Model-Based Decision Support Methodology with Environmental Applications

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Introduction

Jaap Wessels and Andrzej P. Wierzbicki

Decision making is a major component of living and, therefore, a fascinating topic for discussion and investigation. Several fields in science also occupy themselves with the nature of different aspects of decision making: philosophy, psychology, sociology, economics, etc. There are many types of decision making and all types are equally intriguing, e.g., How do people react when they are threatened? How should one select a spouse? What is the most appropriate factory layout? Which markets would be most profitable? In this short list we already recognize the distinction between individual decision making and institutional decision making. In the last 50 to 60 years, institutional decision making has attracted much attention, particularly for decisions regarding the design and control of military operations. Later, similar ideas were used and extended for decisions in trade and industry. Policy making in the public and semi-public sectors of society also began to be based more on systematic analysis.

In most institutional decision-making problems, there are three main aspects of concern:

- The information about the current situation and, possibly, about the past.
- The processes that are to be influenced by the decisions.
- The actual decision-making process.

For instance, decision making concerning acid rain illustrates the above three aspects clearly, as follows:

- The information consists of huge amounts of data regarding industrial, agricultural, and automotive activities. It also consists of data about wind and sun activities and about the types of power stations used.
- The processes to be influenced by the decisions consist of the production and emission of polluting material, together with the atmospheric transformation (chemical reactions and transportation) and the deposition process. Therefore the processes are basically of a physical and economic nature.
- The decision-making process consists of several interacting subprocesses at the local, national, and international levels.

In the history of decision support and decision analysis, one sees that many tools and methods have been developed to help make decisions. We also see that most of these methods and tools concentrate on one of the three main aspects of institutional decision-making problems. For instance, in most college textbooks dealing with operations research, we find several generic models describing the relation of the basic processes with the possible decisions. Each model is usually presented together with at least one technique for constructing a most favorable decision. Linear programming models and the simplex method provide the most classical example.

The first aspect, information, has been the source of inspiration for particular types of information systems that consist of one or more data bases and special methods for arranging the information. Typical examples are geographic information systems (GIS) and management information systems (MIS), each with their own way of structuring and storing the information and with their own way of dealing with the information.

Finally, the decision-making process has inspired several approaches to the structuring of the process of reaching decisions and ways of comparing different alternatives. The process of reaching decisions may be complex because the decisions themselves are complex and consist of many subdecisions, which should be taken in the right order (decision trees can be an appropriate tool to model this type of situation). The process of reaching decisions may also be complex because of the number of persons, departments and other groups involved, each with their own interests, constraints, and ambitions. In such cases, group decision-making methods or even negotiation support can be helpful.

One of the most striking features of the existing decision support methodology is that most tools and methods concentrate entirely on one of the three aspects and often only on a part of that aspect. This is understandable, because often it is difficult to integrate the other aspects. For instance, GISs are able to handle a wealth of information in a very user-friendly and enlightening way. However, it is difficult to translate this information for the basic processes to models in order to use this information for deriving consequences of possible decisions. A direct linkage is possible only if the process models are closely related to the information structure, as in guiding car-systems, where an optimal route is indicated on a map. This decision selection can easily be adapted if information about traffic jams or blocked bridges becomes available.

For more strategic decisions, however, it is unlikely that the process models relate so closely to the information structure. Even if something can be done, the approach is probably specific to a particular problem and therefore not generally applicable. One reason for this situation is that there are accepted standards for keeping information in data bases, but there are no accepted standards for model building.

Quite often, methods are implemented as if the designers are not even aware of the other aspects. As a result, implementations have been developed that are practically infeasible. For example, approaches to modeling and optimization of the basic processes have been commonly advertised that do not fit with the way information becomes available, or, more seriously, with the way the decisions are chosen.

Many institutional decision processes relate to well-defined processes of a technical, physical, or economic nature. This is particularly true for environmental problems, like the acid rain problem. In such cases there is usually a lot of knowledge about the basic processes and about the way they are influenced by possible decisions. However, not all institutional decision processes possess this property. Consider, for instance, the structuring of the funding organization for research in Poland. In such a case there is certainly a basic process to be influenced by the choices to be made, namely, the research process in Poland including quality, quantity, and distribution of research topics. However, there is not much accepted hard knowledge about the basic process and the core of the decision problem consists of a careful structuring of the influences of relevant institutions and of the decision process.

On the other hand, if there is a well-defined basic process and if the core problem essentially consists of deciding how to influence that basic process, then it is obvious that the starting point for any reasonable approach should be the modeling of the basic process, including the changes caused by possible decisions. As stated above, environmental policy problems usually belong to this class. The aim of this book is to present a decision support methodology for decision making concentrated around the basic processes, taking into account the information aspect and, particularly, the process of reaching decisions.

The methodology presented in this book is largely inspired by the experience at IIASA, the International Institute for Applied Systems Analysis. IIASA provided several environmental decision problems that helped develop our concepts of decision support. IIASA also provided the expertise about the basic processes together with the knowledge about the "decision environment". Many of the tools for implementing our concepts have been developed by several Polish groups of colleagues in a long-lasting cooperation with IIASA.

Methodology

In the first part of this book we consider the circumstances under which decision support methods should fulfill their tasks and also what these tasks are. From these considerations, we derive rules for constructing decision support systems. We concentrate on model-based decision support, that is, the relation between basic processes and possible decisions. However, the circumstances under which such decision support methods should work are highly co-determined by the available information and by the decision-making process. Therefore, these aspects strongly determine the rules for constructing decision support systems.

In Chapter 1, the concept of model-based decision support is introduced. Chapter 2 discusses the concept of a modern decision maker, the role of intuition versus decision support in decision making, the dynamics and phases of decision processes, experiences with decision support systems, and the position and way-of-operating of potential users of such systems. In Chapter 3, some basic concepts related to the architecture and implementation of decision support systems are presented. Chapter 4 shows how to use decision support systems for learning and for supporting decision making, while stressing multi-objective optimization and the reference point methodology developed at IIASA. Finally, Chapter 5 concentrates on the various paradigms of model analysis made possible by this methodology and applicable for model-based decision support.

Decision Support Tools

The second part of the book concentrates on more technical aspects of the basic types of tools needed in model-based decision support. These include tools for modeling, simulation, optimization, tools supporting choice, and user interfaces.

Chapter 6 describes modeling tools, both standard, commercially available, and nonstandard, together with tools for model simulation – in the classical sense as well as in a more advanced sense of inverse and softly constrained simulation. Chapter 7 gives a review of optimization tools, not only in the sense of solving single-objective optimization problems, but also as tools of multi-objective model analysis, advanced simulation techniques, etc. Chapter 8 presents in more detail some mathematical background, concepts, and tools for multi-objective optimization and reference point methodology, more generally presented in Chapter 4.

Chapter 9 describes various tools for supporting the choice of a preferred decision either for automating choice, generating options for interactive choice, or using a convergent interactive decision-support procedure. Chapter 10, finally, describes some user interfaces of decision support systems.

Environmental Applications

All four environmental applications presented in the third part of the book rely on many years of cooperation between the Methodology of Decision Analysis project at IIASA and various other – mostly environmental – projects at IIASA. They are all characterized by an intensive use of model-based decision support.

Chapter 11 discusses issues of river basin water quality management based on a multi-objective model analysis, as developed at IIASA for use in the decision-making support for some Central European river basins. Chapter 12 presents model-based methods of land-use planning, developed at IIASA in collaboration with the Food and Agriculture Organization of the United Nations (FAO). Chapter 13 describes issues of assessment of air quality, transboundary air pollution abatement, and related problems; models developed at IIASA in this field were used as a basis for international negotiations on pollution control. Chapter 14 presents an overview of various applications of model-based decision support in energy planning with environmental implications, as developed at IIASA in cooperation with several national and international authorities. Finally, the Epilogue presents conclusions and the lessons learned from the practice of using model-based decision support.

Appendix

This contains a short description of some of the software tools described in the book that are available from IIASA, free of charge, for research and educational purposes.