DECISION SUPPORT SYSTEMS ENGINEERING

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A Wiley-Interscience Publication
JOHN WILEY & SONS, INC.
New York / Chichester / Brisbane / Toronto / Singapore

Library of Congress Cataloging in Publication Data:

Sage, Andrew P.

Decision support systems engineering / Andrew P. Sage.

p. cm. — (Wiley series in systems engineering)

"A Wiley-Interscience publication."

Includes bibliographical references.

1. Decision support systems. I. Title. II. Series.

T58.62.S25 1991

658.4'03—dc20 91-15539

ISBN 0-471-53000-X CIP

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

This book is addressed to two groups of people. The first are information systems engineering professionals who *design* decision support systems that aid knowledge workers in a variety of judgment and choice activities. It is also addressed, through the provision of appropriate overviews, to those who *utilize* decision support systems in any of a number of important contemporary activities. These activities include the design of complex technological systems, such as aircraft flight control systems. They include management systems to enable better financial decisions. They also include decision support systems that enhance judgment and choice in areas in which there is a need for integration of technological, economic, and sociopolitical concerns, such as group decision support systems that enable identification and choice among alternatives to improve urban and regional transportation mobility. Specific examples of "real-world" decision support are generally not discussed, although all of the presentation is relevant to DSS design and use. It is my hope, by addressing both the design and user communities, to present a reasonably complete and comprehensive treatment of this important subject area that will have a wide scope of utility for each group.

The first part of the book focuses on a description of the generic technological components of a decision support system: data-base management systems, model-base management systems, and dialog generation and management systems. The emphasis on these information systems engineering design concerns is relatively technological. The focus is also on the basic and applied technology that makes the application of decision support systems feasible and practical. Emphasis is placed on decision support system requirements analysis and specification, the use of alternative analytical methods, and iterative design approaches for realization of decision support systems. A portion of the first part is also concerned with how decision support systems can be evaluated.

In the second part of the text, approaches are described for developing appropriate integrated information systems architectures that result in effective decision support. These approaches are discussed in the framework of a total life-cycle systems management process. Emphasis is placed on the formulation of user needs, the translation of user needs into system requirements, the hardware and software allocation of these requirements, and the development of suitable hardware and software architectures for decision support systems.

There has been much research in cognitive and behavioral psychology concerning human information processing in judgment and choice situations. Major results of these studies indicate that human information processing is often very flawed. A number of these human information-processing biases have been identified. This second major portion of this text first discusses the general subject of cognitive systems engineering and concludes with a presentation of the way in which decision support systems can be utilized to avoid cognitive information-processing biases and errors.

The second major part of the book provides a discussion of computing, communication, and decision support technologies and associated design efforts that result in useful systems for the formulation, analysis, and interpretation of unstructured issues by groups and organizations. Available systems are described as well as the impact of group decision support systems on decision making in design and management situations. Command and control system design and corporate planning systems will be briefly examined from the perspective of group decision support systems. We discuss design and user environments for decision support systems. This will serve both as the concluding portion of the text and as a vehicle for integrating the material presented earlier. References are presented on a chapter-by-chapter basis. Problems and case-study suggestions are presented at the end of each chapter.

This text is written for beginning graduate students in systems engineering, information systems, computer science, and management. Prerequisites for the text are moderate. The discussion of data-base management systems assumes a moderate background in data structures and some familiarity with applications systems programming. The discussion of model-base management assumes a moderate background in calculus and, to a lesser extent, linear programming. This is specifically needed only for that part of the material that deals with decision analysis and related material. The treatment of human and organizational information-processing concerns is nearly self-contained. For the most part, this is the case also with respect to the group decision support systems design discussions. Some elementary knowledge of computer communications and architecture will be helpful but not required for the group decision support systems and the design and environments chapters (Chapter 7 and Chapter 8, respectively).

Each of the chapters in this text is interrelated. For this reason, Chapter 1 provides a relatively detailed overview of much of the material in this book. This perspective should support the design and evaluation efforts discussed in Chapters 2–5. While this effect could be obtained by placing this technological material after the behavioral and organizational material, the discussion of the organizational and behavioral material would suffer because of the need for knowledge of the support systems design features.

The book is designed for a one-semester graduate course for students in the areas mentioned earlier. It has been used for this purpose by the author in courses taken by students with the same general core background of virtually all students in engineering, computing, and management-related areas.

This text should also be attractive to and suitable for use by the many professionals in industry concerned with decision support systems, information systems, and software development for these purposes. The book has a good many applied discussions from the area of information-processing psychology and it may be of interest to those concerned with human–computer interface design as well.

Many people contribute to an effort as large as a textbook. I must first acknowledge the many who have written research papers and monographs. Generally, these are acknowledged by the references at the end of each chapter. Doubtlessly, I have forgotten, or unintentionally neglected, to mention some authors and for this I apologize in advance. Contributions were also made by students in an information technology graduate course at George Mason University who were thoughtful enough to spend time marking class notes with corrections and suggestions. Particularly helpful in this regard were Pershing Anderson, Philip Barry, Raymond Curts, Lynne Fellman, Jianhong Liang, Richard Librizzi, Michael McFerren, and Kwang-Su Yang.

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Fairfax Station, Virginia
June 1991

Contents

Chapter 1

An Introduction to Decision Support Systems Engineering

In very general terms, a decision support system (DDS) is a system that supports technological and managerial decision making by assisting in the organization of knowledge about ill-structured, semistructured or unstructured* issues. The primary components of a decision support system are a *data-base management system* (DBMS), a *model-base management system* (MBMS), and a *dialog generation and management system* (DGMS). Emphasis in the use of a DSS is on provision of support to decision makers in terms of increasing the effectiveness of the decision-making effort. As we will see, this involves the *formulation* of alternatives, the *analysis* of their impacts, and *interpretation* and selection of appropriate options for implementation. Efficiency in terms of time required to evolve the decision, while important, is usually secondary to effectiveness.† Generally, DSS are intended for use in strategic and tactical situations, and less in operational situations. (In operational situations, which are often well structured, an expert system may often be gainfully employed to assist novices. Those very proficient in operational tasks generally do not require support, except perhaps for automation of some routine and repetitive chores.) In this chapter, we will provide an introduction to decision support systems engineering.

There are many application areas in which the use of a decision support system is potentially promising. These include management and planning [1], command and control [2], system design [3], health care, operations management, and essentially any area in which management has to cope with decision situations having an initially unfamiliar structure.

*For our purposes, a structured issue is one that has a framework with elements and relations between them that are understood.

†In those instances in which decision-making speed is essential to effectiveness, an appropriate DSS *will* provide primary support in enabling quick decision response.

1.1 INTRODUCTION TO, AND TAXONOMIES OF, DECISION PROBLEMS

Numerous disciplinary areas have contributed to the development of decision support systems. These include computer science, which provides the hardware and software tools necessary to implement decision support systems design constructs. In particular, computer science provides us with the *data-base design* and programming support tools that are needed in a decision support system. The field of management science and operations research has provided the theoretical framework in decision analysis that is necessary to design useful and relevant normative approaches to choice making, especially those that are concerned with systems analysis and *model-base management.* The areas of organizational behavior, and behavioral and cognitive science, provide rich sources of information concerning how humans and organizations process information and make judgments in a descriptive fashion. Background information from these areas are needed for the design of effective systems for *dialog generation and management.* The area of systems design engineering is concerned with building large systems of hardware and software, including systems for decision support.

There have been many attempts to classify different types of decisions. Among the classifications of particular interest here is the decision type taxonomy of Anthony [4]. He describes four types of decisions:

1. *Strategic Planning Decisions:* decisions related to choosing highest-level policies and objectives, and associated resource allocations.
2. *Management Control Decisions:* decisions made for the purpose of assuring effectiveness in the acquisition and use of resources.
3. *Operational Control Decisions:* decisions made for the purpose of assuring effectiveness in the performance of operations.
4. *Operational Performance Decisions:* day-to-day decisions made while performing operations.

Figure 1.1 illustrates the way in which these decisions are related and the way in which they normatively influence organizational learning.* A key point in this figure is that low-consequence decisions are made less frequently that high-consequence decisions. Also, strategic decisions are associated with higher consequences and are likely to involve more significant risk, and must be made on the basis of considerably less perfect information than operational control and operational performance decisions. These latter two decisions relate to specific tasks and may be called task control decisions [4].

Simon [5] describes decisions as structured or unstructured depending on whether the decision-making process can be explicitly described prior to the time when it is necessary to make a decision. This taxonomy would seem to lead directly to that in which expert skills (wholistic reasoning), rules (heuristics), or formal reasoning (holistic evaluation) are normatively used for judgment. Generally, operational performance decisions are more likely than strategic planning decisions to be pre-

*Learning is needed or there will generally be no way to do things better next time.

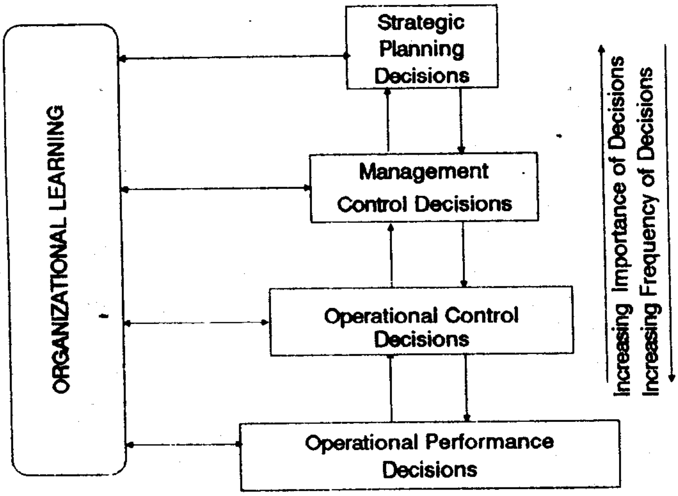

Figure 1.1 Organizational information and decision flow.

structured. Thus, expert systems can usually be expected to be more appropriate for operational performance and operational control decisions than for strategic planning and management planning decisions. (Most expert systems are based on extensive use of what are generally called *production rules.* This *rule-based reasoning* may not be suitable for situations that require either formal knowledge based reasoning or skill-based expert reasoning. From this perspective, *expert systems* might well be more appropriately called *proficient systems;* but, this is getting ahead of our story as we will have more to say later about this. Much research is currently being undertaken to overcome limits to expert systems.) In a similar way decision support systems will often be more appropriate for strategic planning and management control than they are for operational control and operational performance.[†] We will provide some discussions relative to the use of expert system (AI) tools for decision support, such as expert data-base systems, and expert model-base management systems. This will be a relatively small part of the coverage, and these discussions will always be put into the perspective of decision support system design and use. Basically, there is no need for the decision *support* of well-structured decisions. It may be desirable to automate well-structured decisions, such that the decision maker is relieved of the need to accomplish relatively routine tasks and thereby increase the time available for significant decision-making activities. Alternatively, a person inexperienced at the task at hand may be asked to perform it. An *expert system* may be of support to such a person, for whom the required decision tasks may not be well structured. We will have much more to say about these issues later.

It is very important to note that expertise is a relative term that depends on familiarity with task and the operational environment into which it is embedded.

[†]Decision making systems generally make use of *formal reasoning based* knowledge.

Since decision environments do change, and since novices become experts through learning and feedback, it is clear that there should exist many areas in which the proper form of knowledge-based support is a hybrid of an "expert system" and a "decision support system." This suggests that there will be a variety of decision-making processes in practice and that an effective support system should support multiple decision processes. In a similar way, the information requirements for decision making can be expected to be highly varied, and an effective support system should support a variety of data-base and model-base management needs.

There are a number of abilities that a decision support system should support. It should support the decision maker in the *formulation* or framing or assessment of the decision situation in the sense of recognizing needs, identifying appropriate objectives by which to measure successful resolution of an issue, and generating alternative courses of action that will resolve the needs and satisfy objectives. It should also provide support in enhancing the abilities of the decision maker to obtain the possible impacts on needs of the alternative courses of action. This *analysis* capability must be associated with provision of capability to improve the ability of the decision maker to provide an *interpretation* of these impacts in terms of objectives. This interpretation capability will lead to evaluation of the alternatives and selection of a preferred alternative option. These three steps of formulation, analysis, and interpretation are very fundamental ones for formal analysis of difficult issues. They are the fundamental steps of systems engineering and are discussed at some length in the chapter on DSS design (Chapter 5). It is essential to note that the purpose of a decision support system is *to support humans in the performance of primarily cognitive tasks that involve decisions, judgments, and choice.* Ultimately, there may be some human supervisory control of a physical system through use of these decisions. Nevertheless, the primary purpose of a DSS is support for cognitive activities that involve human information processing and associated judgment and choice.

Associated with these three steps—formulation, analysis, and interpretation—must be the ability to acquire, represent, and utilize information or knowledge, and the ability to implement the chosen alternative course of action. All of this must be accomplished with due consideration to the particular rationality perspective that is used for decision making. As will be discussed in Chapter 6, these include economic and technical rationality, satisficing rationality, organizational process rationality, incremental or bureaucratic politics rationality, and other forms.

There are many variables that will influence the information that is, or which should be, obtained relative to any given decision situation. These variables are very clearly task dependent. Keen and Scott-Morton [6], who wrote an early seminal text in this area, identify eight information relevant variables:

1. *Inherent Accuracy of Available Information.* Operational control situations will often deal with information that is relatively certain and precise. The information in strategic planning situations is often uncertain, imprecise, and incomplete.
2. *Needed Level of Detail.* Often very detailed information is needed for operational-type decisions. Highly aggregated information is often desired for strategic decisions.

3. *Time Horizon for Information Needed.* Operational decisions are typically based on information over a short time horizon, and the nature of the control may be changed frequently. In contrast, strategic decisions are founded on information and predictions based on a long time horizon.
4. *Frequency of Use.* Strategic decisions are made infrequently, although they are perhaps refined fairly often. Operational decisions are made quite frequently, and are relatively easily changed.
5. *Internal or External Information Source.* Operational decisions are often based on information that is available internal to the organization, whereas strategic decisions are much more likely to be dependent on information content that can only be obtained external to the organization.
6. *Information Scope.* Generally, operational decisions are made on the basis of narrow-scope information related to well-defined events internal to the organization. Strategic decisions are based on broad-scope information and a wide range of factors that often cannot be fully anticipated prior to the need for the decision.
7. *Information Quantifiability.* In strategic planning, information is very likely to be highly qualitative, at least initially. For operational decisions, the available information is often highly quantified.
8. *Information Currency.* In strategic planning, information is often rather old, and it is often difficult to obtain current information. For operational control decisions, very current information is often needed.

The extent to which a support system possesses the capacity to assist a person or a group to formulate, analyze, and interpret issues will depend on whether the resulting system should be called a management information system (MIS), a predictive management information system (PMIS), or a decision support system (DSS). We can provide support to the decision maker at any of these several levels, as suggested by Figure 1.2. Whether we have a MIS, a PMIS or a DSS depends on the type of automated computer-based support that is provided to the decision maker to assist in reaching the decision. Fundamental to the notion of a decision support system is assistance provided in assessing the situation, identifying alternative courses of action, formulating the decision situation, structuring and analyzing the decision situation, and then interpreting the results of analysis of the alternatives in terms of the value system of the decision maker.

In a classical management information system, the user inputs a request for a report concerning some question, and the MIS supplies that report. When the user is able to pose a *"what if?"* type question and the system is able to respond with an *"if then . . ."* type of response, then we have a predictive management information system. In each case, there is some sort of *formulation* of the issue and this is accompanied by some capacity for *analysis.* The classic MIS need only be able to respond to queries with reports.* The typical MIS is comprised of the following

*Thus, it would respond to a request for inputs concerning airline flights from Washington to Chicago on July 4 with a report of available flights on that date. Search of an electronic file cabinet, or perhaps a relational data base, would provide information from which a report generator could construct the desired report.

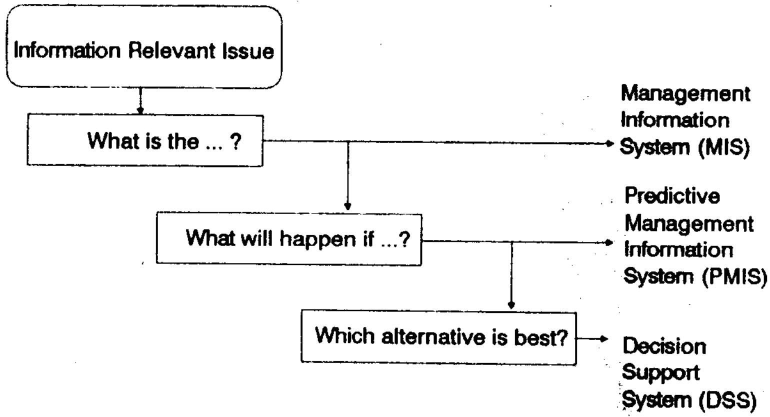

Figure 1.2 Conceptual differences between MIS, PMIS, and DSS.

capabilities: a focus on data processing and structured data flows at an operational level, and summary reports for the user. The predictive management system would also include an additional amount of analysis capability.† This might require an intelligent data-base query system, or perhaps just the simple use of some sort of spreadsheet or macroeconomic model.

To obtain a decision support system, we would need to add the capability of model-base management to a MIS. But much more is needed, for example, than just the simple addition of a set of decision trees and procedures to elicit examination of decision analysis based paradigms. We also need a system that is flexible and adaptable to changing user requirements such as to provide support for the decision styles of the decision maker as these change with task, environment, and experiential familiarity of the support system users with task and environment. We need to provide analytical support in a variety of complex situations. Most decision situations are fragmented in that there are multiple decision makers, and their staffs, rather than just a single decision maker. Also there are temporal and spatial separation elements involved. Further, as Mintzberg [7] has indicated, managers have many more activities than decision making to occupy themselves with, and it will be necessary for appropriate DSS to support many of these other information-related functions as well. Thus, the principal goal of a DSS is *improvement in the effectiveness of organizational knowledge users through use of information technology*. This is not a simple objective to achieve, as has been learned in the process of past DSS design efforts.

†For example we might desire a response to a "what if" type question such as "What will likely happen if we drill for oil at location x?" The computer might then respond with "Based on the physical characteristics of source x it is predicted that if you drill at this source then you should likely expect . . ."

1.2 FRAMEWORKS FOR DESIGNING DECISION SUPPORT SYSTEMS

As we have discussed there are three principal components of a decision support system:

- Data-base management system (DBMS)
- Model-base management system (MBMS)
- Dialog generation and management systems (DGMS)

and an appropriate decision support system design framework will consider each of these three component systems and their interrelations and interactions. Figure 1.3 illustrates the interconnection of these three generic components and shows the interaction of the decision maker with the system through the DGMS.

Sprague and Carlson [8], authors of another early seminal book on decision support systems, have indicated that there are three technology levels at which a DSS may be considered. The first of these is the level of *DSS tools* themselves. This level contains the hardware and software elements and those system science and operations research methods that are needed to design a specific decision support system. The purpose of these DSS tools is to design a *specific* DSS that is responsive to a particular task or issue. The second level is that of a decision support system generator. The third level is the specific DSS itself. The specific DSS may be designed through the use of the DSS tools only, through use of the DSS generator only, or through combined use of these.

Often the best designers of a decision support system are not the specialists familiar with the DSS tools. The principal reason for this is that it is difficult for one person or small group to be very familiar with a great variety of tools, the requirements needed for a specific DSS, and the systems management skills needed to design

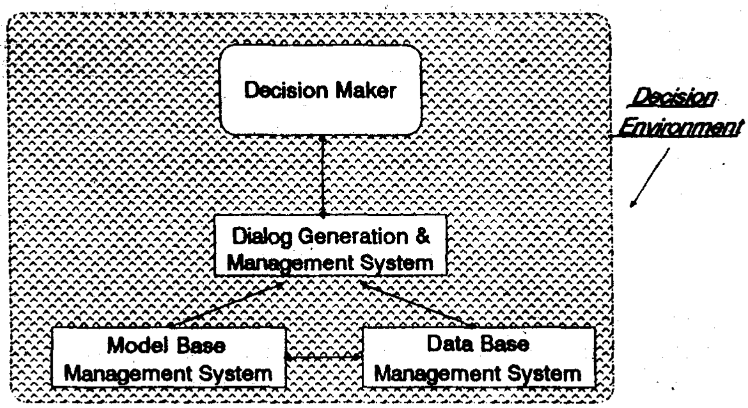

Figure 1.3 Generic components in decision support system.