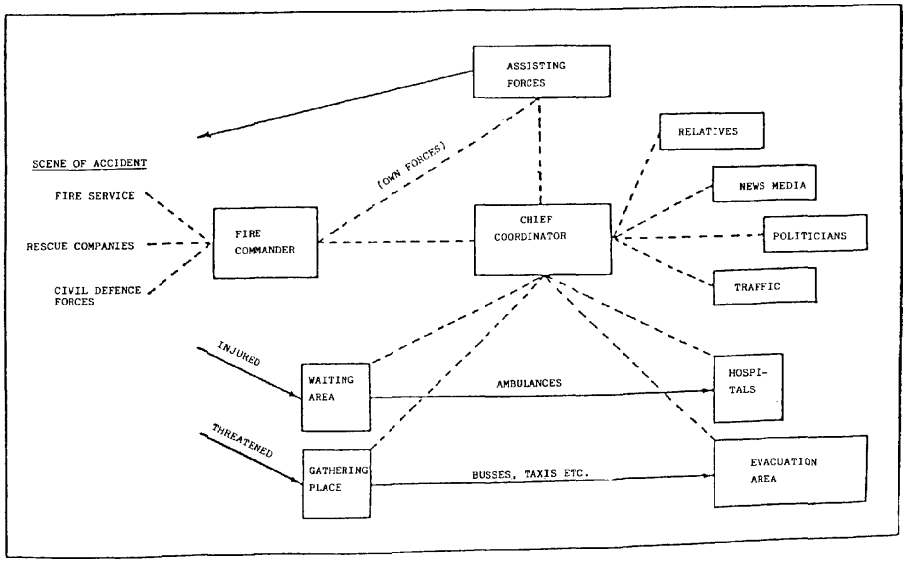

Figure 10

5.1.2. Accidents with dangerous substances

The local fire services have special equipment and are trained to control minor accidents of this sort. Therefore, the local fire service constitutes Step 1 of the general Danish emergency plan for dangerous substances, described in a guidance from the Environmental Protection Agency (Farlige stoffer, 1974).

Step 2 of this plan will include further mobilization of forces with more specialized equipment, situated at selected fire stations, etc. Eventually, Step 3 may be activated, in which case assistance is acquired from the nearest Civil Defense Center, which is able to control larger pollution cases. The civil defense forces may also bring communication staff and equipment to build necessary communication lines.

The guidance lists several services and authorities which may be of some help in the accident situation: ambulances, hospitals, medical personnel, labour inspectorate, road authorities, advisers on chemistry and poison, etc. The guidance on dangerous substance emergencies does not add to or modify the command structure given through the Fire Services Act and shown in fig. 11.

5.2. Release of Hazardous Chemicals

5.2.1. The problem

As described above, the organization set up to manage hazardous release is a modification of the organization for fire emergencies. Also the chemical accident has to be controlled by a fire commander, but special equipment and clothing will be available, and an advising system has been established towards hazardous chemicals. These arrangements and this entirely new working field have been developed within the last ten years, and practical experience with the systems will be rather limited.

Today's fire commander has to rely very much on external knowledge, while in this situation he himself is not the expert. Even an experienced chemist would have to depend heavily on handbooks, measurements, and calculations to aid rational decision work. Accidental fire is much more recognizable to a human than most chemical releases. Some characteristics will therefore trouble even a future emergency commander with more experience on this matter, and perhaps more theoretical knowledge.

The chemicals that may be involved in transport accidents, or be released during industrial accidents, are innumerable, and new chemical compounds are invented every day. Most chemicals do not expose humans to immediate danger, but many chemicals will represent a risk factor when complete ecosystems are considered.

A chemical may bear several identification marks: trade names, professional names, formulas, digit codes, etc. There will sometimes be signs painted or labelled on the container, on walls, road signs, etc., telling about the risk and perhaps stating procedures in case of release. In cases when the identity cannot be obtained from labels, signs, accompanying persons, etc., one often tries to use observable characteristics: colour, odour, weight, viscosity, etc., and perhaps comparison with well known substances. This leads to pure guessing work, even if such identification is made with telephone contact to an expert. When an early identification does not succeed, it will be necessary to mobilize a specific expert or a general expert. The former may be a representative of an involved company or of another firm using the same class of compounds. The general expert will be an analyst who can work out an identification with proper indicators and perhaps laboratory work.

When a proper identification has been made, chemical data can be found in handbooks and other general sources. Business interests may restrict available information about certain chemicals, and this

represents a practical but not a principal problem relating to the feasibility of expert systems.

Today's expert system in Denmark for the management of hazardous release centres around two main blocks; a set of chemical emergency cards supposed to be a standard tool for field use in the emergency organization, and a 24 hours advisory system. This situation will be described in the following two sections.

5.2.2. Chemical emergency cards

More than a hundred cards have been worked out and distributed by the Civil Defence authorities to fire brigades, hospitals, railways, etc. Every card gives all the information pertinent to one specific chemical, under these standard headings:

means for protection
procedures in case of accident
dangerous properties
further characteristics (physical constants, recommended dose limits, hints for analysis)
suggestions for the doctor
cleaning of equipment and tools
references to handbooks and data bases.

The procedure section starts by giving a general procedure for the first attack, for example in the case of tetramethylplumban:

"Personal protection. Attack in the direction of the wind. Rescue of injured persons. Evacuation (at first: 4 km in wind direction, 2.5 km zone width). In the outer 2/3 part of the zone, or by short (below totally 30 minutes) release, "stay indoors" will be appropriate. In case of explosion risk: safe distance: 600 metres. Call expert assistance (use telephone list)."

The procedure section goes on specifying release control, operations on environment, fire fighting, human reactions after exposure, first aid, and prevalence of the chemical.

Dangerous properties are listed under: fire and explosion, poisonous effects, characterization, reactions, environmental danger. The section ends up by giving further names of the chemical, including a few common trade names.

To find the relevant card, one needs a UN number and the standard name: 1649, TETRAMETHYLBLY. The system register leads to "1649" from several names, including German, British and French standard designations as well as TML, Octel TML, and Octel Mix, etc. The UN number can frequently be found on containers, tank cars, storage tanks and may be accompanied by a three digits danger code stating in priority order the most important hazard characteristics.

5.2.3. Advisory system

The description of this system has been extracted from Sonnich Thomsen (1984a).

An advisory group based in the Civil Defence analytical-chemical laboratory can be contacted day or night. This arrangement has been open to fire brigades etc. since 1978. Out of working hours the group consists of four chemists who are familiar with the problems on the scene of an accident, and who are engaged in relevant R&D activities. A goal for the advisors would be that they are able to provide the most urgent advice within, say, 10 minutes. Answers may cover both chemical information and approximate responses.

In serious or complicated cases, the chemical advisor will move himself to the scene of the accident. Analyses to find identity or concentration can be made by the Civil Defence units in "step 3" of the emergency organization for chemical accidents, mentioned previously, or by the Civil Defence Chemical Analytical Laboratory.

According to the Danish Fire Inspection (Haurum, 1985) a development is under way with this information gathering system. The Civil Defence Analytical Laboratory is about to establish communication lines into the German TUIS-system. The "Transport-Unfall-Informations- und Hilfeleistungs-System" is made up by large chemical companies and oil companies to deliver these services:

a. advice via telephone
b. on the spot advice from experts
c. assistance with equipment and personnel by very large accidents.

Obviously, a large group of experts will be accessible that way who can supply specialist knowledge out of the reach of any central laboratory.

5.2.4. User problems

The route from a greasy substance spilled on the ground or a strange smell during an industrial fire, to the most appropriate response may be a very long one to follow. Fire commanders have added to their job a lot of data handling with no parallel in the normal work of a fire brigade.

Already the identification of the actual chemical, and the preparation, concentration, etc. may be troublesome, if labels of documents are missing or some mixture or intermediate product of a chemical process is involved. The identification of unknown compounds has no appeal to the fire commander except as the necessary key to his information sources. What he really needs is the code translating his observations to appropriate response guidelines.

I want: necessary precautions and suggested procedures for reaction.

I have: large tank leaking greenish, heavy fluid with no particular smell. The site is a furniture factory.

This fictive example shows that most fixed data sources may be surpassed by the expert who is able to work backwards in his knowledge space. As put by Sonnich Thomsen: suppose the fire commander observes a red coloured chemical, when the expert programmer had seen a pink coloured one, and ordered his data input accordingly.

Sonnich Thomsen (1984b) reports statistics from 151 acute cases where he was called as a member of the group of four expert chemists. The trouble to translate names for the purpose of chemical identification is illustrated by this table:

TABLE 1. The distribution of chemical names and trade names. (Sonnich Thomsen 1984b).

Immediately understandable chemical names			53%
Trade names:			
- easily found in the literature	17.1%		
- difficult to "translate"	9.9%		
- impossible to "translate"	6.6%		
- total		34%	
Other		13%	

6. ANALYSIS OF SELECTED DANISH ACCIDENTS

Specific accident experience and examples have been gathered from 10 selected accidents in Denmark, covering the period 1978 to 1984. Information about these cases has been collected mainly from the principal Danish periodical on this matter: "Brandværn", which is issued every month and reports most Danish as well as selected foreign fire cases and accidents with dangerous substances.

The criteria for choosing these 10 cases were that environmental effects or the threat of such effects should be a principal factor in any selected case. There are no large-scale disaster in the group, but potential disasters were faced in most cases. The sample is therefore supposed to give a fair representation of both typical and severe problems of a fire commander when he is in charge of an accident outside the every week routines.

6.1. Case List

The following 10 cases have been selected:

1. Kolding, 780704. Fire in a factory producing preser-vation fluids for wood. Threat: smoke withpoisonous sub-stances.
2. Stigsnæs, 781011. Oil refinery fire. Threat: exploding equipment and tanks, pollution with oil products and smoke.
3. Nørresundby, 800131 Liquified gas release when loading a storage tank from a railway tank waggon. Threat: gas cloud spread in the residential areas of a city.
4. Stigsnæs, 800714 Oil refinery fire. Threat: Cf. case 2 above.
5. Copenhagen, 800715 Explosion in extraction plant for vegetable fat. Threat: Spread of explosive vapours to traffic area and nearby residence, long-distance effects of explosion at the plant.
6. Ålborg, 820919 Petrol release from transfer line in the ground. Threat: ground pollution, danger of explosion in sewers.
7. Fredensborg, 830109 Chemical reaction turns hot outside working hours. Threat: Spread of poisonous gases.
8. Copenhagen, 831110 Container leak during transport of chemical, suspected to be phenol. Threat: water pollution and spread of poisonous vapours.
9. Hillerød, 830910 Motor-carleft filling station without disengaging filling hose for liquified gas. Threat: gas cloud.
10. Highway, 840120 Turned over tank-car on highway. Petrol spill. Threat: Pollution of ground and lake. Explosive vapours in sewer system.

Case 1, Kolding

During transport of 10 litre bins with preservation fluids inside the store for finished products, some bins were overturned, and fluid was spilled. The product gave off flammable vapours, and these were ignited, when personnel in the area tried to control the release using saw dust. It has been supposed afterwards that ignition arised from a creeping foil unit, which continued operation at the moment.

Already before his arrival to the scene of the accident, the fire commander ordered all disposable forces called, due to the violent smoke observed. Upon arrival, alarm was given also to fire services from neighbouring districts and to the nearest civil defense center.

Efforts to stop the fire did not succeed until three hours later, when almost the whole factory had burnt down. The factory was contained in one building, complete with stores, administrative functions, canteen, etc. Characteristic troubles with this fire were:

large amounts of flammable solvents
misjudgement of fire resistance of walls, etc.
low pressure in water supply

vast amounts of preservation fluid washed down with water.

The first strategy seemed to be stopping the fire in the storage area where it started. However, the walls did not resist a fire which was so well "fuelled" by solvents, and forces had to be withdrawn step by step, until at the end the forces shifted their efforts towards saving more distant objects. Two storage tanks outside the factory building were cooled by firemen, an ignition was avoided, partly also due to a suitable wind direction.

The very early alarms for further assistance may indicate that the fire commander did expect a very large fire potential caused by the substances used and stored at the factory. The firm was - and still is - a well-known factory in the area, and the potential for fire as well as poisonous gases has been common knowledge to the local fire service. Surprise may have come from structural characteristics and water supply pressure.

A local firegroup existed in this company, but it was not activated due to the violent character of the fire. However, a specialist from the company prepared himself to assist public efforts directed towards environmental pollution. Civil defense personnel performed repeated surveys around the site to monitor the concentrations of dangerous substances and products of combustion.

A pollution control crew of the civil defense organization succeeded in stopping pollution of the nearby inlet. A 150,000 kg mixture of water and preservation fluid was removed, to be transported to "Kommunekemi", a public plant for destruction of dangerous substances.

The case raises a general and very important problem, where fire commanders may experience great dilemmas. With such fires, pollution may result no matter which strategy is followed. The fire commander may choose among rather different courses:

putting out the fire as expedient as possible will cause large amounts of chemical substances to end in the sewerage and perhaps in a lake or inlet

the quite opposite strategy will produce more smoke and probably air pollution with hazardous chemicals.

An expert system might help the fire commander work out raw classifications of risk.

Valuable information to the fire commander in the Kolding case might have included:

fire potential of wood preservation fluids

fire resistance characteristics of the type of structural elements used in the factory

typical burn-through times of the actual constellations of "fuel" and concrete walls, etc.

combustion products and parameters to evaluate the spreading and the need for evacuation

water supply data

layout of sewers in the area.

Most of the problems were solved in the end without using any expert system, but presenting some of this information earlier in the run might have saved valuable time and would probably have directed the attention towards a more efficient strategy. Some of this information has presumably been in the possession of local authority departments, and some even in the fire inspection files, but not in a form suitable or accessible from the scene of the accident. General information on wood preservation fluids would have to be obtained from national or international knowledge banks.

Case_2,_Stigsnæs_1978

This case is a serious one, in that one person died after the accident as a result of burns he acquired immediately after arrival to the plant where the fire evolved.

The oil refinery has its own fire brigade, and this was alarmed when a small fire started by an oil oven. The alarm was signalled to the public fire service simultaneously, and in this way three levels of emergency operation were initiated at the same time:

the public fire service started mobilization

the refinery fire brigade was activated

people at the actual plant started mitigation efforts

When the refinery chief fire officer and his assistant arrived to the site and went out of the fire engine, a sudden burst of fire stuck the two men and the car. The chief fire officer died later from his burns. The fire engine burnt out completely.

Process control personnel now signalled "disaster alarm", and continued shut-down procedure and mitigation. The local fire brigade had started cooling with water monitors, when the first public unit arrived. In total a lot of 29 fire engines and 98 men were called to the refinery from outside.

A radioactive source in the plant was localized and removed from the accident area. A search for injured and trapped persons in the plant was conducted, but all had escaped. After the plant had been shut down, mitigation was easily completed. Vast amounts of process equipment had been destroyed by this fire, but no harmful effects were reported for environment or public.

In cases like this, however, there are very large fire potentials involved and the fire commander may have to face questions like:

fire spread outside the refinery?

spill to ground, sewers, etc.?

missiles from ignited volumes of refinery products?

air pollution?

Oil refinery plants in different countries must have several common characteristics, and one must assume that certain approaches and general hints would be useful for the fire commander. In cases where well informed personnel from the refinery is available, these may help the commander to classify fire, plant, and equipment in such a way that specific questions can be phrased, and more useful answers obtained.

Input to an expert system could be types of product, plant equipment, etc. The answers could be obtained as risk ordering and simple rules such as suggested safety zones and procedures for localizations and removal of radiation sources.

Case 3, Nørresundby

The inlet of Limfjorden passes between the Ålborg town area and the Nørresundby town area in the northern part of Jutland. On an everyday noon the fire service got the message "outflow of gas due to an open valve on a railway tank-car". Three railway cars were parked in a special discharging area close to a big tank store for liquified gas. Discharge to the tank store was going on when a flange connection failed due to gas pressure, and gas was let out in the open air. The personnel tried unsuccessfully to close a safety valve, but this did not operate, because this operation had not been prepared properly before discharging of the actual tank car had begun.

This event happened under cold weather conditions, and the fire personnel arrived to a large cloud of vapour and gas. At first they were misinformed by the gas people, and tried to turn the wrong tank-car off. At the second attempt they operated on the right car, and eventually succeeded in stopping the outflow.

The operation was troublesome and rather dangerous to the firemen. Cold weather and evaporation of the gas combined to give rather low working temperatures and thus the firemens' boots and gas mask windows were covered by ice.

In parallel to these operations, a warning was given to residents in the affected area, and traffic was stopped on roads and railway lines. 2 1/2 hours after the alarm, the gas cloud had dissipated and traffic restrictions could be cancelled. More than 13,000 kg of liquified gas

had been released to the environment, but no serious consequences were recorded.

The fire commander has considered the risk of explosion and the consequence if the stored gas volumes had been involved, too, as a secondary effect. Dangers to the public are obvious in this case, but the operation was conducted to a lucky end under rather bad working conditions. Many questions are raised: emergency plans?, suitable tools and operating procedures?, etc. The fire commander might use these types of information in the case:

how far does the zone of potential explosion stretch, when comparing with the region occupied by the visible gas cloud?

for how long may the gas flow continue, when the tank car has contained 26,000 kg?

are there schools, nursery homes, hospitals, which may be affected by the gas cloud and may need extra warning time?

which organizations should start thinking now, because the explosion is a very real possibility? (Disaster prewarning).

Case 4, Stigsnæs 1980

In the desulphurization plant, light fuel oil leaked out and was ignited. This started a chain of events:

burst in 6" pipe with hydrogen and fuel oil

a moment later a 12" pipe with hydrogen and naphta broke

burning fluids were sprayed around and a third pipe burst later on.

Observation of the fire led immediately to external alarm and to activation of the own fire brigade of the refinery. Sprinkling and cooling with water monitors was started and shut down of the actual plant initiated. When the public fire service arrived, they proceeded with cooling operations, and prepared for extinction. A command post was established for communication purposes and for distribution and coordination of the forces. The first alarm message had activated five fire engines, four ambulances, and several diverse units.

The fire was put out 2 1/2 hours after the alarm and extensive material losses had resulted with complete destruction of very large plant components.

This may be looked upon as a case where public fire service worked merely as a more powerful continuation of a local fire brigade. They added highly trained firemen, but much equipment and material was, however, already available in the refinery. When emergency operations have been organized in advance, and risks are considered in the everyday routine, the best experts can be found among local personnel.

When fire may evolve violently and strike several plants at the site, the fire commander has to consider:

where do I get extra water?

which plants, tanks, etc. must not be caught by fire?

Even if these are internal problems, external effects will depend on the success to avoid disaster. Information about release, air pollution, etc. is mentioned above, case 2 which took place at the same refinery.

Case 5, Copenhagen (A)

The explosion of an extraction plant in "Dansk Sojakagefabrik" led to broken windows in city regions hundreds of metres away. The emergency operations and the actual alarm history include several details worth a further study both with respect to information handling and emergency planning. We will here concentrate on obvious information needs.

The accident plant produced vegetable oil by an extraction process utilizing a light petrol type, which was retrieved afterwards by destillation. That evening the plant personnel had some troubles in keeping the process temperature on level and more heat was therefore supplied to the toaster. The smell of petrol increased, and after some time forced the staff to leave the extraction plant. The first alarm signal told the public alarm centre that "airplane fuel was spilled on the road in front of this firm". The alarm was sent by a public bus driver at the place.

With this plant no local fire brigade took over momentarily, and according to the report in "Brandværn", information from local experts did not have much influence on emergency operations. The fire commander had to work towards several goals:

avoid ignition

stop further evaporation

consider warning and perhaps prepare for evacuation of close residental areas.

Therefore, he should evaluate the zones with high risk of explosion and predict further spread of petrol gas. He should find some means to stop evaporation by removing the heat or the petrol, or possibly to keep the vapour inside a controlled volume.

After some discussions with the engineer in the power control section, the fire commander decided that the power lines to the extraction plant which were presently unloaded should be turned off. Fulfilling this order led to a violent explosion blewing up the entire extraction plant. Considering the massive material damage at the site, and the damaged windows far away, it is surprising that no one was

killed, but several persons suffered first order burns in face and hands.

Immediately following the explosion, 40,000 kg of light petrol was on fire and the fire was developing on different places at the plant. There was a general fear of coming explosions. The violent events started alarms to come from anywhere in the city, and rather big forces with fire engines and ambulances were directed to Dansk Sojakagefabrik.

The first fire commander on this event had his face burnt during the explosion and was sent to hospital, after he had acquired mobilization of a command post, and briefing of the chief fire officer. The chief fire officer arrived when the fire commander was under way to the hospital, he therefore started making his own observations. Rather soon the command was taken over by a new fire commander, and the chief fire officer could concentrate more on external communication and news media.

Conditions after the explosion involve:

darkness

ruin piles

large water consumption for extinction

search for injured people supposed to be missing

silo fires with soy beans.

Extra water supply was arranged from a special boat belonging to the harbour administration, and flood lights were established by fire service specialists.

According to this source, no dedicated strategies were used, specific to the extraction plant, and formulated in advance in an emergency plan context. But the following general strategies were followed:

arriving units park at a reasonable distance from the potential centre of explosion

remove ignition sources from risk zone

establish defensive cooling on selected objects.

Under such circumstances the fire commander should consider the threat from petrol vapours, when residents could be affected, and the evacuation need should be evaluated. Could the sewer system accept petrol and combustion products and material from damaged containers and stores?

The following question should be asked a group of experts when one was available:

which strategy is a wise one to follow, to control an extraction plant which is turned on which utilizes light quality petrol and which is supposedly starting an explosion rather soon?

The answer is very urgent to the person in charge, but he does not have the knowledge and the conditions to choose the most reasonable answer. Had the command post and the chief fire officer been mobilized at that time, they might assist the fire commander together with the necessary company experts.

The accident demonstrates that some sort of very fast risk analysis could be of obvious value to the fire commander. The evaluations consider technical matters and a few data are essential for the expert system: specific data about control units, breaker construction, etc., or general data on the degree of automation, in addition to a few plant characteristics. It is not at all clear which format should be preferred: universal risk tables, universal procedures, or more specific ones.

Some data from the outside world could serve the fire commander and the police:

where and when do ambulances arrive?

which hospitals have capacity for burns, for other casualties, etc.?

road status and traffic data to be used for ambulance routes and for restrictions on common traffic.

locations available as evacuation addresses: schools, theatres, restaurants, stores.

Case 6, Aalborg

An industrial area of Aalborg was the scene of a leakage from underground petrol lines to the public sewer system. The alarm came in the early afternoon one day when personnel at a sewer pump station experienced a rather strong smell of petrol from the input flow to the station.

The first reactions of the fire service were based on experience from other cases with petrol smell in that area: these had originated in the environment of a gas production plant. Gas for household use in the region is produced from a highly volatile type of petrol with a low content of lead additives. This time, petrol was at first detected in any well which was tested. Then a measurement programme was conducted to fix the necessary size of a safety zone around the pump station. This safety zone involved 40 to 50 wells.

All wells in this explosion zone were covered with sand and plastic sheets, and the sewer system was ventilated as well as the pump station. The flow of petrol to the zone did not stop, and both the gas production plant and several industries were suspected sources. Inspection of the gas plant showed that all valves were positioned correctly, and other potential sources came out negative as well.

Now, samples had been taken at the pump station and sent for laboratory analysis, and after some hours results arrived. These

analyses showed that the petrol found in the sewer system had characteristics common with the gas production type of petrol. A more intense search was made on the gas production plant, and the leak was eventually localized to an underground pipe line running 2 km from the pier to the gas production plant. This pipe line was running in parallel with the main line of the public sewer system on some part of the 2 km distance.

A batch of petrol had been delivered one week earlier, but also internal transfers of petrol supplied the leakage, as there were no shut-off valve or non-return valve.

The safety zone and the corresponding restrictions were maintained for 24 hours.

The chief fire officer concluded that fire brigades ought to know the layout of sewer systems and procedures for accident cases, involving:

isolation of grid sections
alternative means of drain
possible reservoirs for the gathering of releases
admittance and inspection
contact to authorities and experts.

Case 7, Fredensborg

On a Sunday morning during the winter, the fire service was called to a chemical company "Sadofoss", where adhesives are produced.

The plant director and the production leader explained to the fire commander that lots of white milky smoke came from one department, and that the smoke had a strong smell. They hypothesized that the smoke could originate from self-ignition in one out of three 1200 l containers with additives for the production of sealing compounds.

Two firemen with full protection kit inspected the department and found one container smoking. Access to the container would be difficult due to machinery and a fork-lift truck parked in front of it. According to the plant people, the actual content was a mixture that might generate heat when reacting, and the smoke would contain hydrochloric acid.

Firemen were instructed by the production leader how to drive a fork-lift truck and they attempted to transport the container out of the building. Meanwhile, the police had arrived, and had started to warn residents in the neighbourhood, instructing people to stay indoors with closed doors and windows.

Additional firemen had to assist with the transportation job, which was complicated by the bad sight and a greasy floor surface. Civil defence forces were alarmed with an air compressor unit for the

reloading of air cylinders in the breathing equipment. The poison information centre of a national hospital in Copenhagen was contacted, and so was the Danish broadcasting system. It was decided not to use the public sirene warning system, as this would cover a larger area than that affected by the hydrochlorid acid emission.

More than one hour after the arrival of the fire service to the plant, the transportation job succeeded. On a place in front of the building, the container was turned over, the content washed out, and the process stopped.

Later considerations by chemists have suggested that the smoke would include not only hydrochlorid acid, but also unknown amounts of lead, likely as a chlorid.

Case 8, Copenhagen (B)

One pier in the harbour of Copenhagen was closed by the fire service due to strong smelling of chemical vapours from a tank on a ship. The chemical was suspected of being phenol.

The firemen and police experts and specialists from the environment control unit of Copenhagen tried to identify the chemical without success. Contact to the receiving firm - a chemical company outside Copenhagen - revealed that the chemical was a relative to phenol. According to the company this chemical would be rather safe due to the strong smell which would warn people before poisonous concentrations were obtained.

The police and the environment specialist had found that below half a litre of the chemical had leaked. 12 workmen on the harbour were sent to hospital for observation due to the risk of getting lung oedema as a result of the exposure.

The leakage had partly been caused by a failed temperature control, and the batch had an increased temperature. Therefore, some discussions followed the event, because the company wanted to have the container moved to their place immediately. The authorities decided, however, that the container should stay overnight and cool down.

This transport case emphasizes the need for clear labelling of chemicals, using standard names and codes that can be used by the police, fire brigades, etc. In the actual case, the identification problem was solved eventually by the receiving company the chemical. In the common case one may figure that information could be obtained from a file with Arbejdstilsynet - the Danish occupational health and safety agency - where a file registers chemicals used by individual

companies. The "product file" is not accessible for external users, due to business interests, but access during emergency might be allowed.

In addition to the alternative methods of specific identification, it may be suggested that expert systems might help the fire commander do a rough kind of classification using immediate observations, smell, etc. In this way it could be possible to point out very general procedures to be effective in most of the cases.

Case 9, Hillerød

After filling his motor-car, the driver forgot to disengage the hose used for petrol. The filling-stand broke when he left the petrol station.

This event took place at nine o'clock on a Saturday morning with a lot of people in their houses near the filling station. When the fire service arrived, it was judged that petrol clouds had spread to 500 metres from the filling station. The fire personnel were able to smell petrol at a distance of 150 metres from the leak.

The firemen localized a valve on the petrol tank, where the leaking of petrol could be stopped. A large police force had been mobilized, and the policemen established the necessary traffic restrictions. At the same time the police sent out warnings to the people in the district, using police - car public address systems. People were asked to close doors and windows, and they were urged not to use open fire.

The fire service also tried to scatter the petrol cloud by using water jets, when the cloud was moving towards the central parts of the town of Hillerød. The possible evacuation of a zone up to 500 metres from the source was considered, but the fire service managed to stop the outflow of petrol, and the petrol concentration was lowered beneath the limit of explosion, before the evacuation could be started.

Accounts on this case have been obtained from newspaper articles and the basis for the fire commander's decisions has not been described in detail. However, the following information problems can be suggested to exist in this class of accidents:

if explosimetres, Dräger-tubes, etc., are unavailable, how can one then derive safety zone parameters from immediate observations, sight and smell?

universal procedures for "petrol station leaks to living quarters" should be stored centrally, and be available through an appropriate information system.

general purpose town analyses for any quarter of any town could be useful for fire service, police, civil defence, giving distribution of people, building characteristics, schools, theatres, etc.

Case 10, Highway

A truck with a trailer both carrying petrol had an accident on a highway. 36,000 litres out of a total of 38,000 litres of petrol were spilled on a parking area, and the majority of this amount ended in a nearby lake.

An explosive fire was experienced in a villa close to the sewer line between the parking area and the lake. This fire may have been initiated by evaporated petrol coming from a sewer drain just outside the cellar of the house.

The operations were conducted by two leaders: the fire commander controlled operations on the two scenes of accident, and a police officer controlled traffic and communications with residents, journalists, broadcasting people, and the electricity company.

This case gives a very clear demonstration of the need for access to external files. One of the involved fire officers brought a radio from a parallel job, and this radio operated on the the radio system of the municipal technical oprganization. Thus it was possible to obtain information about the sewer systems directly, and at the same time it would be simple to communicate with pump stations if necessary. The same radio link was used to acquire a row boat and material for closing of the drains.

7. THE VIEWS OF EXPERIENCED FIRE OFFICERS

A group of fire officers and civil defence officers has been contacted and interviewed about the subject "expert systems for emergency management":

Ole Brøndsted, Civil Defence, Roskilde
Ebbe Bødker, Fire Service, Roskilde
Alex Jacobsen, Civil Defence, Roskilde
Bengt Knudsen, Fire Service, Vestegnen
R. Ringsted, Fire Service, Copenhagen

They were requested to look 10 to 15 years ahead and imagine the future emergency manager's situation. What types of data, and what types of decision aids ought to be managed by expert systems? Should expert systems be brought to the emergency site at all? The interviewed were required to think of the emergency manager in a general way, covering both the fire commander and the command post staff.

The interviews took place on two occasions; the first time with two specialists, the second time with the other three specialists. No written material was presented, and the interviews were made as group discussions using some well-known cases as a general

reference, especially case 5 above. Several examples were set forth by the specialists during these two meetings.

The interviewed specialists assume that a future fire commander and the command post staff may very well use electronic data systems connected to data centres far away. But concerning the type and content of such communication, the impression is that updated status information will be the most important item. The experts do not imagine more developed types of communication to be of much use to the fire commander.

Results from the interviews have been grouped under three headings: update status information, basic expert knowledge, other types of information.

7.1. Updated Status Information

7.1.1. Route

Which way is recommended leading from station to the scene of the accident? Such advice shall be an optimal suggestion where both actual traffic load, road repair, weather, sight, one-way restrictions, and the most recent traffic accidents are taken into consideration.

7.1.2. Access to the accident site

Today's plans for access to specific sites: theatres, sport grounds, factories, etc., are frequently out of date. There is a constant need for updated plans.

7.1.3. Capacity of hospitals

An information centre in one of the hospitals in Copenhagen keeps an account of actual (hour by hour) capacities for receiving patients on hospitals in the region. Such information is urgent to the emergency officers and ambulance drivers.

7.1.4. Plant descriptions

Local geography, plant functions, materials and chemicals are the typical information one gets from local people, when these are available. Some of these data should already be contained in the chief fire officer files, because they are the basis for inspection. Ignition sources, fire potential, water supply are evaluated regularly, as well as emergency exits, fire extinguishing systems, also showing that the fire service may use technical means to draw information from their own files.

7.1.5. Sewers

Water and other substances used in the fire fighting will normally end up in the sewerage in many cases. The fire commander needs information on sewer systems, if explosive or polluting substances are drained into a sewer. He may warn sewer stations on the actual line, and warning may be given to residents and people on the roads.

Such information does not belong to the fire service, but resides in another branch of the local authority.

7.2. Basic Expert Knowledge

7.2.1. Chemical expertise

Today, a very comprehensive knowledge system is made available to the fire commander, with chemical emergency cards, expert advisors, and information centres with links to foreign systems. Development trends for chemical knowledge systems should preferably aim at:

means for more expedient identification, as far as this key is a necessary first step

more selective presentation of relevant information

Fire officers often feel burdened by too much information.

7.2.2. Medical expertise

Fire personnel traditionally follows simple and mostly rather efficient rules during rescue operations, concerning priorities, transport of injured persons, and first aid principles. In disaster cases there will be doctors and nurses mobilized to work on the scene of the accident and relieve the fire commander.

The chemical emergency cards give specific first aid information for each chemical. This information is formulated specifically for fire personnel, ambulance drivers, etc., who can administer first aid in the absence of experts.

It may constitute a large step forward, if the emergency manager can one day obtain the set of first aid rules specific for the actual case, i.e. the optimal procedure, based on the information presented. Under present conditions, this information is available in fixed sets and released only when specific keys are presented.

7.2.3. Technical expertise

Case 5 above shows an example where electrical and mechanical expertise might be of great help: is it advisable under the circumstances to shut down the extraction plant, for instance by breaking the electrical power supply? And which procedure is suggested? In the actual case, an explosion happened at the moment,

where one power line was broken in order to reduce the amount of potential ignition sources inside the explosive zone.

The item was not discussed thoroughly during the interviews, but it seems obvious that a whole class of questions exist with electrical equipment, control systems, data systems, and mechanical equipment which could receive some attention, like the chemistry problem has done for years now.

7.3. Other Types of Information

7.3.1. Relevant strategies

Updated and efficient strategies applying to that particular situation in which the fire commander finds himself could be suggested.

7.3.2. Rules of the business

Simple reminders could be presented without request, at a suitable occasion depending on the actual requirements. An example: Do not leave the scene of a fire until you have inspected the place from all sides, i.e. horizontally and vertically. Also, some very useful relations for fire control can be derived from the basic formula

object + oxygen + ignition = fire.

Presented at the right moment, a rather general suggestion of this class may turn the attention of a fire officer in a more fruitful direction. However, according to the interviewed fire officers this is not the kind of help one would like to receive from an expert system.

7.3.3. Risk analysis

For tactical considerations and planning on the scene of the accident one may need some guidance for risk classification. One often has to rank risks that are connected, but have a different character making comparisons difficult, such as:

the risk of fire spread

the risk of residents' exposure to dangerous smoke

the risk of pollution/explosions.

With limited resources, the fire commander must give priority to one operation at a time.

During the interviews it was not possible to arrive at a more specific characterization of this problem, or at a way to solve it with expert systems.

Implicitly, the risk analyses are part of the scene, whenever specific emergency plans have been made for the actual object.

7.3.4. Map of resources

At present a lot of book-keeping has to be done in command centres, etc., to keep track of resource movements and distributions. On this basis one is able to inform the fire commander about expected arrival times of fire engines, ambulances, etc.

It will be possible to include actual traffic data, road restrictions, and standard times for setting up equipment after arrival at the scene of the accident, and in this way suggest, for instance, the time when the next fire engine has arrived, and a fire escape is made operational.

The improvement with respect to the present situation should be that data from road authorities and the police might be collected automatically, instead of depending on actual investigations made by the command staff when resources do not arrive as expected.

7.3.5. Command post, coordinating center

In cases when a command post or coordination centre is established, these may take over long-range planning and trouble shooting, as requested by the fire commander. They may also do the book-keeping job just mentioned.

With an organization like this, the preference of a fire commander would be an expert system giving immediate and short answers, whereas the staff at a command post or coordinating centre will be able to run dialogues with the expert system.

7.3.6. The experts of the plant

When the fire commander gets in touch with local people at the company having the accident, he will be very receptive to information and evaluations. If a local fire brigade is organized at the site, the officer on duty will most probably be used as a knowledge bank by the fire commander.

Most local experts will be better informed and much more easy to consult than general experts, because the fire commander does not have to specify the input explaining the actual situation.

7.4. Conclusion

Today's fire commander typically brings a few specific data sets with him to the scene of the accident:

a collection of chemical emergency cards

a "catalogue" with key information on selected objects of the area

an inventory with useful addresses and telephone numbers.

These data will be sufficient in very ordinary cases, but supplementary information may be needed, from public files and from

private firms and experts. An important class of data includes updated status information concerning:

people on the roads, in residences
road systems and traffic data
hospitals, doctors, first aid teams
sewers
useful data for evacuation
stocks of selected material and equipment for fast delivery: tools, food, extinguishing agents, etc.

A resuming statement from the interviews will be that a future fire commander will be able to communicate with an expert system, but he does not have the time for stepwise dialogues to direct the expert system towards the answer he needs. In other

words, the expert system shall offer him a very high degree of efficiency.

But at the moment fire commanders often have to rely on information from experts and public files, which they have to gather with big delays, and where they sometimes may do without such knowledge, because the accident takes place outside working hours.

The fire commander wants fast answers, short answers, and operational answers. He will traditionally be better motivated to communicate with the accidental event: his own observations and the fire personnels' observations draw his attention from any other data source. Therefore, expert systems may seem best suited for command posts and coordination centres.

The best advice from an expert is obtained when he has a rather specific image of the actual trouble. This places a communication load on the part of the fire commander, resulting in a high price for the information he needs.

8. STRUCTURE OF AN EMERGENCY MANAGEMENT SUPPORT SYSTEM EXEMPLIFIED BY DANISH CONDITIONS

8.1. Information Sources Available and Their Contents

The purpose of this subsection is to review important and typical information sources and their contents, relevant for emergency management support systems, and to relate them to the problem domains proposed previously. A more detailed description of the main information sources is given in section 5.

In Table 2 the more important of the available information sources are listed. Each type has been given an individual number referred to in the following discussion. In the schemes of figures 12 and 13 the

type numbers have been added in order to indicate the locations of the problem domains related to the particular information source.

TABLE 2.

Type of information	
	Information sources relevant to fire fighting
1.	Fire Law (641 29/12-1976). (Brandloven, 1976)
2.	Municipal regulations
3.	Guidelines for materials and preparedness of the fire fighting service (1977)
4.	Personnel education (336 21/7-1970)
5.	Textbooks from the national fire fighting school including "dangerous substances"
6.	Alarm procedure (23/8-1974)
7.	Water supply for fire fighting (28/7-1976)
8.	List of localities of hydrants
9.	Instruction for the fire commander (4/1-1983) (incl. his role in accidents with dangerous substances), (Instruks, 1983)
10.	Emergency plans, meeting plans, fire fighting plans, for specific industries: information on ignition sources, access to fire, dangerous substances present, pressurized vessels, fire-sectioning of buildings, fire extinguishing means available, etc.
	Capacity of specific resources:
11.	The capacity of hospitals for receiving victims
12.	Fire extinguishing means
13.	Compressed air for respiration apparatus
14.	Locality of pipelines for gas/petrol
15.	Locality of pipelines for sewerage
	Information sources related mainly to accidents involving dangerous substances:
16.	Instruction, guidelines from the administration of the Ministry of Environment (Farlige stoffer, 1974)
17.	The civil defence administration: rules for assisting services in time of peace (Bestemmelser, 1979)
18.	Handbook on "dangerous substances" (applicable to first level effort)
19.	Handbook in card-file form (applicable to second level effort)
20. $	Civil defence: chemical advisory and analytical preparedness. (Applicable to third level effort)
21.	UIS-system (Fed. Rep. of Germany, advisory support by telephone or on the scene of the accident, including lists of dangerous substances and of chemical industry experts, accessible through the Danish civil defence chemical advisors)
22.	Rules for classification and marking of dangerous substances (the ADR convention)

23.	Rules for road transportation of dangerous goods (94 5/3-1974)
	Other information sources:
24.	Industrial risk analyses
25.	Analyses of previous accidents

Table 2 reflects the following: From ancient times, the community has developed an accepted balancing between the specific risk of fire and the resources found necessary to counteract the risk: The Fire Services Act (1) and derived regulations (1-9) are elaborated in detail for personnel, materials, and preventive precautions, in the Fire Services Act (1) even the role of the anonymous citizen present at the scene of fire is specified by requiring him to place himself under the command of the chief fire officer.

It is relevant to mention an important aspect of the Danish philosophy of fighting accidents: the emphasis given to personnel education (4, 5) and knowledge. Much information is expected to be learned by the personnel, enabling them to cope with unexpected, non-standard situations (Sonnich Thomsen, 1984a).

New chemical substances may lead to new risks of great variety, and coping with them are the duties (9) of the fire commander supported by resources already in existence (16, 17). The variety of risk is considered by a clear-cut three-stage procedure for search of information: 1) listed information (18, 19) applicable at the scene of the accident, 2) information supplied by advisors (20, 21) and 3) data to be consulted if necessary.

For general availability of resources, the cooperation between, and the assistance provided by, different services are specified by regulations (16, 17): Municipal fire fighting services, rescue companies, civil defense and police.

Also for preparedness of a more specific kind, a trend can be observed: requiring some kind of specific emergency plans (10) for large enterprises such as oil refineries and chemical process plants.

Further preparedness could aim at the counteraction of a specific accident situation in a particular industrial plant for which a risk analysis (RA) has been performed: an obvious suggestion would be that information (24) provided by the RA should be somehow utilized for prioritizing the emergency preparedness or, in an actual accident, for identification of the actual situation and for prediction of courses of events. It should be remembered, however, that a precondition for this is that the assumptions made and the models applied in the RA are still valid in the actual situation. A similar validity problem exists

if utilizing information (25) from previous accidents for identifying an actual accidental situation.

The study of the accident cases indicated that for these cases the following types of information were or could be important:

Table 3

Type of information	Case No.	
10	1	Fire properties of buildings and structures
10	1,2,4	Overview of storage tanks needing cooling or screening from fire
10,12	1,4	Possibilities of supplementary water supply
	3,6,9	Support for judging the extension of explosive gas or petrol vapour clouds
14	6	Plans/maps showing locality of gas/petrol pipelines
18,19	8	Identification of dangerous substances
10,18-21	1,5,7	Fire and toxic properties of manufactured products under storage and under production
15	1,10	Plans/maps showing locality of sewerage pipelines

8.2. Users of Information

In this subsection the more important roles in Danish emergency management are identified and discussed. The discussion is based on the Danish accident cases and interviews with professionals as described in section 6 and 7, respectively.

The key roles in emergency management identified by the Danish sources are: the fire commander who fights the accident on-site together with his firemen. In large accidents a command post may be established close to the scene of the accident and provided with staff and equipment for the support of communication. This was done in two of the cases analyzed (Nos. 4 and 5). In very large accidents, a coordination center may be established at a predetermined location, perhaps distant from the scene of the accident, manned with a chief coordinator and his team.

The distribution of specific functions on the fire commander and the chief coordinator is described in section 5 and shown in Fig. 11.

The fire commander's tasks are (Haurum, 1983),

- to evaluate the situation on his arrival at the scene of the accident

- to decide the first attack to be carried out
- to give orders to the group leader of the firemen
- to evaluate whether the number of firemen commanded will be sufficient
- to report the situation to his station
- to make a more thorough reconnaissance at the scene of the accident
- to plan and give the order for the subsequent attack
- to monitor the effort and evaluate the results.

It is the fire commander's responsibility

- that the effort is carried through as efficiently as possible paying regard to the safety of the firemen
- that the forces brought into action are sufficient for performing the task without binding unnecessary forces on the scene of the accident.

For the planning and resource allocation tasks, it should perhaps be remembered that a dynamic matching of a changing situation with resources to be required for assistance, considering their delays, etc., will probably involve a great deal of "book-keeping".

Furthermore, it should be mentioned that in case of accidents of "normal size", functions such as closing of streets, traffic regulation, and evacuation is performed by the police in direct contact with the fire commander at the scene of the accident.

Scrutinizing this concise description of the fire commander's role on the background of the Danish accident cases, leaves the following impression:

> The fire commander will often be forced to make quick decisions based on incomplete information about the actual situation. His direct interaction with the accident is likely to be considered more important than his communication with any artificial information system. Any kind of communication between the fire commander and an information system should therefore be evaluated for a balancing of benefit versus negative effects, which are perhaps difficult to define as they are likely to be very situation dependent.

From the task description above it is also seen that the fire commander is the (sole) information link between the actual situation and the hinterland. The importance of this role is demonstrated by the Danish case No. 5. Further, it should be noted that the information on the actual situation is a type of information not covered by the previous information domains. However, it is crucial for the emergency management and for its possible utilization of expert systems.

A coordinating center will be established in very large accidents. The meaning of "large" will often be applied to the geographical extent of the accident leading to large forces in action.

An important general characteristic is that the coordinating tasks are not to be performed under the same degree of persistent time stress as the tasks on the scene of the accident.

In addition to the functions already mentioned for "normal size" accidents, the following can be listed:

informing relatives, the press, etc.
coordinating ambulance service, evacuation
providing medical assistance teams
arranging special assistance for the fire commander

A profound analysis of the coordinating task has not been made. However, it is found that, on the Danish scene, the coverage of "emergency management" is the totality of functions under the chief coordinator and the fire commander. In the Danish material the following can be observed:

One coordination center task is of importance for the present study: the arranging of special assistance for the fire commander.

The coordination center serves as a communication link for the fire commander (except for his communication with assisting forces).

Consequently, for the Danish design of the cooperation between a fire commander and a chief coordinator, the scheme of Fig. 14 can be applied, using more general terms and also demonstrating connections with the three information domains identified.

8.3. Information Form and Retrieval

For front-line personnel functions performed, such as fighting fire, rescuing humans, etc., the immediate threats involved make it necessary for them to have training and knowledge enabling them to operate with a high degree of autonomy. This background information (including for instance priority rules for the rescue of persons being under different degrees of threat) is important to have in mind when discussing means of supporting the front-line functions.

Furthermore, for such functions it seems fair to conclude that verbal communication, directly or by radio, is the only possible way. This conclusion, together with one key role of the fire commander, i.e., to provide emergency management with state information from the scene of the accident site, lead to the following proposal: In order to secure efficient and unambigious verbal communication between the expert at the front line and the emergency management center, a communication intermediary at the emergency center should serve as a professional front line-oriented intermediary in both directions of communication. This is shown in the lower part of Fig. 14.

In the following a few typical information forms are discussed.

8.3.1. Alpha-numeric text, codes

In Sonnich Thomsen (1984a) the following was found of interest:

When code-marking containers with dangerous substances, the translation of codes into verbal statements cannot be made quickly and may introduce errors in stressed situations. Verbal text is therefore recommended.

If an "action" code is prescribing what to do in case of an accident, such standard actions might be improper in non-standard situations. For the Danish card-file system for dangerous substances, it is estimated that recording about 400 substances would yield a sufficient degree of preparedness. A higher number would result in an impractical system.

The interviews of fire officers indicated wishes of more expedient identification of substances and more selective presentation of relevant information. The officers often felt burdened by too much information.

8.3.2. Maps, drawings

It could be suggested to transform some types of information stored in maps into procedures directly applicable to the acute situation and thus relieving front-line personnel from this transformation. For instance, an operator of a computerized city traffic control center could by radio-link pilot emergency vehicles through city traffic in an optimal way.

8.3.3. Human expertise

As mentioned in Sonnich Thomsen (1984a) chemical experts should be specialized in "accident chemistry", and be familiar with the circumstances of fighting accidents. Preferably, they should be involved already in the emergency planning phases.

This indicates perhaps that advice from experts needs an intermediary function: translating the questions into the language of the expert, providing supplementary information from the questioner, interpreting the advice to the questioner, and in this way making the advice operable for immediate application in the field. If the fire commander is seeking advice, an important intermediary function would be, in a two-way communication, to verify whether the actual situation fits to the assumptions and models which are valid in the expert's information domain.

Intermediary functions are indicated in Fig. 14.

Also Sonnich Thomsen (1984a) recommends, based on experience, an immediate call to the chemical accident expert, even a very short call, in order to prevent unexpected effects of a dangerous substance.

The interviews indicated wishes of more specific, and hence more optimal first aid procedures for the actual case, than the present standard first aid procedures.

Also the interviews left the impression that information verbally provided on site by people from the plant hit by the accident was considered very useful.

The reason for this might be the very efficient face-to-face communication, controlled by the front-line personnel, enabling them to extract the information they need in spite of the plant personnel's knowledge being mostly about the normal plant state and the plant personnel not unconditionally wishing to display weaknesses of their plant.

8.3.4. Data bases

Sonnich Thomsen (1984a) discusses data bases for dangerous substances and concludes as follows: Presently (1984) there is no obvious advantage by using data bases for the support of Danish fire commanders in fighting chemical accidents. Among the arguments for this conclusion are:

the number of substances is in practice not very high, information at the scene of the accident on about 400 items would be sufficient.

There are still unsolved problems in cross-searching through the information stored.

The fire officers interviewed reported Swedish experiences with advisor systems connected to foreign data bases. These connections had, however, been cancelled due to disproportion between utilization and cost.

9. CONCLUSIONS AND RECOMMENDATIONS

The conclusion of the present feasibility study will be that the recent development of advanced information technology, together with the trend towards more cognitively oriented approaches to studies of decision making, offer promising lines of development of improved tools for emergency management. Such improvements will be necessary in order to cope with the increasing potential for unacceptable consequences of accidents which is the result of industrial centralization together with the widespread use of hazardous substances. In addition, a reconsideration of the information basis of emergency management will be relevant now because much information of great importance for emergency management will be generated or collected from activities such as systematic risk analysis, safety inspections, quality assurance

programs, etc. Such activities are, to an rapidly increasing degree, introduced in response to requirements of safety authorities. This information will not be accessible for emergency management without special precautions, except in the form of "experts on call". In the following section, the conclusions from the above discussions will be summarized.

• The conceptual framework emerging from the cognitive approach to the design of decision support systems appears to be useful and adequate at present for introduction of support of emergency management. For integrated management information systems and, in particular, for decision support in the rather well structured task of supervisory process control, modern information technology is now being introduced for information storage and retrieval and as tools for the information processes involved in situation analysis and planning. For the less structured and stressed situations involved in emergency management, support of the decision processes appears less feasible but the potential for supporting the decision processes indirectly by improved and more coordinated data bases. The information in such data bases will include technical information about potential risk sources, empirical data from previous cases, and information on available resources for emergency control. A systematic analysis of the problem domain in terms of the part-whole and means-end framework can be an effective tool for organizing the data base, formulating the need of the decision makers, and specifying the formats to be used by the data sources. The literature reviews and personal contacts have revealed no model of real life distributed decision making, which will be adequate for the design of support of the decision process. This is clearly a topic of research.

• Information retrieval by emergency managers should be studied carefully for different constellations of decision makers and advisors considering different role allocations and organizations. Extensive data bases including,for instance, information on toxic substances are in existence, but appear to be of limited use because information retrieval is ineffective. Retrieval terms are ambiguous, it requires expertise to make information operational, preplanned procedural information is typically too general, etc. Therefore, field studies should be undertaken of the information needs of emergency managers, the form and content of information from different sources, and the transformations necessary to generate operational, procedural information. This study is necessary in order to evaluate the benefit to be gained from improved and more integrated data base design, from the addition of expert system features, and from improved communication with expert advisors. A cognitive task analysis will be

a useful tool for this study, judged from the progress now obtained in retrieval systems for library use, based on studies of user needs.

- Review of several different existing data bases which are important for emergency management, covering information such as road construction work, topography of sewerage systems (for potential propagation of explosive release), technical information from risk analysis and inspections, etc. This kind of information is typically collected and organized by various technical services for their own use. Evaluation of the organization and administration of such data bases to judge the possibility of adaptation to the requirements of emergency management in terms of data formats, retrieval attributes, and rapid updating, will be necessary.
- The requirements should be formulated to content and format of risk analysis, incident reports and inspection logs from potentially risky industrial installations in order to extract and store information for easy and effective retrieval during emergency management. As a consequence of the major industrial accidents at Flixborough, Seveso, etc., legal requirements are now established for systematic risk analysis and preparation of emergency plans for a large number of industrial installations. Such activities will as intermediate results generate a large amount of data of potential benefit for emergency management. It will, however, be necessary to specify the content and format of reports carefully, to make the data available in an acessible form.
- Tools for design of data bases for distributed decision making are now becoming available from the artificial intelligence research. System architechtures such as, for instance, the black-board concept in HEARSAY should be considered for organization of the distributed data bases and the coordinated information retrieval necessary for effective emergency management.

10. PLAN FOR FUTURE ACTIVITY

Further work on the topic will require a specific project plan including several coordinated studies. To be of significant impact, it will have to include studies in different European countries. The basic approach would be to accept the present emergency management services with their established task force organizations and equipment. The executive decision structure and information systems should, however, be reconsidered and redesigned from the point of view of the integrated systems approach suggested by Sutherland (1983) and Rasmussen (1985). This implies that the system should support strategies for situation analysis and planning which match the needs

of the actual task, but also that decision makers will have to adapt to more efficient strategies, given the change in information basis. This prototypical design will only be possible, if several lines of research are followed in an integrated way:

•Detailed studies of selected accident scenarios will be necessary as a basis for the modelling of distributed decision making and the possible decision strategies depending on the constellation of decision makers and advisers.

•A study of the data base structure and the communication system relating experts with access to data bases containing basic technical information, "hands-on" emergency controllers with information on the actual state, but needing procedural information, and different human and/or computer based intermediaries serving for transformation of state and technical information into procedural form. This study will involve theoretical as well as experimental studies of distributed decision making and of user formulation of their information requirements in "real life" situations. Techniques for user studies are now becoming available. Such a study in EEC framework could be coordinated with a similar joint Nordic study in a nuclear context, sponsored by the Board of Nordic Ministers.

Finally, a study of suitable computer system architectures, communication systems, and user interface formats will be a necessary part of the prototypical systems design. Modern AI tools are available for design of "intelligent" decision support, and such tools should be carefully evaluated as a part of the experimental study (this is also considered in the Nordic project). A program for development of advanced data bases, based on intensive user studies appears to be compatible with the present JRC program for development of intelligent data bases (Bastin et al., 1985).

To be able to reach conclusive results, such a theoretical and experimental peogram will have to be a substantial effort, in an interdisciplinary program. (Minimum size is loosely estimated to be in the range of 5 to 10 professional people over at least five years).

11. ACKNOWLEDGEMENT

Inspiring discussions on modelling of distributed decision making with Berndt Brehmer, Upsala, in the context of the Nordic project are gratefully acknowledged.

12. REFERENCES

Bastin, F., Capobianchi, S., Carlesso, S., and Mancini, G. (1985): An Intelligent Interface for Accessing a Technical Data Base. Proceedings of the 2nd IFAC Conference on the Analysis, Design, and Evaluation of Man-Machine Systems. Varesa, Italy, Sept. 1985. To be published.

Brandværn (Danish periodical on fire defense, also contributing accident case stories).

The cases dealt with in this report were described in the following issues:

Case 1: Brandværn 8/78 pp. 16-19
Case 2: " 11/78 pp. 4-6
Case 3: " 5/80 pp. 10-11
Case 4: " 10/80 pp. 18-20
Case 5: " 8/80 pp. 16-17
and " 2/81 pp. 18-23
Case 6: " 11/82 pp. 8-11
Case 7: " 4/83 pp. 30-31
Case 10: " 4/84 pp. 2-4

Case 8 was reported in the daily newspapers Politiken and Aktuelt of November 10, 1983, and

Case 9 was reported in Aktuelt of September 11, 1983.

Brehmer, B. (1985a): Systems Design and the Psychology of Complex Systems. Invited Paper, Third Symposium on the Empirical Foundation of Information and Software Science, Risø, October, 1985.

Brehmer, B. (1985b): Notes on Hierarchical Systems. Personal Communication, Unpublished Note.

Buchanan, B. G. (1982): New Research on Expert Systems. In: J. E. Hayes, D. Michie, and Y. H. Pao, (Eds.): Machine Intelligence, Vol. 10. Edinburgh: Edinburgh Univ. Press, pp 269-299.

Erman, L. F., Hayes-Roth, V., Lesser, V. and Reddy, D. (1980): The Hearsay-II Speech Understanding System: Integrating Knowledge to Reduce Uncertainty. Computing Surveys. June 1980, pp. 213-252.

Fedra, K. et al. (1985): Advanced Decision-Oriented Software for the Management of Hazardous Substances: Structure and Design. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Hayes-Roth, F., Waterman, D., and Lenat, D. (1983): Building Expert Systems. Reading, MA: Addison-Wesley.

Lesser, V. and Erman, (1980): Distributed Interpretation: A Model and Experiment. IEEE. Trans. on Comp. Vol. C-29, No. 12, pp. 1144-1162.

Haurum, G. (1983): Indsatsledelse. København: Statens Brandskole. (In Danish; a textbook on fire fighting).

Haurum, G. (1985): Information om Farlige Stoffer. Civilforsvaret. No. 6, 1985, p. 10 (In Danish; paper on the identification of Hazarduos substances.)

Lehner, P.E., Probus, M. A., and Donnell, M. E. (1985): Building Expert Systems: Exploiting the Synergy Between Decision Analysis and Artificial Intelligence. IEEE Transactions on Systems, Man, and Cybernetics. Vol. SMC-15, No. 4, pp 469-475.

Pejtersen, A. M. (1979): Investigation of Search Strategies Based on an Analysis of 134 User-Librarian Conversations. Third International Research Forum in Information Science. T. Henriksen, (Ed.), Oslo.

Pejtersen, A. M. (1980): Design of a Classification Scheme for Fiction Based on an Analysis of Actual User-Librarian Communications; and Use of the Scheme for Control of Librarians' Search Strategies. In: Theory and Application of Information Research, O. Harboe and L. Kajberg (Eds.). London: Mansell, pp. 146-159.

Rasmussen, J. (1984). Strategies for state identification and diagnosis, in Advances in Man-Machine Systems Research. W. B. Rouse, ed., Greenwich, CT: J.A.I. Press.

Rasmussen, J. (1985): The Role of Hierarchical Knowledge Representation in Decision Making and Systems Management. IEEE Transaction on Systems, Man, and Cybernetics, Vol. SMC-15, No. 2 pp. 234-243.

Rasmussen, J. (1985): A Framework for Cognitive Task Analysis. Risø-M-2519. Also in: Hollnagel, E., Mancini, G. and Woods, D. (Eds.): Intelligent Decision Support Systems in Process Environment. Berlin: Springer Verlag. In Press.

Rasmussen, J., and A. Jensen. (1974). Mental procedures in real life tasks: A case study of electronic trouble shooting. Ergonomics. 17, (3), 293-307.

Rasmussen, J. and Pedersen O. M. (1984): Human Factors in Probabilistic Risk Analysis and in Risk Management. In: Operational Safety of Nuclear Power Plants, Vol. 1, I.A.E.A., Vienna.

Rasmussen, J., O. M. Pedersen, A. Mancini, A. Carnino, M. Griffon, and P. Gagnolet. (1981). Classification System for Reporting Events Involving Human Malfunction. Roskilde, Denmark: Risø National Laboratory, Report No. M-2240.

Sage, A. P. (1981): Behavioral and Organizational Considerations in the Design of Information Systems and Processes for Planning and Decision Support. IEEE Trans. Syst. Man. Cybern. Vol. SMC-11, No.9 640-678.

Sonnich Thomsen, E. (1984a): Private communication.

Sonnich Thomsen, E. (1984b): A Protocol for Coping with Ecoaccidents. In: Cairns, J. (Ed.): Eco accidents. New York: Plenum Press. In Press.

Stebb, R., Cammarata, S., Hayes-Roth, F. A., Thorndyke P.W. and Wesson R. B. (1981): Distributed Intelligence for Air Fleet Control. R-2728-ARPA Rand, Santa Monica.

Sutherland, J. W. (1983): Normative Predicates of Next Generation Management Support Systems. IEEE Trans. Syst. Man. Cybern. Vol. SMC-13, No.3, 279-297.

Thorndyke, P. W. (1982): A Rule-Based Approach to Cognitive Modelling of Real-Time Decision Making. ORNL/TM-8614.

13. DANISH LAWS AND REGULATIONS

Brandloven. Lovbekendtgørelse nr. 641 af 29 december 1976. (The Danish main law on fire fighting, fire prevention, etc.).

Instruks for Brand Inspektører i Kommuner med Brand- eller Beredskabskommission. 4 januar 1983. (Instruction for chief fire officer, fire commander).

Farlige Stoffer. Instruks om Beredskab, etc. Miljøstyrelsens Vejledning nr. 8/74. (A three level general preparedness instruction for accidents involving dangerous substances).

Bestemmelser for CF-korpsets fredsmæssige assistanceydelser, 1979. (Rules for the civil defense services in time of peace).