1 Introduction

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We are pleased to offer the reader a volume consisting of contributions of the Third George Kovacs Colloquium held in UNESCO, Paris from September 19 to 21, 1996. It is a continuation of a series of biannual international scientific meetings organized jointly under the auspices of the International Hydrological Programme (IHP) of UNESCO and the International Association of Hydrological Sciences (IAHS) in the challenging fields of water resources research. These meetings commemorate the late Professor George Kovacs, established authority in hydrology, who paid valuable service to both organizations convening this Colloquium. Professor Kovacs was Chairman of the Intergovernmental Council of the IHP of UNESCO and President of the IAHS.

The theme of the Colloquium, "Risk, Reliability, Uncertainty, and Robustness of Water Resources Systems," denotes an essential recent growth area of research into water resources, with challenges and difficulties galore. The two-and-a-half-day Colloquium included twenty-four oral presentations covering a broad range of scientific issues. It dealt with different facets of uncertainty in hydrology and water resources and with several aspects of risk, reliability, and robustness.

The contributions to the Colloquium concentrated on the state-of-the-art approaches to the inherent problems. They also outline the possible future, identify challenging prospects for further research and applications. Presentations included both theoretical and applied studies, while several papers dealt with regional problems. Methodological contributions focused on underlying concepts and theories.

The presentations at the Colloquium, based on invitation, were delivered in three categories: keynote lectures, invited lectures, and young scientists' communications. Contributions belonging to all three categories are included in this volume.

Uncertainty means absence or scarcity of information on prior probabilities, that is, a situation when very little is known for sure. The term "risk" is usually used in a situation when it is possible to evaluate the probability of outcomes. Uncertainty in water resources may have different sources. It may result from the natural complexity and variability of hydrological systems and processes and from our inability to understand them. On the other hand, human behavior itself has a strong uncertainty component. Priorities, preferences, and judgment of consequences of future societies are largely uncertain: unexpected shifts and unpredictable changes cannot be ruled out.

Among the plethora of uncertainties in hydrology and water resources research, one thing is certain: water-related problems have grown and will continue to grow in a world of high population growth, with consequences such as increased need for food and justified aspirations of nations and individuals of better living conditions. The present convenors feel that, in most cases, contributions to the Kovacs Colloquium presented research that was problem-driven rather than method-driven.

The problems tackled at the Colloquium vary considerably as to the degree of complexity, from high degrees of sophistication to down-to-earth approaches. These latter call for explanatory data analysis in the sense of meticulous work: trying to unveil patterns existing in raw data and decipher the message that the raw data may carry. While studying uncertainty, one often starts from the most essential points and disregards the rest. In order to build up a more general, rough image, it is necessary to forget things of lesser importance, to neglect small impacts. Further, it is prerequisite to identify the bottleneck, that is, the weakest link in the system. Improvements of better parts may not help much if the weakest link in the chain still exists.

Von Neumann once said that the incremental value of information is highest if the existing information is at its lowest level. The real problems encountered are so complex and burning at the same time that a rough, approximate solution is very welcome. The time for refining detail may follow.

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In a number of contributions to the Colloquium, common sense rules were reiterated. Even if calls to be careful with extrapolations, to avoid abusing methods beyond their legitimate applicability, to check whether the simplified assumptions hold, may seem trivial, experience shows that many offenses against these rules still do occur.

The idea of re-initialization was considered by the convenors several times during this Colloquium. This is a notion from the realm of automatic optimization, where a minimum (or maximum) of a complicated, multidimensional functional is being sought. Taking a gradient as the direction of search is fine, but there may exist better directions auguring a faster convergence. Such directions determined by possibly sophisticated algorithms work well at the beginning but may gradually degenerate and deteriorate their performance. The notion of re-initialization means that after some number of iterations, one should go back to common sense, back to basics. Abandoning a complicated way of determining direction of search, one goes back to the good (even if not the best) and safe gradient direction.

There is a strong need for a holistic, cradle-to-grave, perspective and an interdisciplinary approach to solve complex problems. Participants of the Colloquium reached far beyond classical hydrology and water resources research. They considered pre- and posthydrological components in the interdisciplinary chain. Examples of prehydrological components include meteorology and climatology, while the posthydrological ones are social, psychological, institutional implications.

A statement has been issued that availability of a perfect long-term drought forecast in several areas would not solve all the problems since many countries or regions are not ready to use the information and to prepare effectively for a drought. The infrastructure and institutions are inadequate, and widespread illiteracy is a significant barrier.

This book is organized around seven thematic clusters. Following this introduction are two contributions devoted to underlying concepts and notions. Gheorghe's integrated regional risk assessment and safety management refer to a much broader, environmental perspective than water context alone. In his philosophical contribution, Klemes warns mathematical modelers that sometimes their attempts may be described as "the unbearable cleverness of bluffing."

The largest theme, comprising five contributions, is related to floods and droughts. Many facets of risk are inherent in floods. There is a social risk: How to build the flood defense system? How to place the compromise between the will of providing adequate protection and limited resources? To what flood frequencies should the defenses be sufficient? There is also a personal risk: How to behave in case of floods? How to react to forecasts?

Moore presents aspects of the existing flood protection system in the United Kingdom that relate to the theme of the Colloquium. Krzysztofowicz advocates the advantages of probabilistic hydrometeorological forecasting giving the clients significantly more information than lumped yet unreliable figures. Gillard presents a French concept of flood risk management being a combination of two elements for every place of concern: one related to land use and the other related to flood frequency. Thomas and Bates review policy responses to increasing climate variability in Australia, with particular reference to droughts. Okada's chapter on a community's disaster risk awareness raised considerable discussion at the Colloquium. One of the discussers expressed the opinion that the water profession should encourage journalists to write and publish articles rather than to build new reservoirs. This statement illustrates the power of the media and the potential of demand management as a possible activity on the demand, rather than the traditional supply-side approach (planning new reservoirs to meet every foreseen supply). However, it is not unlikely that drought forecasts and vast media coverage may also cause a natural human reaction that will not lead to water savings: to catch as much water as possible, to fill all available storages, bath tubs and buckets, to water gardens and lawns, to intensify washing.

Three papers were presented on quantity and quality aspects of hydrological sciences. The chapter by Kinzelbach, Vassolo, and Li deals with groundwater systems, studying capture zones of wells; Fahmy, Parent, and Gatel present the results of studies of uncertainty in modeling quality of drinking water, using the Bayesian approach. Tecle and Rupp report on stochastic rainfall-runoff modeling for a semi-arid forested environment.

Another area of water resources research with a very high uncertainty component is that of climate change impacts on water resources. Within this theme, two contributions were presented at the Colloquium and reproduced here. Vogel and coauthors consider the issue of reliability, resilience, and vulnerability of water supply systems, while Bárdossy and Duckstein report on their work on hydrological risk under nonstationary conditions. In this latter work, the perspective embraces both prehydrological systems (circulation of the atmosphere) and the posthydrological ones (ecology and health).

The general area of water resources systems is represented in five chapters, demonstrating methodology and case studies. Two contributions present methodology and application of fuzzy compromise programming to water resources systems planning (Bender), and a new variant of stochastic branch-and-bound method for water quality management (Lence and Ruszczyński).

Yen's chapter presents methodology of analysis of system and component uncertainties, while Shrestha studies uncertainty and risk of water resources system in changing climates. Shamir offers an overview of problems in theory and practice.

Two contributions (Loucks and Nachtnebel) undertake a very ambitious aim to measure sustainability. These methodological works do not end up with real-world applications, yet are of much interest and possibly set the stage for further attempts.

Finally, among the three contributions on reservoirs and hydrological structures, Takeuchi presents his opinion on the future of reservoirs and criteria of their development and management. Milutin and Bogardi report on the use of performance criteria for multi-unit reservoir operation and water allocation problems. Plate's chapter discusses risk management for hydraulic structures.

A range of interpretation of risk, reliability, vulnerability, and robustness has been noted in the present proceedings volume. The verbal and mathematical terminologies clash, as we still explore the sociopsychological implications of risk and related terms (concepts) while the quest of a natural scientist and engineer is clearly targeting the mathematical definitions and quantification of these performance indices.

The debate is left open. The reader will be confronted with the multiple uses of these terminologies. Is it a failure of the editors not to provide consistency? We claim that it is not. A scientific area as volatile as risk, reliability, uncertainty, and robustness considerations in water resources management cannot and should not be regulated during this phase of rapid development. The fascinating fact of new development implies the lack of a "guided tour," but it also implies a chance for discoveries. Readers may find their own definitions on the nucleus of the idea to be developed further.

Therefore, we are proud to be associated with this endeavor as convenors of the Colloquium and as editors. We take responsibility for shortcomings of the book and calculated risks, while giving credit to the authors, whose enthusiastic participation in the Third George Kovacs Colloquium laid the solid foundation for this book. It was also source of inspiration for us and a very rewarding experience of scientific cooperation.

The word "kovacs" in Hungarian (similarly, kowal, kovar in Slavic languages) means blacksmith, and this name is appropriate to the situation. Kovacs Colloquium indeed helps in forging progress in hydrological sciences.

We are confident that the readers will agree that the Colloquium was an excellent tribute to the late Professor George Kovacs, to his scientific, managerial, and human virtues, and to his broad smile that many of us remember so well.

Janos J. Bogardi and Zbigniew W. Kundzewicz
Convenors and Editors
Paris – Poznań, February 1998

2 Integrated regional risk assessment and safety management: Challenge from Agenda 21

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Motto: Sustainable is what people agree is sustainable.

ABSTRACT
This chapter introduces the field of integrated regional risk assessment and safety management for energy and other complex industrial systems. The international initiative includes compilation of methods and guidelines, and development of various models and decision support systems to assist implementation of various tasks of risk assessment at the regional level. The merit of GIS methodology is highlighted.

2.1 INTRODUCTION

Almost ten years after the UNCED (United Nations Conference on Environment and Development), Rio de Janeiro, Brazil, 1992, some progress has been achieved in relation to the protection of the environment, development policies, and strategical future topics. A number of issues were addressed by UNCED – Agenda 21 that were connected with the topic of this chapter.

Issue 1. Achieving sustainable development, environmental protection shall constitute an integral part of the development process.
Issue 2. Environmental issues are best handled with the participation of all concerned citizens.
Issue 3. National authorities should endeavor to promote the internalization of environmental costs.
Issue 4. Information for decision making would involve:
- bridging the data gap;
- improving availability of information.

Issue 5. Emergency planning and preparedness are integral parts of a coherent sustainable development.

Regional risk assessment and safety planning is a coordinated strategy for risk reduction and safety management in a spatially defined region, across a broad range of hazard sources. It deals equally with normal operation of plants as well as with accidental situations, including synergetic effects.

Regional safety planning requires:

- a framework approach, including a consistent and state-of-the-art methodology;
- legal conditions;
- political will.

Integrated Regional Risk Assessment and Safety Management (IRRASM) has as an overall goal to design, analyze, and conduct practical risk assessment and safety management activities at the regional level for minimizing risks to people and the environment.

Methods and models to be used for IRRASM studies must be specific to the level of details and application as presented in Figure 2.1. In the integration process, a number of models for each individual level, such as engineering, management, politics are available for use and therefore their application is tailored to the area of interest in IRRASM.

Risk, in the content of IRRASM, indicates "the possibility, with a certain degree of probability, of damage to health, environment and goods, in combination with the nature and magnitude of the damage."

A number of indicators are designated to highlight a measure of risk, namely:

- annual fatality rates;
- mean fatalities per year;
- individual and societal risk criteria;
- F–N curves, etc.

Targets at risk, when developing scenarios for risk analysis at the regional level, are:

- people;
- ecological systems;
- water systems;

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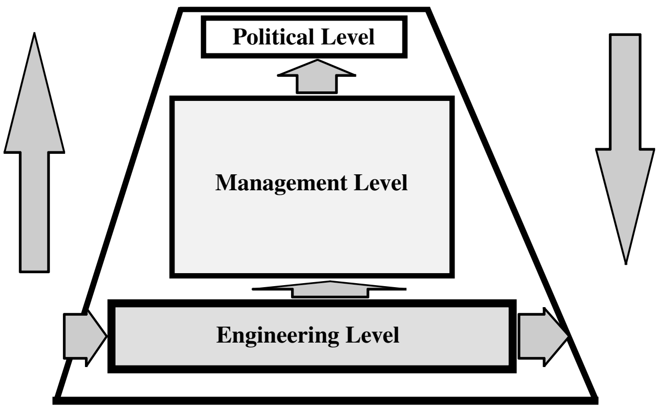

Figure 2.1. A hierarchical approach to problem-solving issues for IRRASM.

- economic resources and other associated infrastructures, etc.

A methodological framework for dealing with the complex tasks of regional safety planning includes:

- development of guidelines;
- adoption of validated models for calculating either probabilities or various types of consequences;
- databases which must include information on a variety of data related to the use of models (e.g., reliability data, emission factors, severe accidents information, etc.);
- knowledge bases that should incorporate expert judgment and non-quantitative information on various aspects related to the regional safety planning;
- adequate tools (e.g., Decision Support Systems – DSS) to assist calculation and representation of various risks which might (co)-exist at the regional level. Specialized DSSs should be addressed to emergency planning and preparedness in relation to safety management;
- GIS (Geographical Information Systems) would be part of the tools available for representing and managing risks at the regional level;
- training and adequate case studies would be a necessary activity within IRRASM.

2.2 REGIONAL SAFETY PLANNING

Definition 2.1

IRRASM is a multidisciplinary process: engineers, computer scientists, and model builders play a central role in the risk assessment stage. Social scientists can contribute with practical advice to the embedding process concerning hazard sources and help communal organizations to deal with such problems, taking into account local economic conditions and political reality. IRRASM involves a complex set of actions for risk reduction and safety management in a defined region across a large number of hazard sources (during normal operation and accidental situations) that includes synergetic effects.

In the process of analyzing risk at the regional level, specific models are available. Integration of risk is achieved in the decision-making process and for this, access to various models, databases, other modern representation environments, e.g., GIS (Geographic-Information Systems), is necessary. In Figure 2.2 a representation of the access of specific models to various levels of use is given. The process of achieving this is rather complex, and involves knowledge of operation research techniques, decision analysis and engineering-economic systems, physical models for pollutant dispersion, etc., databases and knowledge bases.

In Figure 2.2, a detailed representation is achieved in order to portray the hierarchical arrangements in problem solving of risk assessment and safety management when dealing with a large variety of hazardous sources, activities, and decision makers.

At Level I, specific use is made of multicriteria decision models, analytical hierarchical techniques, and instruments to deal with the risk sensitivity phenomenon or the trade-off analysis. At Level II, models and instruments of work have to be adequately tailored to decisions regarding management, and in this case cost benefit analysis, risk estimation and representation, and safety management models are appropriate and instrumental in solving practical problems of risk management. Level III type models involve engineering-economic and simulation models as well as consequence assessment models and tools. Approaches close to the concept of LCA (Life Cycle Analysis) are significant when dealing with various types of impacts and risks that could come within the regional risk assessment.

When working for IRRASM, it is also of relevant importance and use to have access to specialized databases and knowledge retrieval systems. The integration of results from applying these tools and techniques is necessary at all levels of the decision-making process.

2.2.1 Defining a region

The appropriate basis for area selection depends on particular circumstances of each case. Suggested factors when defining a region are:

- The area should be selected for its physical, industrial, and economic characteristics and not necessarily on administrative boundaries.

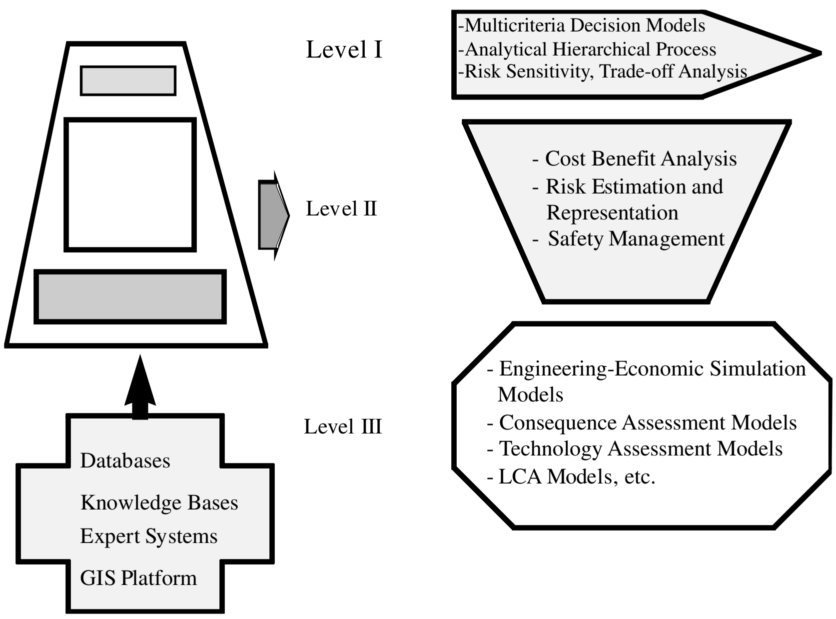

Figure 2.2. Models and knowledge infrastructures and their integration for IRRASM.

- It should be defined on the basis of the facilities and systems of concern and the potential areas that can be directly affected.
- Hard boundaries should not be drawn before an initial hazard analysis and prioritization.
- It is important that as many as possible of the authorities with risk management roles or relevant information become involved.
- Some risk sources will have potential for effects well beyond the immediate area.

2.2.2 Objectives and scope for an IRRASM study

One or more of the following major *objectives* could be considered:

- prioritize hazards in a region;
- evaluate and verify individual/societal risk criteria;
- identify sources of continuous emissions and estimate risks to various targets in the region;
- perform accident and consequence assessment;
- integrate various types of risk in the region;
- design emergency response plans.

The *scope* of these studies includes:

- sources of continuous emissions and accidental releases;
- scenario for accidental states;
- risk assessment for environment and public;
- safety management actions;
- risk management actions.

2.2.3 Hazard identification

A first step in the methodology of regional safety planning is that of hazard identification. The specific aspects within the hazard identification phase are:

- potential hazard sources estimation;
- continuous emissions and their risk to health and environment;
- major accidents from fixed installations and storage;
- transportation of dangerous goods;
- wastes and their associated technology.

2.2.4 A need for prioritization of risks at the regional level

Large and complex industrial areas include various risk sources and activities (e.g., operating process plants, storage terminals, transport activities). The process also goes to the level of an individual plant. A cumulative assessment of such risks should include a detailed hazard analysis and quantified risk assessment for all industrial facilities and associated activities.

Van den Brand methodology

There are a number of methods dedicated to risk prioritization. The van den Brand methodology is based on a step-by-step approach.

Step 1. The user must decide if there are any relevant industrial activities.

Step 2. By using basic information on a given kind of activity and of substances handled, one can determine the kind of average effect that can occur in the case of an accident.

Step 3. By comparing the possible affected area with actual or planned populations living in that area, it is possible to estimate the likely consequences.

Step 4. Assess the probability of such an event. This can be calculated by using probability numbers for different kinds of industrial activity and "correcting" these numbers by using correction factors based on the specific circumstances.

Step 5. Both consequences and probability numbers are visualized as a level of risk in a graphic form (risk matrix).

It is possible to agree on risk criteria for decision making. One limitation of using such a risk graph is that it evaluates fatalities as the only indicator for consequences.

Fuzzy sets approach (ETH Zurich)

As was highlighted above, quantitative methods in IRRASM normally use Boolean logic and classical set theory. In the overall risk estimation process, problems arise when fitting knowledge and experiences (which are not "crisp"). In the classical set theory a set A is the combination of well-distinguished objects x in the universe X. A fuzzy set A doesn't distinguish objects in this way and x shows qualities of other objects. The other main difference to classical set theory is the usage of linguistic variables, given by the quintuple $\{C, T(A), U, G, M\}$. An example to describe "incidental loss" is given:

1. Expression $C = \{\text{consequences}\}$
2. Term $T(C)$ fixes the range of C:
   $T(C) = \{\textit{negligible}, \textit{marginal}, \textit{critical}, \textit{catastrophic}\}$
3. All values in $T(C)$ are represented as a fuzzy set in the universe U
4. G gives the description for C, e.g., G: = "catastrophic" means 75% up to 100%
5. Membership functions for every value of C is associated.

An interface with the prioritization scheme of van den Brand follows. Classifications are widely used in IRRASM studies in order to assess consequences or probabilities for risk calculations. In practice it is often difficult to establish and separate such classes from each other. The documentation of membership grades or functions to characterize various issues of risk makes an IRRASM transparent to the risk assessment process. The fuzzy set theory allows flexibility in handling risk at the regional level. A large number of consequence indicators – up to nine – were integrated into a comprehensive methodology.

Calculation and representation of risk involves a significant number of subjective factors. The fuzzy set tool used for IRRASM has the ability to formulate and document all steps in the risk assessment process which, by definition, has a large degree of subjectiveness. The risk evaluation process can be considered in a more flexible manner, by using normal language, jointly with scientific and engineering descriptions and calculations.

2.3 ON SOME ORGANIZATIONAL ASPECTS

The following procedural steps are suggested in order to address and implement IRRASM studies:

- The organization that intends to undertake the study should formulate the study objectives and draft a project proposal, including the timetable, the manpower, and the financial and other resource requirement.
- The initiating organization should ensure that all the relevant organizations, industry and institutions are involved, on the basis of the draft project proposals. These organizations should decide on the conditions under which they wish to participate and on whether the proposed objectives and the draft study proposal require any modifications to fit their needs. They should also decide on the practical forms in which they are prepared to participate, be it manpower, information sources, or funds. Should any adjustments applicable to the objectives of the study be made, joint agreement must be reached by all the participating organizations. They may also establish a joint coordinating committee. Industry participation in these studies is considered essential and every attempt should be made to ensure the cooperation of industry from the outset.
- A steering committee for the project should be established by the participating organizations, specifying its responsibilities and terms of reference. For complex and sensitive projects, a supervisory steering committee (with political representatives) may be formed, again specifying its duties and responsibilities.

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- The steering committee should establish working groups. The steering committee should formulate the project proposal into a detailed plan and establish working groups to carry out various analyses. If external consultants are necessary, the steering committee should make tenders for the work and choose the best person for the job. The working groups should undertake the various analyses associated with the project.
- The steering committee should accept, if necessary after some modification, the final report of the working groups and prepare its own covering report, including conclusions and recommendations.
- The participating organizations should receive the reports and decide on: the final conclusions and recommendations, the policy changes to be implemented, and which of the proposed actions should be carried out, including final prioritization and action plans for implementation.

The participating organizations should put their decisions into effect, ensuring that the responsibilities and procedures are properly arranged to monitor and evaluate the implementation process. They should evaluate, together or separately, the results of their risk management policy, implemented on the basis of the results of the study.

2.4 TECHNIQUES FOR INTERACTIVE DECISION PROCESSES IN IRRASM

New techniques are available today in order to assist the integration of models, citizens, and the potential decision makers. One of these techniques is known as *the cooperative discourse model*. A formal representation of the use of this technique is given in Figure 2.3. Various actors are involved in the decision-making process. Specific steps one can consider include concerns and criteria, assessment of options, evaluation of options. Potential products in the cooperative discourse model are value tree representation, performance profile, priority options.

The actors involved in the process of IRRASM work and implementation are stakeholder group, experts, citizens, sponsors, research team.

Step 1 (Concerns and criteria) involves the following tasks: elicitation of value trees for each group, additions to concern list and the generation of options, additions and modifications of concern list, input to concern list (generation of options), transformation of concerns into indicators.

Step 2 (Assessment of options) involves the following tasks: suggestions for experts (group specific assessments), Group Delphi (collection of expert judgments), transformation of expert judgments into group utilities, incorporation of institutional knowledge, verification of expert judgments (literature search and independent review).

Step 3 (Evaluation of options) involves the following tasks: witnesses to citizen panels, participation as discusser or videotaped presenter, option evaluation and recommendation, compilation of citizen report.

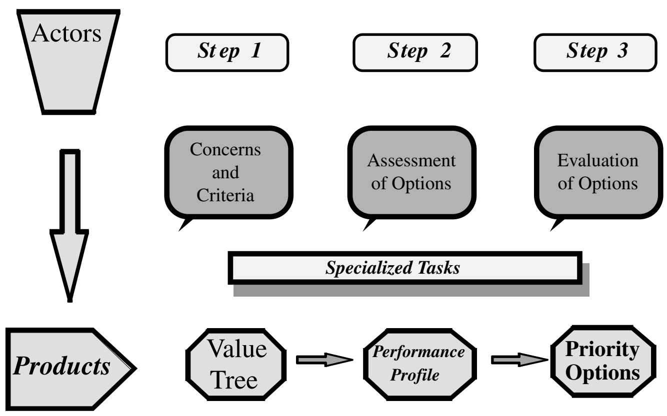

Figure 2.3. The cooperative discourse model described in a number of major steps.

Figure 2.4 is a representation of the cooperative discourse model. It is argued that "because no single mode of discourse can fulfil all of the needs of competence and service all the various actors in an efficient manner, co-operative discourse is a hybrid of different discourse settings. Each discourse setting is oriented toward facilitating a discussion about a primary type of *validity claim*. The differentiation is based in a conceptualisation of four different types of actors: sponsor and research team, experts, stakeholders, and citizens; and four different types of validity claims: communicative, cognitive, normative, and expressive" (Webler 1994).

In the context of this chapter, a *validity claim* is defined as a type of statement that makes an appeal to acceptance and it is fundamentally different in the sense that the appeal must be validated by the group according to a unique set of criteria.

2.5 THE USE OF DSS FOR INTEGRATED RISK ASSESSMENT STUDIES

It is evident that the information technology has large capabilities in assisting various stages of the IRRASM work and dissemination of results. An integrated approach is adequate; in Figure 2.5 it is considered the overall integration to be achieved within the technical, economical, environmental, and legal

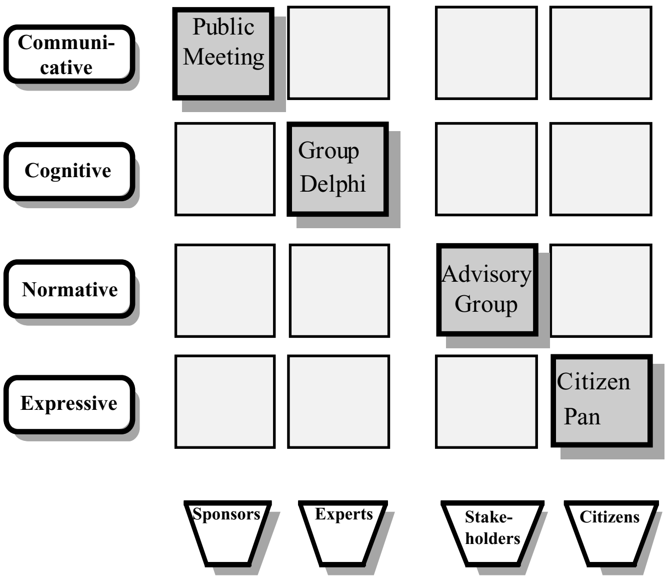

Figure 2.4. Structural approach to cooperative discourse model.

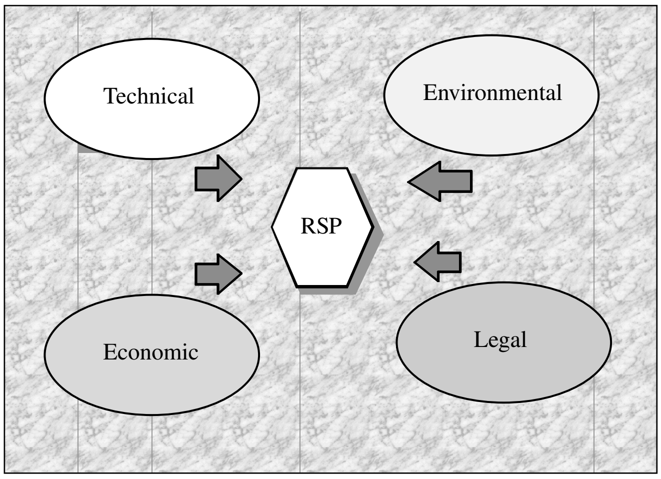

Figure 2.5. Integration of technic, economic, environmental, and legal aspects for IRRASM.

framework. The use of CD-ROM technology is ready to assist various stages in the practical process of IRRASM. Next, some basic definitions and further extensions related to DSSs and decision analysis framework are given.

Definition 2.2

A decision support system (DSS) is defined as a computer-based system that supports technological and managerial decision making by assisting in the organization of knowledge about ill-structured, semistructured, or unstructured issues.

A general taxonomy for DSSs is given next:

- foundation/management theory
- group DSS
- routing DSS
- database management systems
- multiple criteria DSS
- marketing DSS
- multiple criteria decision making
- management science.

Recent experiences with DSS for energy, risk,[1] and environmental management[2] indicate the use of the following methodologies: ad hoc design, expert systems, operational research, genetic algorithms, neural networks, fuzzy logic.

2.5.1 Decision process and the role of models and tools in IRRASM

It is acknowledged that the process of initiating, promoting risk analysis, and implementing safety management studies for large industrial complexes involves complex decisions as well as the participation of many actors. The process of integrating various aspects of risk such as environment, health, performance of hazardous installations, safety culture, management, involves decision-aiding techniques known as decision analysis, which are close to the field of management science.

There are, in general, positive and negative aspects associated with decision making. Indeed, many decisions are made intuitively by experts and do not use structured processes or techniques. For many decision problems related to energy, the solutions and then advantages and disadvantages may not be immediately apparent because of the complexity of the issues involved. There is a need for systematic processes to be followed that help structural thinking and analysis, and allow different viewpoints to be taken into consideration. Structuring helps avoid inappropriate ad hoc decisions and allows the process of reaching a decision to be more open and the decision itself to be more readily defensible (decisions made today very often have long-term effects). In the end, the use of various decision-aiding techniques and the overall process and technology of decision analysis allows the integration of various risks at regional and area levels. The integration of various risks within the decision-making process is the appropriate mechanism that allows displaying various risks and choosing the most appropriate resilient solutions.

[1] See Beroggi and Wallace 1995.
[2] See Paruccini 1993.

There are many inputs, influences, and constraints that a decision maker will consider when deciding which actions to initiate regarding risk reduction or safety management to a particular situation.

Comment

Decision-aiding techniques (DAT) are tools for decision makers; they are decision-aiding techniques, but not decision-making techniques. A large number of tools are available to assist in solving and structuring decisions of such complexity.

The main stages of DAT with reference to IRRASM are:

Step 1. Define and describe the problem (e.g., selecting an appropriate regional risk scenario).
Step 2. Consider and define appropriate quality assurance requirements.
Step 3. Formalize the descriptive model of the problem (e.g., options for alternative production technologies, electricity generation, and system constraints).
Step 4. Obtain the necessary information for modeling.
Step 5. Analyze, in order to determine the set of alternatives and criteria.
Step 6. Ensure selection of the proper method to make the decision regarding the proper integration of various criteria and their optimization.
Step 7. Establish a clear record of the process and any decisions taken as a result of the integration process of various types of criteria and constraints.

To make a decision means to select a method of action, out of a set of possible alternatives. The decision process is complex and sometimes iterative; the set of alternatives or criteria may vary from iteration to iteration.

Decision making involves three major elements:

a. alternatives, among which the “best” one will be chosen
b. criteria for judgment
c. methods for selecting one alternative from the whole set.

Decision-aiding process (DAP) is needed because it helps to generate a degree of shared understanding among interested parties who are concerned with issues on energy mix planning. There are a few issues to be highlighted: in this domain one has to involve complexity, uncertainty, or even fuzziness, multiple criteria with the objectives in conflict, and group interests. DAP can provide models that integrate these features into an adequate methodology.

Decision aiding

- Aiding, not making
- Role of expert judgment
- Flexibility: Different techniques suited to different problems

DAP provides a framework within which informed discussions of key issues (e.g., environmental or health risks) can be conducted, and they facilitate, for example, generation of consensus and integration of such issues. The relative costs and benefits to the user of applying a decision-aiding process should be compared to the costs and benefits of not using one.

Overview of DAP

- Choice of options and relevant factors
- Assessment of different options according to each relevant factor
- Techniques yielding unacceptable results
- Estimation of weighting factors
- Sensitivity analysis
- Probability-encoding techniques
- Presentation of results

The cost of not using a DAP can be high, especially in terms of inefficient use of human resources and in the end the incapacity of integrating various types of risks and selective safety improvement measures in the overall decision process.

Techniques yielding unacceptable results. It should be noted that there are techniques in use for the purpose of making decisions that may not yield acceptable results, even though they appear to provide the user with a very simple methodology. Examples are the “break-even” technique and the “successive goal” technique. The first of these is based on the law of diminishing returns according to which, beyond a certain point, further expenditure is not accompanied by a comparable reduction in the associated risk. In this respect, the performance of each option can be plotted on a graph in order to determine the break point that separates the efficient from the inefficient options. However, because the relative importance of each of the different factors is not taken explicitly into account, this