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# 2 DECISION MAKING AND DECISION SUPPORT

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## 1. Introduction

Agenda 21, the Brudtland Report and other seminal documents discussed earlier in Chapter 1 provide a number of frameworks for the development and implementation of information systems methods and technologies to aid and support development decisions. There is a great demand for information and tools that facilitate making well informed decisions, assist in evaluating and analyzing their direct results and indirect implications, and provide strong basis for subsequent decisions. The complexity of sustainable development issues requires that all available technologies be used in an integrative and collaborative manner. Subsequent chapters of this book show that there have been many successful developments in the area of information systems and also that individual decision makers still face many challenges on the levels of regional, national and international organizations.

Support for integrated management, environmental protection, and sustainable use of resources requires flexible and content-rich methodologies. Multiple viewpoints, cultures, organizational structures and cognitive efforts need to be considered. Chapter 1 provides a list of various areas of sustainable development issues with those factors and requirements that need to be considered in order to develop and implement a decision support system.

This chapter examines decision making and support from the following four perspectives: information processing, managerial activities, decision problems and human organizations. This broad framework allowed us to identify different aspects and requirements of managerial support and led to a formulation of a set of decision support system design principles. This framework can be applied to position, study and develop a variety of systems, including geographical and spatial decision support systems and also to plan support systems discussed in Chapter 3.

The aim of this discussion is to extend the existing perspectives and taxonomies of decision support systems (DSS) and to position them within the context of information processing activities in both a narrow and broad sense. This leads to a perspective that takes into account recent methodological and technological developments. More importantly, it provides a framework for bridging such key issues as culture, tradition, local knowledge and procedures, multi-dimensionality of decision outcomes and their multiple interpretations, and interactions between the decision makers and their decisions.

The discussion of decision making is based on three levels of reasoning (Kersten and Cray 1996) and Simon's decision phase model (Simon, 1960). The phase model has been recently considered as an obstacle for the evolution of DSS research and practice (Anghern and Jelassi, 1994). In our view an integration of reasoning levels with the phase model provides a sound basis for discussion on DSSs methodologies, functionalities, and most importantly, their integration to the decision process. We argue that the limitations of the model, including the consideration of decision outcomes and knowledge creation, can easily be alleviated.

Several alternative frameworks for DSS development have been proposed. Brooks (1995) suggests that the phase model proposed by Mintzberg et al. (1976), has more relevance to DSS design then the phase model. These two models, however, are not incompatible. The focus of the process model is on support functions and specific tasks as opposed to the main types of activities (phases) in the process. An integration of the decision phases with managerial functions and tasks allows us to enrich the DSS framework.

Four decision making issues are discussed in Section 2. They build upon the cognitive view approach and stress the importance of the concept-to-stimulus focus that positions the decision maker at the center of the decision making and support process. Presentation of the phase model is followed by a discussion of functions and issues in managerial decision making. This provides the basis for a knowledge-based view of decision outcomes.

This discussion aims at the specification of support requirements and support functions that is presented in Section 3. In this section two types of support are also outlined; model-oriented support and data-oriented support.

In Section 4, DSS functional and performance requirements and DSS architecture are discussed. The requirements and design principles for decision support systems that interact with decision makers and aid them in their activities are formulated. Considerations for new system analysis and design methodologies are developed for an architecture centered around knowledge-based methodologies and control components. Support methodologies and functions introduced in the previous sections are then related to different DSS methods.

DSSs can be viewed as active participants in the decision making process. They have to behave, however, according to accepted organizational and managerial norms and rules. To illustrate this point two extreme types of DSS behavior, bureaucratic and entrepreneurial, are introduced in Section 5.

Despite the vast literature on DSSs many gaps remain. There is no unified decision support methodology that integrates the many existing methods, approaches and techniques. This may be due to the evolution of these systems on one hand and multiple technological revolutions, on the other. This chapter does not attempt to provide a unified framework. Rather it complements a decision support ontology proposed by Kersten and Szpakowicz (1994), and attempts to establish linkages between several frameworks and models in an attempt to provide some functional and architectural extensions. We conclude with brief discussion on several other issues relevant to DSS theory and practice.

## 2. Decision making

The development and implementation of decision support systems (DSS) requires knowledge about, and understanding, of managerial decision making, associated levels of reasoning and problem solving and the roles managers play in organizations. These topics are discussed in this and the following sections and along with their implications for decision support requirements.

### *2.1. Levels of reasoning*

At the most general level problem solving and reasoning about decisions, including managerial decisions, can be articulated at three distinct levels (Kersten and Cray 1996):

1. The *level of needs and values.* Humans experience n and values as a hierarchy that provides a rationale for actions undertaken to solve problems and make decisions. These hierarchies also facilitate the assessment and interpretation of the world and its possible states (Maslow 1954). The decision maker's needs and values have a discriminating effect on her subjective perception of the world; this is one of the key features of the cognitive system. The consideration of the hierarchy of needs as the driving force guiding the decision process has been introduced in decision science literature by Keeney (1992).

2. The *cognitive level.* A cognitive system incorporates needs and values in a structure which is often resistant to change. This system focuses on what needs can be fulfilled, to what extent and how. At the cognitive level, where the world model is formulated and maintained, needs are matched against opportunities and threats. Decision making articulated at the cognitive level involves connecting opportunities for satisfying needs with aspects of the problem and other entities in the world.

3. The *tool and calculation level.* Complex or otherwise difficult decisions require some form of support. Problem elements need to be visualized, computed, compared, analyzed and evaluated with the help of analysts and/or the use of monadic and structural systems. These activities are chosen at the cognitive level and they are carried out at the tool level.

Looking at these three levels and considering the specific activities required to reach a decision, we see that all levels have to be present in a decision making process and the activities have to fit with each other. Further, the cognitive paradigm emphasizes the two-way nature of the human-computer interaction as opposed to the one way channel of classical information systems.

De May (1992) observes that the classical information processing approach tends to operate on the stimulus to concept basis. That is, the process begins with the object or problem domain and activities for the transformation, storage and usage of the sensory input are applied. In contrast, the cognitive view stresses the importance of what is contributed by the user (concept to stimulus) when "knowing" or studying a problem.

The shift to concept-to-stimulus is precisely what is illustrated above by the first and second points, placing the *decision maker at the center of the entire problem analysis and solution synthesis process*. The decision maker has needs and a world model that guides the search for information, the selection of support tools, the construction and evaluation of alternatives, and other problem solving activities. Any active or cognitive system would have to exhibit similar characteristics. It is clear that since these ideas are only recently beginning to appear in the decision analysis community, among practitioners, let alone system developers, the existing decision support systems have not been designed with such attributes.

Most DSS have been primarily conceived and executed primarily at the tool level so that only specified and separate sub-problems are processed. In both behavioral and decision support research, however, there have been successful efforts to build representations of cognitive level perceptions with the use of cognitive mapping techniques (Eden 1988; Eden and Ackerman 1998). While cognitive maps have been used as a mediating technique between managers and consultants they also can be used in a similar capacity in mediating between managers and DSS (an example of the use of cognitive maps in managerial decision making is given in Chapter 10).

### *2.2. Decision making and decision problems*

Support for decision making requires prior knowledge and understanding of the problems, processes and activities leading to a decision. These can be achieved by studying the reasoning activities involved in a choice process, and remembering that they engage human faculties acting within clearly distinguishable phases (Mintzberg et al., 1976; Simon, 1960). The three phases of Simon's model are intelligence, design and choice.

During the *Intelligence* phase information is gathered to understand the problem for which a decision is required, and the necessary assumptions are made explicit. Then, during the *Design* phase, various alternatives are explored through building models and making appropriate calculations to predict the consequences that would arise from each particular alternative. Finally, in the *Choice* phase, a best or satisfactory decision is sought and selected. Often some final verification is undertaken.

Decision theory provides decision makers with a wide range of instruments which can be applied to uncover existing relationships and to help represent, analyze, solve and evaluate a decision problem. The selection and use of a specific method is, however, inherently subjective and guided by the decision maker's preferences expressed in his/her current understanding of the situation. It is often assumed that preferences remain stable, at least for the duration of the choice process, and the selection of a support tool is compatible with these preferences.

This outlook essentially places both choice and reasoning about choice at one level. However, the framing of choice and its impact on a decision process can be articulated by the decision maker at the cognitive level (which also includes needs and values), as well as the tool level.

The multi-faceted character of the cognitive level can be manifested by the hierarchy of the decision maker's objectives and constraints. Objectives provide a rationale for some actions the decision maker undertakes to solve problems and make decisions. Constraints provide the boundaries for choice and distinguish feasible decision alternatives from infeasible ones.

Analysis of the problem should link a decision opportunity to the ability to realize objectives (Heylinghen, 1992). This involves the recognition of the type of problem, the definition and interplay of its components and its relation to earlier experience. Thus, decision making articulated at the cognitive level includes connecting objectives' achievement with problem recognition and definition, and with the situational constraints within which a decision has to be made. The building blocks of the decision problem are considered, major difficulties or obstacles in determining a solution are specified, and the relationships between possible decision outcomes and needs are determined. Choices concerning problem solving strategies and methods that can support them are also made at this level.

While it is hard to conceive of a decision that can be made without being articulated at a cognitive level, many routine and simple decisions are made without the use of the calculation level, where different mechanisms are involved to reduce the mass of information to be processed, or to reduce the complexity of a problem. Support is provides at this level by most DSSs. It can be directed to any of the three phases of Simon’s model, as indicated in Fig. 1.

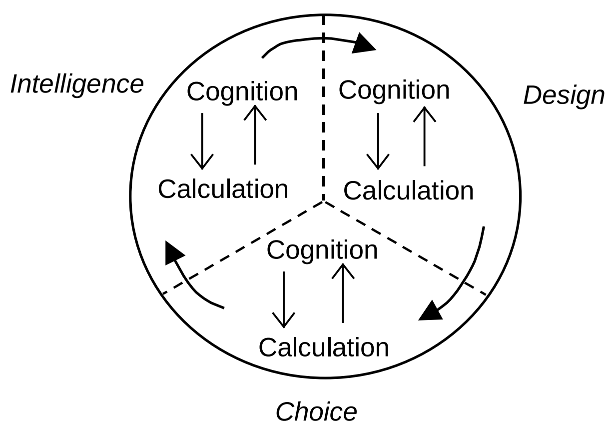


Figure 1. Simon’s phase model and levels of articulation

The activities at the calculation level may involve the use of complementary representations to determine the set of feasible alternatives, to investigate the preference structure of the decision maker, and to conduct what-if and sensitivity analyses. All levels of problem articulation may be present in each phase. The importance and the scope of each of the levels, although not indicated in Fig. 1, are likely to vary between the decision phases. They depend on a number of factors, including the decision topic, its complexity and its familiarity to the decision maker, and the context of the decision process. The implication of this for decision support is that both the level at which the need for support is generated and the type of support required are likely to change from phase to phase of the decision process.

### *2.3. Managerial decision making*

Managers are not able to use many DSSs because their design is not compatible with the nature of managerial work nor with approaches to problem solving and decision making managers normally employ. To illustrate this point we give a brief overview of the main aspects of managerial problem solving and decision making and their implications for support.

1. Managerial decisions are always made within an organization and context including the organization's own culture, routines and operating procedures. Support systems need to allow for the influence of cultural and other traits, and must fit the organizational structure. While DSS contribute to changes in the way organizations operate, such changes are inevitably evolutionary in nature so systems that require drastic changes will typically be rejected.

2. Decision problems evolve and their structure changes. Managers devote significant efforts to control organizational which leads to the redefinition of decisions and decision processes. Support has to be well defined in the sense that DSS users need to know not only how the output can be used but also how the system fits in the process and structure.

3. Decision making is a process involving multiple participants and requires conflict resolution. It also involves multiple information sources. This implies that DSS, including group and multi-participant DSS, rarely are the sole source of information. Further, the system should be able to interact with other information systems and make use of historical and current data from multiple sources.

4. Decision makers have different perspectives and use multiple interpretations in creating problem representations and solving problems. The *analytic perspective* allows one to identify and represent sub-problems and apply algorithms to solve them. The *holistic perspective* encourages one to view the overall problem and focus on its few assumptions, issues or implications. A manager can focus only on a few aspects at a time; seeing the big picture, he may choose what he needs or wants to consider in more detail, cycling between analytic and holistic perspectives. Decision analytic methods and models allow for problem decomposition and analysis. Data aggregation and visualization techniques, maps and visual simulation can be used for overall problem and solution assessment.

5. Managers consider and attempt to integrate both qualitative and quantitative aspects of a problem. Problem decomposition and the analysis of problem elements

provide only partial understanding of the problem and its implications. Integration of symbolic representations, knowledge processing with quantitative models and preference elicitation schemes partially address this issue.

6. Managers formulate some decision alternatives only superficially and discard them before they are fully articulated. For other alternatives they use partial quantitative analysis, while still other options may be fully considered. Some systems can be used to assess a problem's importance, others promote a general understanding of the problem and yet other systems perform detailed analysis. The same problem may be considered by different systems at different levels of detail.
7. Decision making does not end with the choice of an alternative. The decision-theoretic concept of outcomes can be used in simple, repetitive, and already well structured decisions. In other cases, managers and executives cannot rely only on precise numerical estimates and expected values that describe outcomes because a decision problem may describe a unique situation with significant qualitative aspects and because decision makers can influence outcomes through decision implementation and control.
8. The assumption that decisions can be made solely on the basis of their utility, i.e., “decision quality in the rational perspective”, is unrealistic. Decisions lead to other decisions and opportunities so it is often impossible to assess a priori utilities for these sunsequent decisions. Flexibility that allows the use of unexpected opportunities or adaptation to unforeseen setbacks is an important decision criterion. Other decision criteria, including, fairness, equity, political acceptability, and power implications, may also take precedence over utility. The ability of the decision maker to shape subsequent decisions may also be an important criterion.
9. Decision makers do not conform to one choice paradigm (e.g., rationality, bounded rationality, garbage can, politics and power). Systems must allow for the use of multiple paradigms which are complemented by cognitive and descriptive models, and heuristics. They should also facilitate, not restrict, the role of insight and intuition of decision makers.
10. Making decisions involves the determination of what will happen if a decision is selected, how it can be implemented, what may happen when it is implemented, why this may happen, what happens next, and who may obstruct the implementation and why. What-if and sensitivity analyses, scenario generation and management techniques are important DSS tools. It is no less important, however, to accept that the outcomes of a DSS are only a partial outcome of decision making.

### *2.4. Decision outcomes*

The main aspects of decision making outlined above provide a setting in which a decision is made and a context in which support is provided and utilized. They provide a broader perspective for the decision phase model and indicate that there are results of the process other then a decision selected in the choice phase. Decisions are undertaken to maintain the organization's competitiveness, the productivity levels of the farm, improvement in the regional health care system or the reliability of a water supply system. They set the stage for future decisions. They also allow individuals and organizations to enhance and increase their problem solving and decision making knowledge. In this perspective, called the *knowledge-based view* (Holsapple and Whinston, 1996), decision making is a creation of descriptive and/or procedural knowledge.

The knowledge view of decision processes positions decision support as an activity oriented toward the manufacturing of new knowledge. This knowledge needs to be stored and maintained because it is used in future problem solving and decision making activities. The outcomes are represented by a set of values on the decision variables and a prescription for their achievement. They also include modification of the context caused by the decision making process and decision implementation, and learning and expertise gained from the process. In this view decision support is considered as both a part of organization-wide information support and knowledge management efforts.

## 3. Requirements and support functions

The discussion about decision makers, decision process, context and outcomes allows us to specify requirements for decision support and to describe specific functions that may be expected from support systems.

### *3.1. Fundamental requirements for decision support*

There are two fundamental requirements of decision makers that any support system needs to address: *simplicity* and *consistency* (Hill et al., 1982, p. 62-66). Simplicity is needed in selecting and organizing information. Human beings, whether operating as individuals or in groups, can access only a limited amount of information at a time. As Simon (1960) argues, decision makers bound rationality to derive structured, simplified depiction of the decision. Thus, the presentation of a problem within the DSS must be driven by the cognitive capabilities of the decision maker in order to provide information that is critical to the solution of a problem. At the same time the DSS should perform as detailed and comprehensive a computation as possible with the results communicated concisely and succinctly. All additional queries from the decision maker should be treated in a similar manner unless the decision maker wants to enter into a discourse with the system and understand its reasoning. In short, the DSSs must present a simplified version of the problem to the decision maker while maintaining its underlying complexity. At the same time it has to provide easy access to every mechanism used to allow for the verification of the mechanisms' role in the support process.

Consistency in decision making and support can be considered in three dimensions.

The first dimension includes *internal consistency* of data and representations and consistent application of procedures for representation construction and solution derivation. This is an obvious requirement and a prerequisite for simplicity.

The second facet deals with *needs-outcomes consistency*. The relationship between the decision maker's needs and outcomes is the cornerstone of decision analysis. Typically, it involves preference elicitation, alternatives' comparison or determination of a measure of decision quality. While there are numerous approaches for the specification and formal representation of needs, their explanatory power has been questioned (Tversky and Kahneman, 1981).

The third facet of consistency involves the relationship between various decision problems belonging to the same class. This is *inter-decisional consistency* and it reflects the history and expertise of the decision maker and the requirement to maintain consistency among needs and values that are part of the decision maker's personal context (Hill et al., 1982; Newcomb, 1953). With the shift of DSS support to the cognitive level it becomes more important for the system to exhibit inter-decisional consistency, taking into account needs in the decision maker's requests and requirements. Inter-decisional consistency can be achieved when a support system is viewed as a part of a larger organizational information technology infrastructure and its use and results are recorded in the organizational memory (knowledge).

### 3.2. Methodologies

The functional classification of support for decision making should be interpreted within the frameworks of Simon, Mintzberg, and others. This classification should also be positioned within the general taxonomy of information systems proposed by De May (1992). The purpose is to view decision support within a broader class of information systems that include human decision makers. Following De May we will define three groups of support methodologies.

1. *Monadic methodologies* involve pattern recognition with the use of simple or complex sets of procedures. There is no input analysis, as preprocessed inputs are compared to pre-defined templates. Monadic processing cannot deal with ambiguous inputs and cannot resolve conflicts. Query languages, text retrieval, graphs and data visualization are used to aid decision makers who have to define the scope and limitation of the presentations.

2. *Structural methodologies* involve analysis of specific aspects of information input and decisions as to its further processing. The input is decomposed and a structural analysis of its attributes is performed. Structural analysis allows the resolution of some ambiguities embedded in the input. It can also cope with the conflicting signals. Formal models (e.g., financial, econometric, optimization), are often used to support this function.

3. *Contextual methodologies* involve dealing with the ambiguities not resolved by the structural analysis. There are several possible interpretations of the input and no one can be chosen on the basis of the input alone. The only opportunity to determine proper interpretation is through an assessment of the context in which the inputs were produced and/or received. The key feature of contextual processing is that the inputs and their attributes are analyzed in a broader context outside their domain. Cognitive maps, goal seeking functions and sensitivity analyses can be used to support this function.

Monadic systems provide a variety of presentations of data and models with the use of different media, including text, tables and graphics. Data visualization techniques are successfully used to provide users with information about the organization, potential problems, and the environment. These techniques together with drill-down, drill-up, data slicing and other methods for problem recognition are used in the intelligence phase. In the design phase presentation methods can be used for model construction. Iconic presentations of model primitives allow users to build and view models. Similarly, decisions can be viewed, compared and evaluated separately and in a broader context.

While monadic systems facilitate data, model and solution analyses, structural support systems can conduct these analyses. On-line analytic processing, time series and other statistical methods are used to inform users about potential problems and areas of concern. Regression and log-linear models and modeling environments test model validity and consistency. Data mining methods are used to establish relationships among data and construct representations.

Contextual functions require the application of knowledge to interpret data, modeling efforts, and the implications of alternative decisions. Knowledge-based systems and learning methods are used to resolve ambiguities and to interpret and synthesize data and information. Software agents can represent decision makers and undertake specific decision tasks (Franklin and Graesser 1996).

A general approach to decision support requires that the cognitive predilections of the decision maker acting as the link between the needs fulfillment and circumstantial interpretation provide both a template for support and a limitation for its utilization. A decision maker is unlikely to use a DSS that is incompatible with his/her enacted environment either in terms of decision elements or decision processes. This does not imply that the decision support must be molded to the requirements of a specific decision maker but that it should be flexible enough to match a decision maker's cognitive and reasoning abilities. The support functions positioned in the context of Simon's model and De May's methodologies are presented in Table 1.

Table 1. Decision making phases, support methodologies and support functions

| | Intelligence | Design | Choice |
|---|---|---|---|
| Monadic | Presentation | Presentation | Presentation |
| Structural | Analysis<br>Verification<br>Representation | Analysis<br>Representation<br>Verification | Analysis<br>Representation |
| Contextual | Interpretation<br>Synthesis | Interpretation<br>Critique<br>Verification | Interpretation<br>Synthesis |

### *3.3. Model-oriented support*

Traditionally, decision support has been model-oriented. A decision opportunity or a problem identified in the intelligence phase led to the selection of a modeling technique. A model was constructed in the design phase and used to determine decision alternatives. To obtain alternatives model parameters were calculated with the use of data stored in databases and the user's input. This type of support is centered on user-model interactions

The sequence of key activities in model-oriented support is presented in Fig. 2. The interaction between the decision problem (opportunity) and the model describes activities of model selection and fitting. The data is used inasmuch as it is required to obtain model parameters.

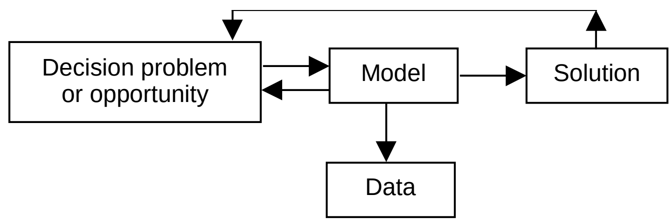


Figure 2. Model-oriented support sequence

Many of the applications presented in Part 2 use model-oriented support (Chapters 5, through 10). Models are used to obtain optimal or efficient decision alternatives, to search through the set of feasible solutions for alternatives with specific characteristics, to conduct sensitivity analyses, and so on.

### *3.4. Data-oriented support*

Model-oriented support assumes that models exist prior to decision making activities. Developed by researchers and analysts, they are embedded in a support system. In contrast, in data-oriented support no model as given, rather it is constructed from the analysis of available data. Data mining and knowledge discovery techniques (see Chapters 13 and 18) are used to extract knowledge and formulate models. This approach depends on the availability of large datasets, often stored in a data warehouse. The sequence of key activities in this type of support is given in Fig. 3.

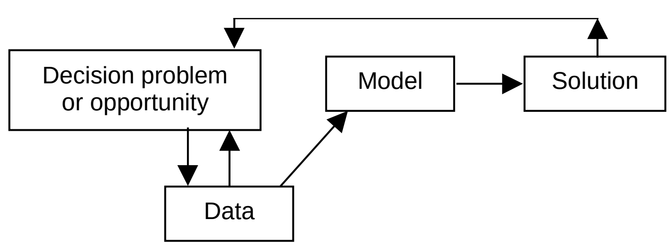


Figure 3. Data-driven support sequence

The realization of a decision problem or opportunity may initiate model construction. This type of support, however, may be initiated by the user but it may also originate with the the system itself. A routine analysis conducted, for example, by on-line analytic processing may indicate the existence of a problem and invoke an extensive data analysis with statistical and other data mining techniques leading to model construction and problem formulation. Only at this stage will the decision maker may enter the process of finding a solution to the problem.

We expect that in future the two types of support will merge. Models generated by data mining techniques will be tested and validated. They can be used to determine parameters for other models or be included in models of an organization, its unit or of a complex activity.

## 4. Decision support systems

Decision makers' requirements are met with different types of information systems. Management information systems, database management systems (DBMS), on-line analytic processing (OLAP) are just a few examples of systems that provide information used in decision making. It has been suggested that DSS address some or even all of the key requirements.

### *4.1. Definitions*

Decision support systems (DSS) are computer-based systems used to assist and aid decision makers in their decision making processes. Because of the continuously growing number of different types of computer-based systems it is important to distinguish among them and position DSSs within the family of information systems used by decision makers. Little (1970), in one of the earliest works on computer-based decision support, proposed that a DSS be “a model-based set of procedures for processing data and judgments to assist a manager in his decision making”.

From the inception of DSSs, it has become clear that they aid and assist decision makers but do not replace them. This feature distinguishes a DSS from other IS. Some IS replace decision makers in well structured, routine and recurring decisions; others are used to verify, record or extract data. Keen and Scott-Morton (1978) note that DSS play a different role and propose the following definition:

> “Decision support systems couple the intellectual resources of individuals with the capabilities of computers to improve the quality of decisions. It is a computer-based support for management decision makers who deal with semi-structured problems.”

Moore and Chang (1980), define a DSS in terms of its features and use. They view a DSS as a system that is extendable, capable of supporting ad hoc analysis and decision modeling, oriented towards future planning, and of being used at irregular, unplanned intervals.

Bonczek, Holsapple and Whinston (1980), define DSS in terms of its components. A generic DSS consists of a language system for communication between the user and the DSS, a knowledge system containing problem domain knowledge consisting of data and procedures, and a problem processing system consisting of programs capable of solving decision problems.

The difficulties with defining DSSs were recognized already at the early stage of their introduction. Sprague and Carlson (1982) note that some definitions are so restrictive that only a few existing systems satisfy them, while other definitions are broad so that they include almost all computer systems. Systems for extracting, summarizing and displaying data are also viewed as DSSs (McNurlin and Sprague, 1993). This led Naylor (1982) to observe that "… it seems that virtually every computer hardware and software firm in the industry refers to its products as DSS". This statement is even more justified today as DSSs have gained much popularity and software companies use it as a marketing attribution that indicates their product's innovative character and ability to solve complex managerial problems.

It is clear that DSSs are used to support decision processes as do management information systems (MIS), database management systems (DBMS), on-line analytic processing (OLAP), and also some knowledge-based systems (KBS). All these systems may support decision makers on-line and in an interactive mode so that this feature does not distinguish DSS from other systems.

The main difference between DSS and other information systems lies in the model component: formal quantitative models are an integral part of a DSS (Emery 1987; Bell 1992). These models, for example, statistical, simulation, logic and optimization models, are used to represent the decision problem; their solutions are decision alternatives. However, the model need not be defined a priori but may be constructed during the decision making process. Following the two orientations in decision support introduced in Section 3, we distinguish two types of DSS: *data-oriented* DSS and *model-oriented* DSS.

Dhar and Stein (1997) distinguish between data-driven and model-driven DSS. However, they consider simple aggregation models, query and reporting tools as DSS data-driven systems. We view these systems as a modern version of MIS rather than DSS. While they are helpful in managerial work, including decision making, they are not specifically designed for oriented toward providing support. The inclusion of SQL, OLAP, and other tools used to access and present data would lead to lack of distinction among information systems as most, if not all, provide data that can be used to make a decision. In our view, data-oriented DSS are used to construct models and obtain knowledge about decision problems rather than simply condensing and summarizing large amounts of data (Dhar and Stein 1997, pp. 30-51)

Beulens and Van Nunen (1988) reiterate that a DSS enables managers to use data and models related to an entity (object) of interest to solve semi-structured and unstructured problems with which they are faced. This view allows us to incorporate some of the functions of DBMS and MIS in a DSS. It also emphasizes that a DBMS is an important component of a DSS which also needs reporting capabilities. This is because data used to determine the parameters of a decision model needs to be analyzed and verified. A decision maker requires facilities to extract and view data describing an entity or an object to be able to verify and possibly modify the parameters. While DBMS and MIS are used to provide information about past and present, a DSS is used to determine decisions that will be implemented and will produce outcomes in the future. Thus, the decision maker may need to use models to extrapolate data and obtain a description of the future state of an entity or of an object of interest.

### *4.2. Functional and performance requirements*

From the viewpoints and definitions presented above, we can determine specific characteristics and properties required of a DSS. A support system is used to analyze a problem, determine alternative decisions and select one. Historical data and models are used to generate and evaluate forecasts and decision alternatives. In other words, DSS are future oriented and used to determine the future course of actions in dynamic environments.

Future states and situations can be predicted and assessed only with uncertainty. This requires generating several alternatives or scenarios and imposes a requirement to evaluate the consequences of the alternatives, simulate future situations and provide answers to ‘what-if’ questions. Alternatively, the user may require a 'goal-seeking' capability, in which the system searches for decision alternatives that can satisfy certain criteria. Sensitivity analysis is also needed to determine the impact of parameter changes on solutions. This approach requires that the robustness of models and procedures be analyzed. This, in turn, imposes a requirement that the solution procedures be efficient and able to generate necessary decision alternatives and to perform sensitivity analysis.

DSS systems often require user involvement in the construction of problem representation and model verification. They also require direct user involvement in the analysis of the decision problem, evaluation of decision outcomes and preference specification. These activities involve subjective judgments and, therefore, a DSS should focus on effective support and not on automatic selection. A DSS, to be effective, needs to be flexible and adaptable to changes in the decision making process and in user requirements.

A DSS participates in the decision process which is controlled and coordinated by the user. Active user involvement requires that a DSS be user friendly and cooperative. This is important in case of episodic or fragmented usage. User involvement also requires that a DSS be well integrated in the decision making process. The implementation of a DSS heavily affects the decision making organization and its procedures and, therefore, needs to be flexible and adaptable to changes in the decision making process.

Active user involvement in problem specification and solution also requires a DSS to support decision processes which embrace qualitative as well as quantitative aspects. The quantitative aspect of the problem may be well structured; it is its qualitative nature (including comparison, evaluation and choice) that makes the problem semi- or unstructured. Decision alternatives need to be judged by both quantitative and qualitative criteria. The use of qualitative and subjective criteria may mean that a satisficing solution is selected rather than an optimal one. This imposes a requirement on the problem solvers and procedures so that the user is able to inspect optimal (efficient) and non-optimal (non-efficient) solutions.

If a DSS is to aid and assist decision makers it must support one or more phases of the decision making process. The required information is provided by quantitative models and data that describe the entity (object) of interest in order to help identify problems or to generate, evaluate, and compare decision alternatives.

A DSS is used to generate, analyze and compare decision alternatives. Data and the parameters that are used to determine them need to be stored separately. We call the database containing alternative solutions and other information a solution base.

The evaluation of decision alternatives or scenarios requires their comparison which a DSS should facilitate. The user-system interface should provide facilities for model- and report-generation, and allow for multiple modes of information display.

We said that models are an important component of a DSS. Many systems are built "around" only one type of model (for example systems that incorporate only linear programming models). If a system is designed to support more than one phase of the decision process including the analysis of both data and solutions then a class of models may be required rather than just one. If the problem is semi-structured, only a part of the problem can be captured by one model and complementary models may be required. In these situations multiple models need to be integrated into the system in such a way that they can interact with each other.

### *4.3. Difficulties with DSS development and use*

The problems associated with building and using DSS partly result from the fact that some of the requirements discussed above are ignored or not fully met. Other problems include insufficient access to databases external to the DSS. This may be due to technical problems such as unknown data models, data models of different types or interfacing difficulties. Those problems may also be caused by badly designed data models and the lack of consideration for systems' interactions.

Many users of DSS have experienced difficulties in learning how to use a system properly and effectively. Beulens and Van Nunen (1988) list the following reasons for these difficulties:

1. the procedures to be used in the system have little in common with procedures or systems that users normally employ;
2. it is difficult to know the interdependencies of the functions provided by the system;
3. it is difficult to keep track of the consequences of a DSS function usage with respect to decision scenaria and the integrity of the database;
4. there are applications that require extensive knowledge of a specific problem domain or technical knowledge (for example optimization or forecasting models);
5. users have to deal with several databases and models, each with different data models and resulting translation problems; and
6. users may have to work on several decision scenarios at the same time. As a consequence they have to keep track of what they have done for each of them.

Model building for semi- and unstructured problems is difficult and requires considerable expertise. Therefore, they are often constructed by system analysts and MS/OR specialists and not by the managers who are the direct users of DSSs. This, however, may defeat the very purpose of the system since it may not meet the managers' requirements, and therefore, is unlikely to participate directly in the decision process. In this case, and also when the decision maker is a direct user, the model may be considered as a black box. A friendly interface (e.g., a graphical user interface and extensive reporting capabilities) does not alleviate the difficulty in the user's understanding of the model assumptions and the relationships between data, models and solutions even though it may make the system easier to access..

### *4.4. Generic DSS Architecture*

The specifications which the DSS needs to satisfy lead to recommendations with respect to the technical/architecture and functional aspects of the DSS. As we show in Fig. 4, the DSS has an architecture comprising of data components and software components. The data components include data, models and solution databases. It also requires a bank with dialog primitives that are used to compose interfaces.

The software components comprise a database management system (DBMS) capable of handling the databases, a model base management system (MBMS) to handle the model base and a solution (scenario) management system. DBMS and MBMS need a large array of data management and representation functions to manipulate the different databases as well as the model base. The solution management component needs a number of functions to generate and evaluate the decision alternatives and scenarios. The dialog system controls the display of information and the system's interaction with the user.

The traditional DSS "dialog-data-model" architecture (Sprague and Watson 1997), limits communication between the system's components and also the components' communication with external systems in ways independent of any pre-specified control mechanism (Kersten and Noronha 1999). A major problem with this architecture is that it does not have a plug-and-play philosophy.

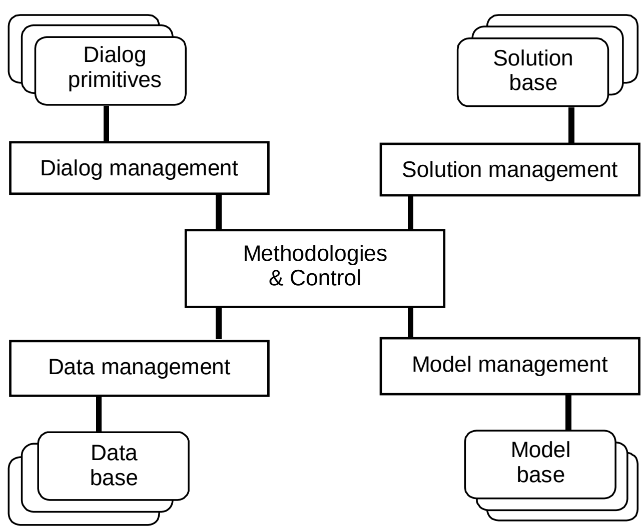

Figure 4. Generic DSS Architecture

A DSS system should be viewed and implemented as a collection of loosely-associated smart objects. Its design must always be open-ended and amenable to change. Many DSS systems, however, are weak in providing a methodology for change. Kersten and Noronha (1999) view system change as an upgrade in the attributes or behaviors of *individual* objects (occasionally, modules), independent of other objects or modules, rather than one synchronized change across the whole system. They propose a *methodologies and control* (M&C) component that allows for:

1. the situation-dependent use of different data analysis, modeling and visualization support methodologies (defined by available data, meeting specified constraints or requested by the user);
2. content rich communication between the user and other systems;
3. use of specialized models for dialog, solution and communication components, in addition to those used in the model management component; and
4. expandability in directions not necessarily envisaged by the developers.

The M&C component comprises knowledge about other DSS components, relationships among them, and their use. This component is used to activate other DSS components depending on the actions undertaken by the user and the system, the system's state and the actions it is to perform. Hence M&C allows for context-sensitive DSS behavior. It also enables the system to intervene actively in the process based on an analysis of the state of the "decision-making arena" (Angehrn 1993).

### *4.5. DSS methods*

Following Alter's (1980) classification DSSs have been categorized as: file drawers, data analysis, information analysis, accounting models, representational models, optimization models and suggestion models. Significant advances in computing and communication technologies, including methods for the development of problem representation, problem solving techniques, and computer and communication technologies, have rendered this classification outdated. Nevertheless, it is still being used to describe the DSS functions and methods (see, e.g., Sauter, 1997; Turban and Aronson, 1998).

Apart from being inadequate from a technological perspective, Alter's classification does not allow for the analysis of DSSs from an information provider perspective. This view implies that six corresponding general support categories should be distinguished (Zachary 1986).

1. *Presentation methods* are computer-graphic, voice and text processing tools to present data and information in a meaningful and suitable form. They are used to make data, information and knowledge used and generated by DSS accessible to the decision maker in terms of the decision maker's own mental representation of the decision process and context.

2. *Information management methods* are used to store, organize, retrieve and summarize data, information and knowledge providing timely and relevant information extending decision makers' ability to access it.
3. *Process modeling methods* are quantitative and qualitative models of real-world processes, and techniques to provide predictions of, and scenarios for, these processes at future points in time and under different conditions.
4. *Choice modeling methods* are used to select and combine decision attributes, define objectives and goals, determine preferences and trade-offs among objectives and utility or value functions. They are also used to determine preference consistency and remove cognitive biases by the consistent use of preferences and trade-offs.
5. *Automated analysis and reasoning methods* are mathematical and logical tools used to automate fully or partially analytical and reasoning activities. They are used to organize the decision process, provide expert knowledge and compensate for situational constraints limiting the unaided decision maker.
6. *Judgement refinement methods* are used to guide decision makers in their efforts, identify and remove systematic inconsistencies and biases that arise from human cognitive limitations. They include aids to structure decision problems, estimate probability distributions, analyze risk and check for consistency of the decision maker's reasoning.

The role of the methods listed above is to organize the technology base and give a framework for the system's functional specification. To establish close linkages between the different aspects of managerial decision making and organizational and individual needs and to position methods and aids in the overall system's architecture, each of the functions needs to be further defined and translated into detailed system requirements.

The six types of DSS methods include techniques and tools that can be used to provide specific decision support functions. In Fig. 5 we identify technologies that can be used to provide the required functionalities. This lists of technologies are not exhaustive but they indicate types that can be used in each category. New technologies are being developed and some existing ones cannot be neatly assigned to a single category (e.g., cognitive mapping and visual simulation).

## 5. Systems and organizations

We have mentioned that DSSs, in serving their users, interact and co-operate with them. Typically, the aspects of integration and co-operation are considered when enlarging the concept of information system so that it includes both the user and the tool in a human-machine system. If we consider cognizant systems, both human and artificial, then this enlargement seems too limited. Almost every complex entity can be designated a system, but there are some features of systems comprising intelligent entities that differentiate them from others. These systems are *organizations* and we attempt here to analyze the roles of DSS from the organizational point of view. We do not posit that a user and DSS form an organization; rather that an organizational perspective, and especially a cultural one, can highlight the requirements and modes of interaction and co-operation between users and DSS.

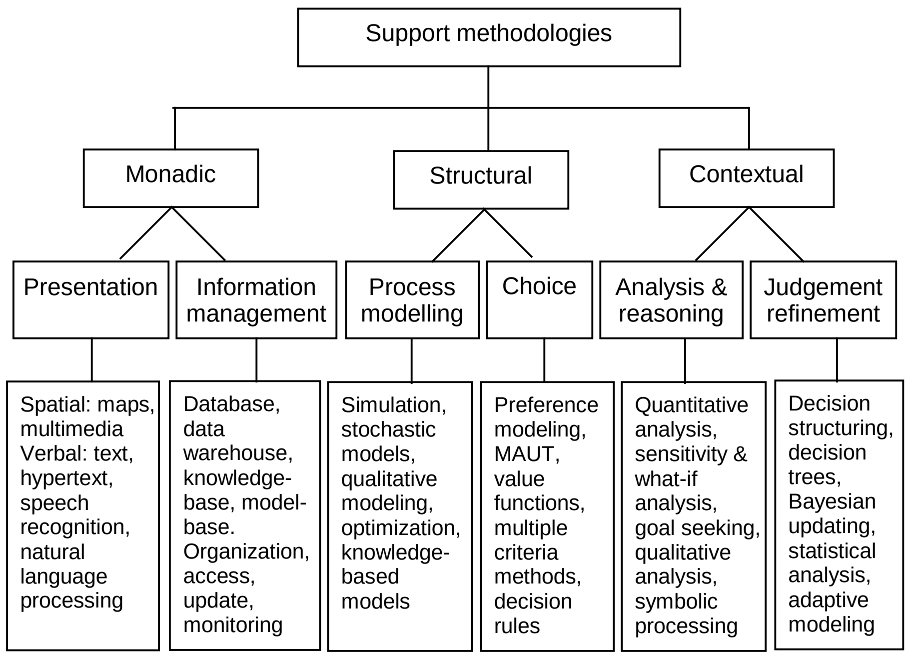


Figure 5. Information system, support categories and technologies

Organizations social units intentionally constructed to achieve a specific set of goals (Etzioni 1968). For our purposes we allow also other, than human, entities to participate in an organization and limit discussion to an organization consisting of the decision maker, i.e., the user and the DSS.

### *5.1. Bureaucratic DSS*

Bureaucratic Weberian organization (Mintzberg's machine bureaucracy) assumes clear-cut specialization of tasks, a hierarchy of authority, accountability, decisions made according to rules, standard procedures and efficiency. The role of the lower-level participants is to implement efficiently decisions of the higher-level authorities. These decisions are not verified, analyzed or evaluated at the lower level but taken at face value. There are clear, universalistic and impartial implementation rules for how these decisions are implemented. The intelligence of the lower-level is thus limited to the ability to use these rules efficiently.

This is also the role of many DSSs; they are used to formulate and solve specific and highly specialized problems with an *a priori* defined sequence of procedures.

These are monadic and structural DSSs. They cannot be used for any variation of the problem unless such a variation was earlier implemented as an option or the user transforms the problem so that it fits the system (e.g., a system cannot solve a minimization problem if it has been designed to solve only maximization problems). The system does not interpret or evaluate the input; it can only use its procedures or fail. Similarly, it does not make attempts to search for additional data if it cannot solve the problem as stated.

Monadic and structural DSSs, like bureaucratic organizations, perform well in well defined and predictable situations. They solve problems efficiently and provide solutions but only for clearly stated and clearly understood problems. Their provision of support for solving ill-structured problems lies in their ability to determine solutions for different parameter values through sensitivity and what-if analyses. A problem may be ambiguous or ill-structured only for the user, who has to present it to the system as a well-structured one.

This type of DSS may have led (Naylor 1982) to the claim that there was nothing new about DSS that does not already exist in MS/OR and MIS. Interestingly, there is almost no distinction in the DSS literature regarding systems that can be used only by specialists in OR/MS, decision analysis, finance, marketing—users who prepare analyses for the decision makers, and systems which can support decision makers. Perhaps, as Finlay and Martin (Finlay and Martin 1988, p. 530) state in their review, “chauffeured use of DSS is the one and only feasible way forward for most organizations” because decision makers are unable to communicate their needs to the computer. This situation has been also shown in empirical studies, for example, a survey of 580 DSSs in Canada (including file drawer systems and MIS) showed that less than 15% of the users were decision makers themselves (Huff et al. 1984).

### *5.2. Entrepreneurial DSS*

Entrepreneurial organizations (also called organic), are small, highly active entities without a clear and inflexible division of labor. They are focused on effective, but not necessarily efficient, use of resources for fast-breaking production developments in a dynamic and volatile environment. In these organizations the tasks are undertaken not according to hierarchy but expertise and current workload. Members of entrepreneurial organizations are often encouraged to be attentive to the environment, to search for problems and opportunities, and to perform various tasks and solve a variety of problems. In these organizations the exchange of information required for problem solving does not follow routine and fixed paths. Rather, individuals who may have relevant information or are able to provide expertise are co-opted and involved in the decision process.

If a DSS is to be used in such an organization then it has to be an active participant in the decision process. Such a system has a significant amount of autonomy in determining alternative actions and issues that the manager might have overlooked. This requires two independent processes, one directed by the user and the other under the DSS’s own control (Rao, Sridhar et al. 1994). In the user/system organization there are parallels to decision making by a group of specialists. They cooperate with each other to define a collective problem and to process problem structures and solutions.

It is obvious that such a DSS has to be contextual if not cognitive. This is because it has to be able to represent, analyze and solve the whole problem, not only some of its elements. While it is not necessary for the system to consider all the perspectives and models of choice it must be able to incorporate the user's perspectives in its processing activities. It must participate in the manager's construction of the cognitive perception of the problem. Monadic and structural DSS do not need to have this feature because the user's perspective is irrelevant or it is fixed and represented with one of the system's constructs (e.g., the objective function). Here, there are multiple perspectives and they may change requiring the system to accommodate variety and change.

Contextual and cognitive DSS, like individuals in entrepreneurial organizations, must have multiple capabilities. They need to be able to incorporate the user's needs and values in their processing, interact with the user on her cognitive level, present the problem in a meaningful way and use specialized (monadic and structural) tools. In an entrepreneurial organization communication encompasses all three levels of managerial problem solving. Therefore, the system needs to have similar capabilities.

## 6. Conclusions

The theory of decision support appears to be playing a catch-up with the real-life applications and with developments of computer and communication technologies. This is not to say that there is lack of different DSS frameworks and architectures. Our attempt was to select and organize views and models for studying support issues and to formulate prescriptions for DSS design and development.

The cognitive framework provided the basis for further discussion. This is in line with the knowledge-based perspective proposed by Holsapple and Whinston (1996). While they propose a somewhat different DSS architecture than presented in Section 4, we view these two architecture as complementary since both stress the importance of integrating a knowledge-based component.

There are many important issues not discussed here. The effect of culture in the international use of DSSs is significant especially if technologies are modified and systems adapted to specific local environments. Some of the architectural requirements posed by software internationalization are discussed in Chapter 15. Others include the impact of social traditions and values on the selection of decision variables and the relationships between models and cultures (Evans et al., 1989).

DSSs can be used by individuals and groups and in different settings. In Chapter 20 references are given to team and group decision support, negotiated and intra- and inter-organizational support. References to numerous real-life applications in several key areas are also given, complementing the theoretical focus of this chapter. The references clearly show that the DSS area is very active; plethora of systems has been developed in the nineties and used to support almost every type of decision problem.

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