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A process-oriented framework for the evaluation of managerial support systems

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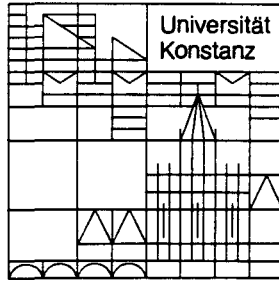
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A Process-Oriented Framework for the Evaluation of Managerial Support Systems

Diskussionsbeiträge

**A Process-Oriented Framework
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Serie I - Nr. 264

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A PROCESS-ORIENTED FRAMEWORK FOR THE EVALUATION OF MANAGERIAL SUPPORT SYSTEMS

**Rudolf Vetschera
Heinz Walterscheid**

1993-01-28

Abstract

We propose a new method for evaluating the benefits of decision-oriented information systems. This method is based on a detailed analysis of decision processes. Using prescriptive decision theory, correct results are established for different sub-phases of the process and possible deviations from these results are analyzed. Systems are then evaluated according to their contribution to the elimination of such errors.

1. Introduction

The evolution of information systems is moving from systems devoted to clerical routine tasks to the support of increasingly complex, unstructured decision tasks. Systems such as Decision Support Systems (Keen/Scott Morton, 1978), Expert Information Systems and Intelligent Decision Systems (Holtzman, 1989) are a rapidly growing area of research. For the purpose of this paper, we will use the term "Managerial Support System" (MSS) as a general expression for any kind of information system oriented towards managerial problem-solving in non-trivial problems. With the development of MSS's, the problem of evaluating and justifying information systems is becoming more complex and unstructured. While the impact of clerical systems can often be measured by means of direct or at least indirect cost reduction, the benefits of decision-oriented systems are much less tangible.

The problem of evaluating decision-oriented systems and especially of measuring their benefits, has already been recognized and dealt with in the earlier literature on DSS (Keen, 1981). As we will show in detail in the next section, process-oriented methods form an important branch of this research. These methods try to evaluate the benefits of an MSS in terms of its impact upon the decision process of the manager. However, this approach leaves the question open of whether a change in the decision process, induced by an MSS, is actually beneficial. Systems built from a "directed change" perspective (Silver, 1990) are designed to enforce a certain structure within the decision process. In this case, one can argue that since the change is based on a normative process model, it is by definition beneficial. However, an evaluation methodology must go one step further and determine whether the system actually achieves the desired changes to the decision process. The situation is even more complicated with systems which do not try to enforce a certain process structure, i.e. with "undirected change" systems, according to the classification by (Silver, 1990). Here, changes in the decision process must be inferred from system characteristics and then evaluated according to a standard provided by the evaluation method.

In this paper, we propose an evaluation methodology for MSS's which is based on a concept of the quality of decision processes. This concept allows us to evaluate possible changes induced in the decision process, as being more or less beneficial. By linking these process changes to features of the system under observation, we can thus evaluate the impact of an MSS upon decision quality, which in turn relates to the decision outcome.

The remainder of the paper is structured as follows: in section two, we provide a short review of methodologies for the evaluation of MSS's, which have been proposed to date in the literature. Section three gives an overview of our proposed methodology, which is

developed in more detail in section four. This methodology is based on a detailed model of the decision process and an analysis of changes to the process induced by certain features of the MSS. In section five, we provide an example of how this detailed analysis, as well as the linkage between system features and our model of a "correct" decision process, can be performed in order to obtain the basis for evaluation. Section six concludes the paper and provides an outlook onto further research topics.

2. An Overview of MSS Evaluation Methodology

In recent years, a considerable number of methods for the evaluation of MSS's has been developed. For previous reviews of research in this field, see e.g. (Keen/Scott Morton, 1978; O'Keefe, 1989; Adams et al., 1990).

Many methods proposed for the evaluation of MSS's are based on traditional cost-benefit analysis (King/Schrems, 1978). Standard cost-benefit analysis approaches encompass capital budgeting techniques, such as the payback method, the accounting rate of return, net present value and the internal rate of return. These methods interpret MSS's as investments to reach ex-ante determined monetary goals. This emphasis upon monetary goals constitutes both the strengths and weaknesses of traditional cost-benefit analyses. On the one hand, the concentration upon monetary goals can be seen as a strength, as these goals are directly related to the actual goal system of business users of MSS's. On the other hand, the emphasis upon monetary goals constitutes a weakness, as, in general, the relevant cash outflows and inflows of an investment project must be determined in order to apply cost-benefit analysis.

The identification and accounting of MSS cash outflows (e.g. for hardware, software, material and personnel) is often only possible to a certain extent. However, the main problem in applying cost-benefit analysis concerns the determination of MSS cash inflows. Only a few benefits of an MSS are directly measurable in monetary terms (e.g. cost savings). To other MSS benefits a monetary value can only be assigned by means of subjective evaluation or indirect methods. For example, productivity increases, arising from the introduction of information systems, can be measured by the hedonic wage model (Rosen, 1974; Sassone, 1987; Stickel, 1992). Benefits like increased productivity are, however, only a small part of the benefits usually associated with the use of MSS's (or as is claimed by the advocates of MSS's). Most other MSS benefit factors, such as a better understanding of problems, improved communication or better control of the decision process, are intangible. The measurement of such "soft" benefits in monetary terms is very difficult and often impossible. Since these intangible benefit factors must be included in an adequate MSS evaluation method, cost-benefit analysis, in its standard form, is not

regarded as suitable for the evaluation of MSS's (Keen/Scott Morton, 1978; Keen, 1981; Lay, 1985; Money et al., 1988).

Because cost-benefit analysis cannot be directly applied, some modified approaches have been proposed. These methods compare the net costs (including the benefits which can be expressed in monetary terms) to the remaining benefits of an MSS. The best known method is Value Analysis developed by (Keen, 1981), which consists of the following steps:

1. Establish the benefits the MSS must achieve and determine the maximum cost that one is willing to pay to obtain those benefits.
2. Build an MSS prototype (version 0) and assess the benefits and the costs.
3. If version 0 is accepted, establish the cost of a version 1, determine its benefit-threshold and build this version. If not, abandon the development.
4. Repeat step 3 until a full version n is reached.

According to (Sprague/Carlson, 1982) Keen's Value Analysis differs in three points from traditional cost-benefit analysis:

- MSS's are interpreted more as an R&D effort than as a capital investment.
- MSS benefits are considered first and the costs second.
- The risk of failure in the development and implementation of an MSS is reduced by requiring prototyping.

Keen's Value Analysis establishes ex-ante trade-offs between costs and benefits and is therefore more pragmatic than traditional cost-benefit analysis. However, this approach can be characterized as only "semi-formal" (O'Keefe, 1989, p.219). No method is provided by which costs and benefits of the systems at different levels can be specified and evaluated.

Another modification of traditional cost-benefit analysis is the graphical cost-benefit approach of (Shoval/Lugasi, 1988). This method also presumes that the costs and benefits for a set of information systems have already been established. It then provides a mechanism for establishing cost-benefit trade-offs. The selection of an optimal system is performed, taking into account the relative importance of the cost and benefit factors by maximizing the weighted sums of normalized costs and the corresponding benefits. Various ways of normalizing costs are presented and combined with the Eigenvector and utility models, thus considering, in addition, risk and uncertainty. The graphical cost-benefit approach of (Shoval/Lugasi, 1988) illustrates the great importance of the qualitative benefits

of an MSS and is thus a very flexible tool, once a measurement of benefits can be established.

Taking this research into account, there still seems to exist a "lack of a systematic framework for MSS evaluation which focuses on value" (Money et al., 1988). To evaluate these non-monetary benefits of an MSS, four kinds of measures can be used (Keen/Scott Morton, 1978; Akoka, 1981; Sprague/Carlson, 1982):

- **Productivity Measures:** Evaluation of the impact of MSS's on decision outputs
- **Process Measures:** Evaluation of the impact of MSS's on the decision making process
- **Perception Measures:** Evaluation of the impact of MSS's on the decision maker
- **Product Measures:** Evaluation of the technical merits of the MSS

Productivity measures are output-oriented and evaluate the impact of MSS's on decisions like the time to reach a decision, the cost of decision-making and implementation and the results of decisions made using the system. The impact of MSS's on decisions can be studied from a microeconomic production perspective, considering the information provided by the MSS as inputs and the decisions made, as outputs (Cooper, 1983; Mukhopadhyay/Cooper, 1992). This approach is based upon information economics and is only applicable to structured decisions. It also requires the relation between information inputs and decisions to be specified in a closed functional form. In contrast, the financially-oriented cost-benefit analysis and its modifications hypothesize that inputs affect outputs in some unspecified manner.

Process measures are based on the traditional definition and objectives of an MSS, i.e. the system assists managers in their decision processes. As it is impossible to directly evaluate the whole impact of an MSS on the decision (output) in a satisfactory way, it is necessary to examine the process leading to a decision and the changes which a system induces in that process. According to the different phases of a decision process, an MSS should be evaluated in respect to its potential for support (Adams et al., 1990). Since our approach is also based on this framework, we will provide a more detailed review of the relevant literature at the end of this section.

Perception measures are used to evaluate the impact of MSS's, as perceived by decision makers. Examples of perception measures are user involvement, control of the decision-making process, understanding of the problem, ease of use and usefulness of the MSS. Most of the literature pertaining to this approach is reviewed in (Swanson, 1982) and (Ives/Olson, 1984). The latter maintain that there is a particular need to develop and

validate standard measures for user involvement and information satisfaction. For two specific variables, perceived usefulness and perceived ease of use, scales have been developed and validated by (Davis, 1989). For most other variables used in this kind of evaluation method, a rigorous conceptual foundation is still needed.

Product measures have been developed, among others, by (Meador/Mezger, 1984), (Shoval/Lugasi, 1987) and (Le Blanc/Jelassi, 1989). These measures are used to evaluate the technical characteristics of an MSS. Examples are resource requirements, calculation speed, problem size, response time, availability etc. The advantage of technical criteria is that they are usually easily quantifiable. They are often used as necessary conditions in an MSS selection process. However, technical quality of an MSS is only one of several prerequisites enabling the system to support the organization's goals. The extent to which support can actually be achieved depends on a variety of other factors which are not measured by this evaluation methodology.

The four groups of evaluation criteria are related. Product characteristics influence process-oriented measures, because the amount of support provided by an MSS to different phases of the decision process partly depends upon the technical capabilities of the system. Outcome-oriented measures, in turn, describe the results of the decision process. The perception which a user has of a system will also strongly depend on how it affects his/her decision process. Process-oriented measures are particularly well-suited as the basis for an evaluation methodology because:

- They closely relate to and can therefore be used as proxy measures for productivity- and perception-related measures.
- They can also be connected to product-oriented measures by considering system features as inputs.
- As we will show in this paper, they can be more easily established than measures which directly try to measure the output of an MSS.

Despite the importance of the decision process in the classical MSS papers and the advantages of process-oriented evaluation measures, only a few authors have considered this approach in detail (Todd/Benbasat, 1987).

The first step towards a process-oriented evaluation methodology was made by (Pieptea/Anderson, 1987). They propose a graphical value-price gap analysis, which is based on a two-dimensional classification scheme for MSS's. One dimension of their framework consists of the three main phases of decision processes (intelligence, design, choice) proposed by (Simon, 1960), which was introduced as one category for the classification of decision support by (Lerch/Mantei, 1984). The second dimension of the

scheme by (Pieptea/Anderson, 1987) is based on a combination of four criteria (degree of decision structure, level of management activity, degree of uncertainty and source of information used). They consider these elements to be correlated and establish three classes of decisions. Based on this classification of systems, (Pieptea/Anderson, 1987) propose to use different kinds of evaluation methods. They argue that for systems supporting the intelligence phase and "class 3" decisions (highly unstructured decisions at the top management level with uncertainty, using internal and external sources of information) traditional cost-benefit analysis should be employed, while for systems supporting the choice phase and "class 1" decisions, value-based methods are more appropriate.

(Toraskar/Joglekar, 1990) found several contradictions and weaknesses in the framework developed by (Pieptea/Anderson, 1987) and the use of Simon's phases of decision-making. They reject equating the intangibility of benefits to the term "value-price gap" and argue that the true relationship between the phases of a decision process and the intangibility of MSS benefits is exactly the opposite of the proposal made by (Pieptea/Anderson, 1987), namely that, MSS's, used for the intelligence phase and class 3 decisions, have the highest intangibility of benefits. The application of traditional cost-benefit analysis is only feasible in situations of lowest intangibility (i.e. choice phase and class 1). Similar to (Lerch/Mantei, 1984), (Toraskar/Joglekar, 1990) find Simon's scheme unsuitable for a clear-cut classification of MSS's, because MSS's usually support more than one decision stage.

An explicitly process-oriented method for the evaluation of MSS generators was developed by (Adams et al., 1990). This method can be used as an ex-ante selection tool as well as an ex-post evaluation tool. A detailed model of the decision process, similar to (Mintzberg et al., 1976) is established and the relationship between different development tools, support characteristics and the stages of the decision process is analyzed. The main argument of (Adams et al., 1990) is that the criteria for the MSS selection and evaluation should be the amount of support provided by the MSS to the different phases of the process. They validate their model by means of a questionnaire from the users of two leading model-oriented MSS generators and conclude that the support provided by the systems which they considered is much higher for the choice/selection phase than for the intelligence/identification stage.

A similar approach to (Adams et al., 1990) is taken by (Buede, 1992) in a review of software packages supporting decision analysis. He proposes an evaluation structure with the three main criteria: performance, user friendliness and cost. The subcriteria used to evaluate performance are process-oriented and based on Simon's decision elements.

3. A Process-Oriented Evaluation Model

As we have already noted in the preceding section, the ultimate goal of evaluating an MSS is to determine improvements resulting from "better" decisions made using the system. Since this impact is not directly observable, we need to rely on other characteristics of the system in the evaluation process. This overall framework is depicted in figure 1: the decision process performed by the user results in a decision, i.e. a course of action being taken, which leads to certain results. As figure 1 illustrates, the decision process is influenced by various features of the system under evaluation. This relationship between the decision process and the system features is closely related to the three-tiered scheme for describing DSS, proposed by (Silver, 1988). The purpose of an evaluation methodology is ultimately to link the features of the system to changes in the results of the organization using the system. To do so, we need to trace the effects of the system through all the stages shown in figure 1.

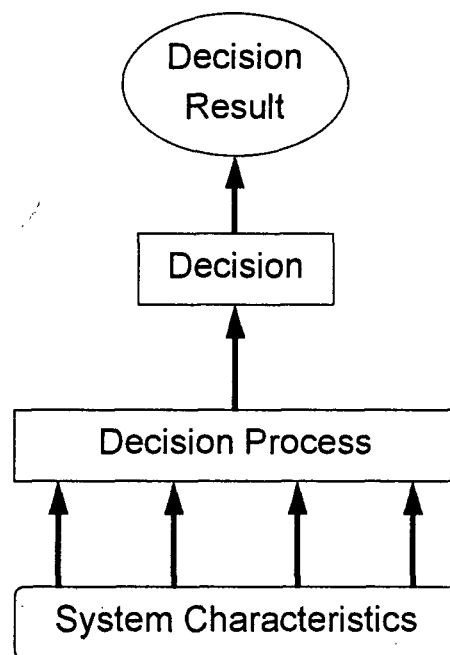


Figure 1: Overall Framework for MSS Evaluation

In order to evaluate an information system, we firstly have to evaluate the decision process induced by that system. From figure 1, it is clear that a "good" decision process is one that leads to "good" decisions, which in turn produce "good" outcomes. Our evaluation methodology is therefore not based on the structure of the decision process itself or its elements, but rather on the outcome of the process, or, more specifically, on the outcomes of individual steps within the decision process. Evaluating a decision process by analyzing the outcomes of individual phases, rather than by looking at the actions performed within the phases, also has the advantage that the definition of a "good" decision process can be based on theoretical concepts from prescriptive decision theory. Prescriptive decision

theory provides an axiomatic definition of rational decision making in various contexts, against which the outcomes of a given decision process can be measured. No comparable concept exists regarding the definition of a rational decision process and the actions one should take in such a process.

One cannot expect actual decision processes, whether supported by an MSS or not, to lead to exactly the results required by prescriptive decision theory in all instances. To measure the impact of an MSS upon the decision process, further steps are needed. When comparing two decision processes, we can say that one process is better than another process if it is more likely to produce a result closer to that required by normative decision theory. The purpose of an MSS can therefore be seen in reducing the possibilities of "errors" (in a very broad sense), which would cause a process to generate incorrect results.

The specific view underlying our MSS evaluation methodology is represented in figure 2. Actual decision processes will usually be different from and produce different results to an "ideal" decision process. The methodology proceeds by analyzing potential errors, i.e. differences between the results of the two processes and the possible sources of such deviations for individual stages of the decision process. The features of an MSS are then evaluated according to their ability to reduce the possibilities of such errors.

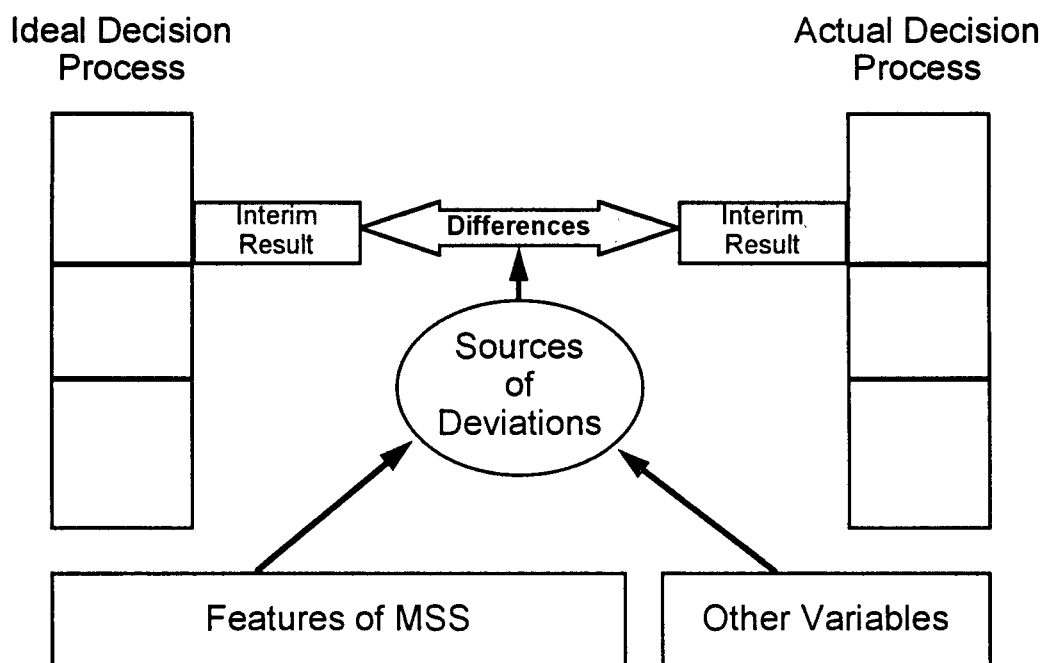


Figure 2: MSS Evaluation Based on Comparing Actual and Ideal Decision Processes

4. Components of the Evaluation Model

In order to perform such an analysis, we have to break down the entire decision process into distinct phases, thus facilitating the establishment and analysis of prescriptively correct results.

4.1. Decision Process

In the literature, several models of the decision process were proposed, dating back to the now classical work of Simon (Simon, 1960), who structured a decision process into the three main phases of *intelligence*, *design* and *choice*. For our purpose, we use an extension of the Simon framework which is based on the work of (Mintzberg et al., 1976). An overview of this model is given in figure 3. It should be clearly noted that, even though the components of the decision process are called "phases" in accordance with most of the existing literature, we do not intend this model to represent the time structure of the decision process. The sole purpose of structuring the decision process is to isolate different sub-activities during the decision process, which can then be matched to prescriptively derived "correct" results and evaluated. For the purpose of this evaluation, it is not necessary that the activities be carried out in some specific order. They can also be carried out simultaneously, if logical consistency permits.

Given this purpose of the model, the main criteria used in differentiating sub-phases of the decision process is their amenability to different types of support and the possibility of identifying specific correct results for each sub-phase. Especially with regard to the second aspect, the formation of sub-phases can be guided by considering the different spaces in which different activities take place during the decision process. Following traditional prescriptive decision theory, we distinguish between the *control space*, defined by the variables under control of the decision maker, the *goal space*, defined by the criteria which the decision maker uses in evaluating different courses of action and a *value space*, in which the individual preferences of the decision maker are taken into account.

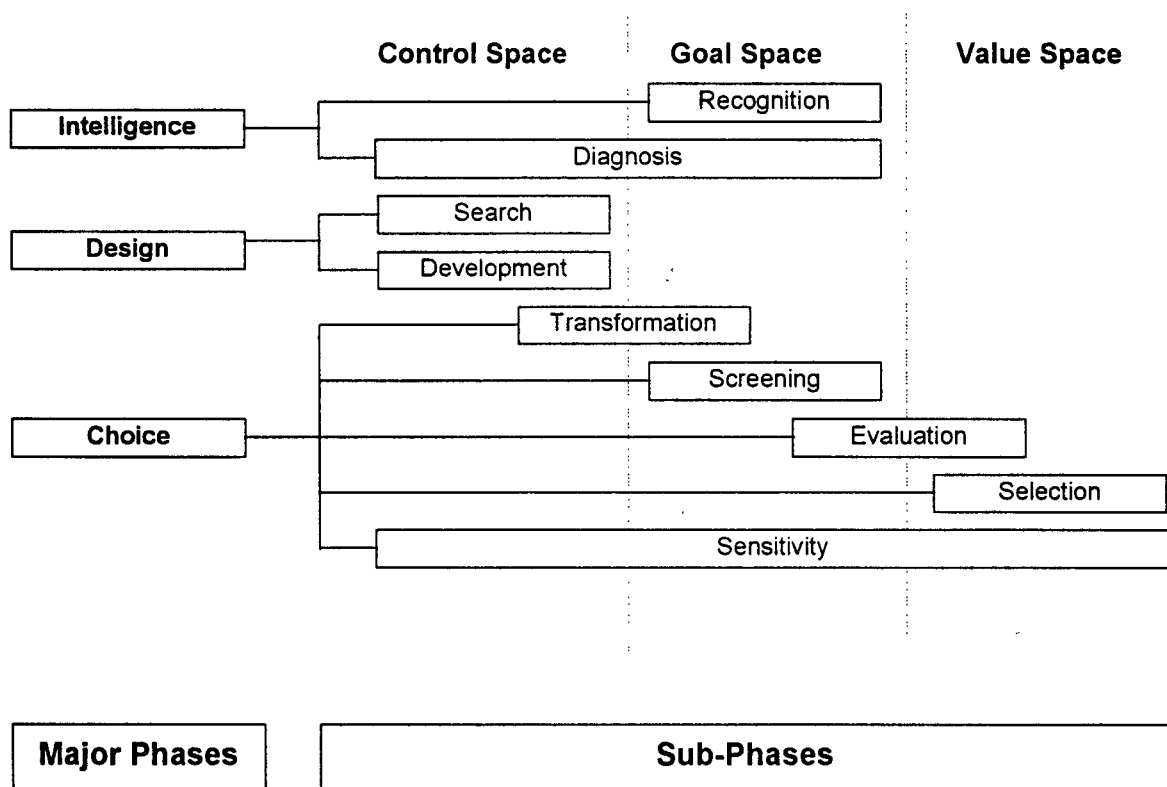


Figure 3: Overview of the Decision Process Model

In the intelligence phase, a problem which requires action is identified. We separate this phase further into a *recognition* sub-phase, in which a problem is detected by observing certain symptoms (e.g. a difference between observed and planned data) and a *diagnosis* sub-phase, in which the precise nature of the problem is identified. Since the recognition phase is mainly concerned with the identification of differences between the actual and the planned achievement of goals, it can be carried out entirely in goal space. In the diagnosis phase, in which the problem is analyzed in more detail, relevant decision variables pertaining to the problem are identified. This phase therefore links the goal space to the control space.

During the design phase, possible courses of action to remedy the problem are generated. This phase takes place exclusively in control space. Each candidate solution created in this phase corresponds to a set of values for the relevant decision variables. We further distinguish between the *search* for existing solutions, e.g. for solutions which were previously employed in solving a similar problem and the *development* of new solutions, i.e. combinations of values of the decision variables which were not considered before.

The structure of the choice phase of our process model is closely based upon the structure imposed by prescriptive decision analysis. Since most of this phase takes place in goal and value space, the first sub-phase is the *transformation* of decision alternatives from control space to goal space. In this sub-phase, the plans of action developed in the design phase

are evaluated according to their contribution to reaching the decision maker's goals. In the next sub-phase (*screening*), inefficient alternatives are eliminated. This operation can be performed in goal space, without taking into account the decision maker's preferences. These preferences enter the process in the next sub-phase (*evaluation*), in which the alternatives are mapped further into value space where the actual *selection* takes place. Finally, *sensitivity analysis* is an activity which spans all three spaces involved.

In the next subsection, we will study these elements of the decision process in more detail, identify correct results postulated by prescriptive decision theory for each step and analyze possible deviations.

4.2. Normative Results, Deviations and System Characteristics

4.2.1. Intelligence Phase

The goal of the intelligence phase, with its two sub-phases recognition and diagnosis, is to indicate whether a decision problem actually exists and to provide a classification of this problem. This phase has no corresponding element in prescriptive decision theory, so we cannot directly apply results from this theory. Nevertheless, our analysis of this phase will take into account the requirements of prescriptive decision theory concerning the phases which follow the intelligence phase, for example, the necessary completeness of alternatives.

The output of the recognition phase is a single binary value: whether a problem exists warranting further consideration or not. Logically, therefore, two errors can be made during this phase: "yes" can be replaced by "no" and vice versa. In the first case, an actual problem is not recognized, while in the second case, a problem is seen where none actually exists. The purpose of an MSS in this phase is thus to reduce the probability of both kinds of errors.

In order to estimate the possible influence of an MSS upon these error probabilities in more detail, it is necessary to structure the recognition phase further. A managerial problem can be defined as a significant deviation between planned and realized values in goals of importance to the decision maker. Such a deviation might already exist or it may occur in the future. Assuming that the set of important goals has already been established, the decision maker (or the support system) therefore has to perform the following steps in order to determine whether a problem exists.

1. Obtain the planned values.
- 2a. Obtain the actual values or
- 2b. Forecast future values
3. Compare planned and actual/forecast values to determine whether a difference exists.
4. If a difference has been found in step 3, determine whether it is significant. A difference can be discarded as insignificant e.g. if it is small or if it has been caused by a unique random event which will not recur in the future.

These steps, in turn, can be traced back to elementary tasks like obtaining a specific value of a variable or identifying and comparing trends and patterns etc. Extensive empirical research exists, linking these elementary tasks to properties of an MSS such as the use of graphics of various types. In section 5 of this paper, we will present an example of how this research can be exploited for the purpose of MSS evaluation.

The diagnosis sub-phase is concerned with the specific classification of the problem, e.g. as a production problem or a marketing problem. In the general framework developed in figure 3, we can characterize a problem class by the subsets of control, goal and value spaces, to which the problem relates. The relevant subset in goal space has already been identified in the recognition phase: it is the set of goals in which a significant deviation takes place. The important output of the diagnosis phase is the relevant subset in control space: which variables can be manipulated by the decision maker in order to correct the problem? Once a problem has been classified e.g. as a capacity problem in production, variables in other domains (e.g. sales promotions) will no longer be considered in the decision process.

Again, two possibilities for errors exist: a relevant variable in control space can be overlooked in the diagnosis phase (e.g. a problem is considered as a capacity problem in production, but the possibility of obtaining a needed part from an external supplier is overlooked) or an irrelevant variable is included in the analysis. The task of a support system here, is to help the decision maker in identifying relevant relationships between variables in control space and their effects in goal space. Such relationships might either be built into the system and activated e.g. by applying a drill-down technique, or the system can either contain an internal knowledge base providing the relevant information or consult an external one.

4.2.2. Design Phase

The output of the design phase consists of a set of decision alternatives, which can either be previous solutions which have been retrieved (search sub-phase) or new solutions,

which must be generated (development sub-phase). These actions take place entirely in control space.

Prescriptive decision theory poses the requirement to generate an "exhaustive list of exclusive decisions" (Lindley, 1985, pp.5-6). The set of alternatives should therefore have two properties:

- It should be complete, i.e. it should contain all relevant decision alternatives.
- The alternatives contained in the set should be mutually exclusive, exactly one of them has to be selected.

The second criterion is always met if, as presumed here, decision alternatives are defined as points in control space representing certain values of control variables. If one set of values is chosen, all other values are automatically excluded. For our analysis of possible deviations from prescriptively correct behavior, the first requirement is more important. Similar to the recognition of problems in the intelligence phase, the recognition of alternatives in the design phase can fail in two ways: actual decision alternatives are not recognized or decision alternatives are proposed which do not exist in reality. While the interpretation of the first kind of error is intuitively clear, the second needs more explanation. The design phase is performed strictly in control space. Therefore, questions of effectiveness of proposed decision alternatives, which would require a mapping from control space into goal space, are not relevant here. A decision alternative, i.e. a set of values for the control variables, is still a (bad) decision alternative, even if it does not contribute at all to the achievement of the decision maker's goals (or the solution of the problem at hand). Even if we only consider control space, we have to take into account the possibility of constraints which a decision alternative has to fulfil in order to be feasible. The second kind of error therefore occurs if a decision alternative is generated in the design phase which violates some constraints, thus preventing its implementation in reality. If previous (successful) solutions are retrieved, they were feasible at the time of their first use. A violation can only occur in this case if either the evaluation of the proposed decision against the constraints or the constraints themselves have changed in the meantime. The function of an MSS, in this case, is to alert the user to such changes. For newly generated alternatives, the MSS should support the user in evaluating them with respect to constraints. Figure 4 presents a fault tree (Pate-Cornell, 1984) which develops the possible sources of error in the design phase and also relates possible errors to system capabilities. In this and all following figures, error nodes are represented by white rectangles. System capabilities, influencing the likelihood of such errors, are represented by shaded and rounded boxes.

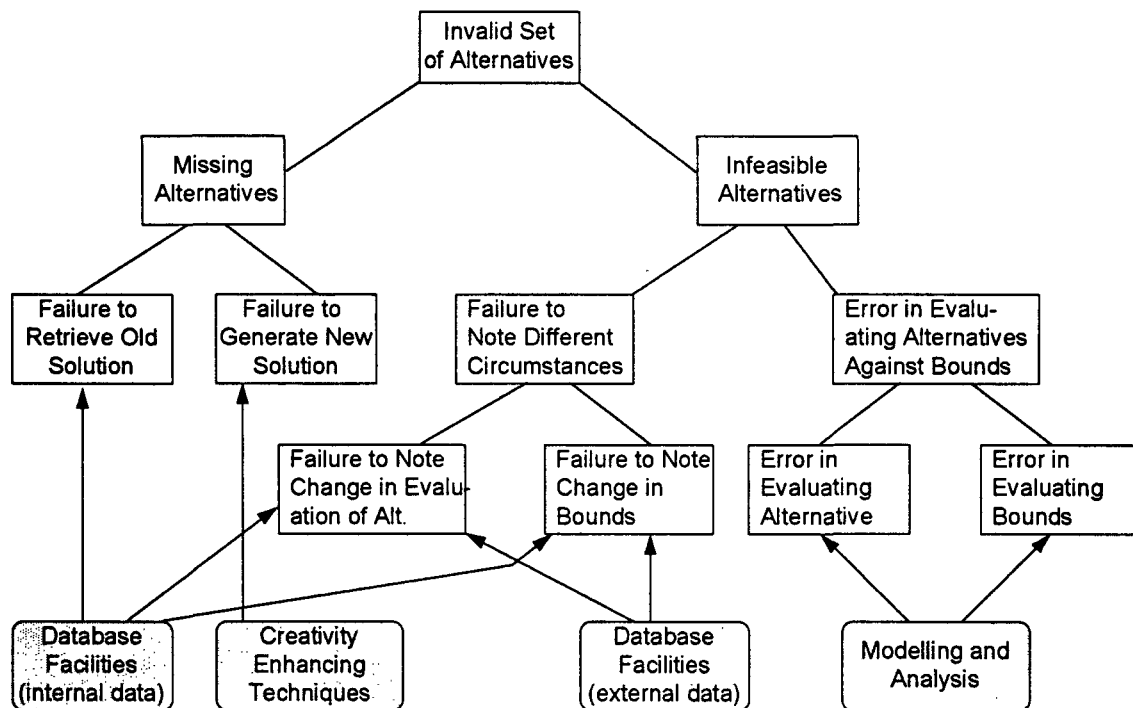


Figure 4: Fault Tree for the Design Phase

Figure 4 provides four examples of system capabilities which can influence the error scenario developed above: database capabilities, allowing access to internal data of the organization, can aid the decision maker in retrieving previous solutions to the problem at hand. This, in turn, helps to reduce the probability of overlooking an existing solution. Similarly, access to external databases might help the decision maker to identify solutions which have been developed elsewhere and which can either be applied directly or as starting points in developing new solutions. Support of creativity enhancing techniques such as morphological boxes can also aid in the development of new solutions. The creation of infeasible alternatives can be avoided by analytical capabilities for modelling and analysis which allow for rapid evaluation of alternatives against possible restrictions.

4.2.3. Choice Phase

As indicated in figure 3, the structure of the choice phase is more complex than that of the other phases. It consists of several sub-phases, linking in part, the different spaces involved. Table 1 provides an overview of the results which each of these sub-phases should generate, according to prescriptive decision theory. We will then discuss outputs of these sub-phases, potential errors and the possible influence of MSS's separately for all sub-phases.

Sub-Phase	Results
Transformation	Outcomes of the decision alternatives with respect to the goals of the decision maker, possibly in the form of probability distributions.
Screening	Subset of efficient alternatives
Evaluation	Description of the decision maker's preferences
Selection	Optimal alternative, taking into account the data and the decision maker's preferences
Sensitivity Analysis	Information about the stability of results

Table 1: Sub-Phases of the Choice Phase and Their Results

4.2.3.1. Transformation

In the first sub-phase of the choice phase, the consequences of the decision alternatives previously developed for the goals of the decision maker are evaluated. In the language of prescriptive decision theory, this task corresponds to the construction of a decision matrix. This matrix should at least contain an evaluation of each decision alternative under consideration in each of the goals pursued by the decision maker. If these results depend on uncertain states of nature, each result itself will be a probability distribution. Evidently, an error is made in this phase if the consequences of an alternative are incorrectly estimated.

This sub-phase contains a wide range of opportunities for decision support. For the estimation of the consequences of a decision alternative, two kinds of analyses must be performed. Future external events must be forecasted and their interaction with the decision alternative must be modelled. A wide range of computerized methods for forecasting and evaluation can be used in this context.

On the other hand, it is rather difficult to develop a general analysis indicating which properties of an MSS will have an influence on the quality of this sub-phase. Specific techniques for forecasting and analysis, like time series analysis or discrete event simulation models, might be extremely beneficial for one kind of problem and completely useless for another one. The corresponding system features can therefore only be evaluated within a specific context.

4.2.3.2. Screening

In the screening phase, alternatives are discarded which are a priori inferior. Prescriptive decision theory requires the elimination of dominated alternatives. An alternative is

dominated if there exists another alternative, which is as good as the alternative under consideration in all criteria and strictly better in at least one criterion. Similar definitions can also be formulated for risky decisions, when different states of nature are taken into account.

Starting from this prescriptive requirement, we can again distinguish between two possible deviations: the elimination of alternatives which are not dominated and the failure to eliminate dominated alternatives. With regard to the outcome of the decision process as a whole, the first error is more severe than the second one, because the optimal alternative could be eliminated due to this error. If, on the other hand, dominated alternatives remain in the process, the effort required to carry out the subsequent steps will be greater, but the result will be the same as without the error (assuming that all subsequent steps are carried out correctly in both cases). The first kind of error therefore impedes the effectiveness of the decision process, the second kind of error its efficiency. A fault tree for this sub-phase is given in figure 5.

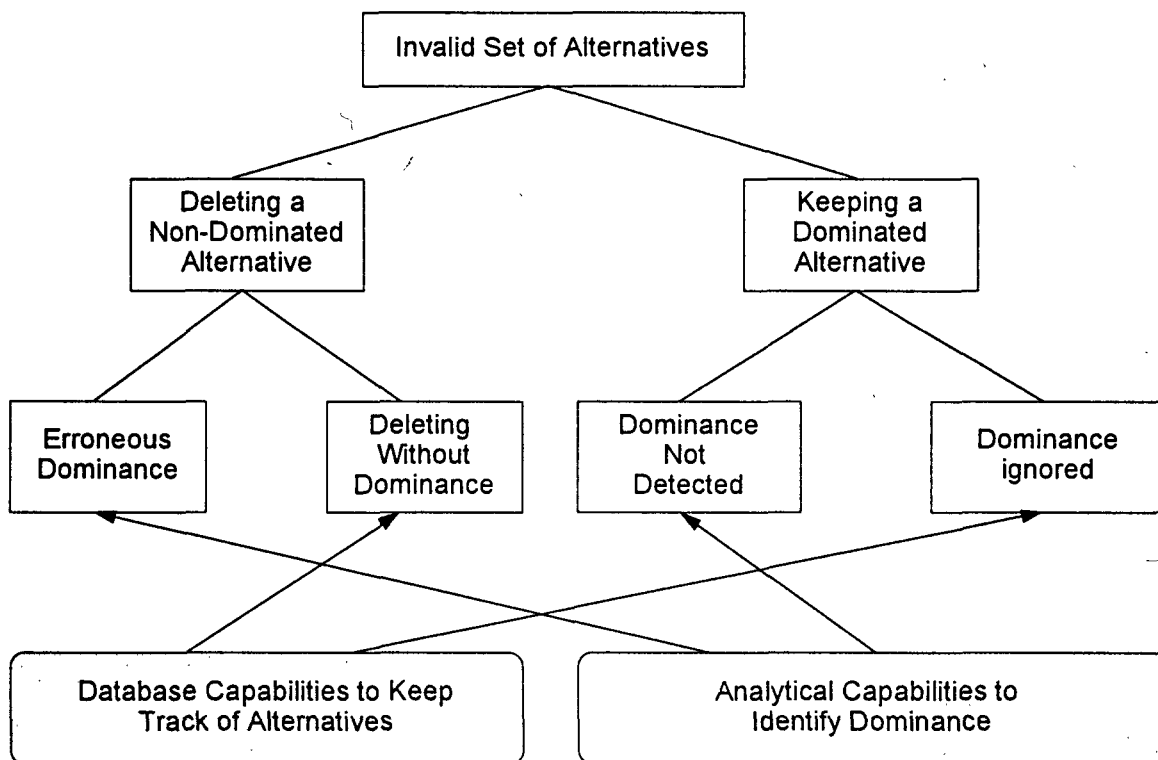


Figure 5: Fault tree for the screening phase

As also indicated in figure 5, two system capabilities are of importance in reducing these types of error: analytical capabilities of an MSS help to identify possible dominance relations between alternatives and database capabilities can be used to correctly apply the dominance relations which have been detected.

4.2.3.3. Evaluation and Selection

In the next sub-phase, evaluation, alternatives are mapped from goal space into value space by taking into account the decision maker's preferences. A number of software packages based on prescriptive decision theory have been developed for preference estimation (Humphreys/Wishuda, 1979; Jacquet-Lagrange/Siskos, 1982; von Nitzsch/Weber, 1988; Kimbrough/Weber, 1993) and also for the entire estimation and choice process (Vetschera, 1988; Logical Decision, 1989; Expert Choice Inc., 1990; Hämäläinen/Lauri, 1992; von Nitzsch, 1992). For a survey of these software packages see e.g. (Golden et al., 1986; Barba-Romero, 1990; Buede, 1992).

Empirical research, based on prescriptive decision theory, has identified a number of biases (Fraser et al., 1992) by which actual behavior deviates from the prescriptive theory, in the context of evaluation and selection. The purpose of an MSS in the evaluation and selection phases can be seen in reducing these biases (Weber/Coskunoglu, 1990), although few systems are designed in a way which explicitly tries to avoid such problems. If the system is not designed to counterbalance bias phenomena, it is even possible that the use of computer-based decision making tools, like those mentioned above, will increase the possibility or extent of a bias (Kydd, 1989).

A major problem of these two sub-phases is the methodological variety of approaches. Since no methodology is universally accepted, no theoretically correct result can be given. Within the framework of one methodology, however, the evaluation of a system's features, with respect to the elimination of errors, is still possible. However, since the requirements are rather different between evaluation methodologies, no general description of errors can be given and the development of specific analyses for several methodologies is beyond the scope of this paper.

4.2.3.4. Sensitivity

The purpose of a final sensitivity analysis is to determine the robustness of a decision against changes in assumptions made and parameters specified, during the decision process. The results of sensitivity analysis can have an immediate impact upon the solution chosen, when an optimal, but highly sensitive solution is replaced by a more robust alternative with slightly worse performance. However, even if sensitivity analysis does not have an immediate effect upon the outcome of the decision process, it might have an influence on the implementation phase. For example, stricter control might be exercised when implementing a sensitive solution than when implementing an insensitive one.

Errors in sensitivity analysis can again occur on both sides: a solution which is actually robust can be classified as sensitive and vice versa. In sensitivity analysis, changes in the

outcomes are related to possible changes in parameters. Errors in sensitivity analysis can therefore be traced back to misjudgements in these two changes, as shown in figure 6.

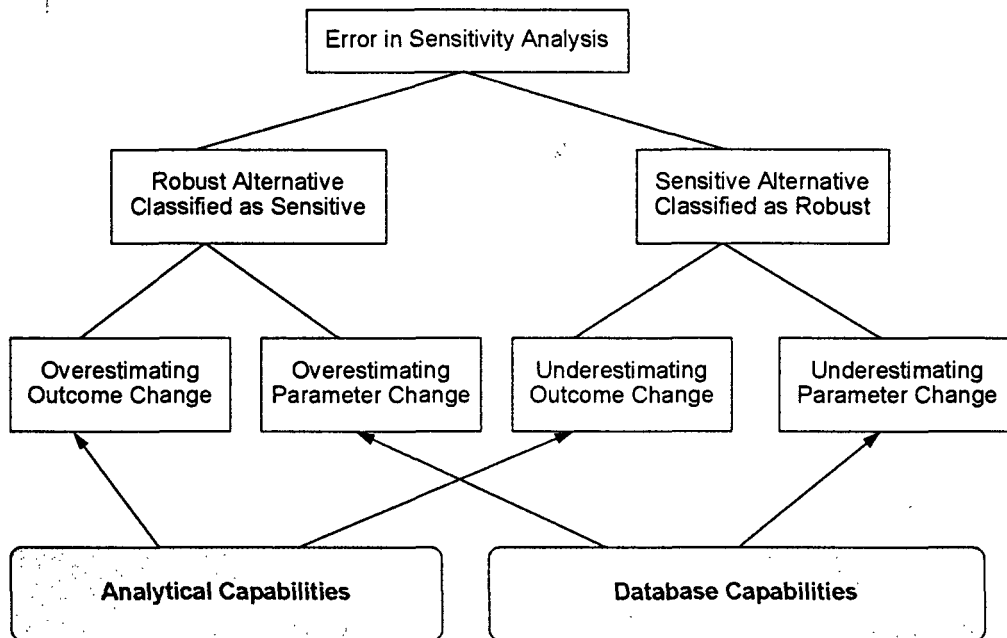


Figure 6: Fault tree for sensitivity analysis

4.3. Synthesis

A set of extended fault trees, like the one developed above, makes it possible to relate features of the MSS to possible improvements in the decision process. This relation is firstly established at the bottom level of each fault tree and is initially only qualitative. In order to establish a final evaluation of MSS design alternatives or products, two further steps are necessary:

1. The relations have to be quantified.
2. An aggregation has to be performed, first across the fault trees for each phase of the decision process and then across the phases of the process, in order to obtain an overall estimate of the benefits of an MSS.

In technical risk analysis, fault trees are evaluated using standard rules of probability theory: the probability of an error at the top level is derived from the individual probabilities of errors at the lower levels, taking into account possible dependencies between them. This approach is not feasible for our problem, since it would require information both on the relative frequency of the various errors analyzed and on quantitative, probability-based evaluations of the effects of MSS's upon these errors. Eventually, this information can be gained from empirical studies. However, such empirical studies do not exist for all the areas which need to be covered. In areas in which they do exist (e.g. user interface design), they

mainly provide qualitative guidelines, e.g. (Jarvenpaa/Dickson, 1988). Therefore, a different methodology has to be used for aggregation, which can build upon this weaker kind of information.

We propose to model the aggregation process, both within and across phases of the decision process, as a multi-criteria decision problem and to use a multi-criteria decision method. The use of several such methods has been proposed in the literature for selection problems concerning information technology, most notably the Analytic Hierarchy Process of Saaty, which was applied to the selection of IS projects (Muralidhar et al., 1990; Schniederjans/Wilson, 1991) and software products (Golden/Wasil, 1986). Other methods include multi-attribute utility theory, which was used for hardware selection (Brooks/Kirkwood, 1988); goal programming and related methods, which were proposed for system design (Jain/Dutta, 1986; Vlacic et al., 1986) and project evaluation (Lawrence et al., 1983) or screening methods (Le Blanc/Jelassi, 1989).

A detailed discussion of the various methods and their advantages or disadvantages for the problem at hand would be beyond the scope of this paper. At this point, it is sufficient to note that the methods mentioned above, as well as the additional methods developed in the literature (for a survey see e.g. (Vincke, 1992)), allow the aggregation of evaluations of alternatives in several criteria to an overall evaluation, upon which a decision can be based. The importance of the different criteria to the decision maker is taken into account by parameters of the chosen decision methods like criteria weights or aspiration levels.

In the context considered here, the top level criteria for evaluating the benefits of MSS design alternatives are the sub-phases of the decision process. While the importance of each sub-phase for the quality of the entire process cannot be measured in a completely objective way, some aspects can nevertheless be taken into account objectively. The evaluation can be based on an analysis of the existing decision process and its shortcomings, by means of which sub-phases can be identified, for which support is especially important.

5. Example: The Problem Recognition Phase

In the preceding section, we have outlined our evaluation methodology following the general process framework developed above. This presentation, due to the constrained space available, was limited to a broad conceptual analysis of possible influences which an MSS might have upon the phases of the decision process. In this section, we will show how a more detailed analysis, which actually links measurable features of a system to decision behavior, can be carried out. As an example, we will use the problem recognition phase and concentrate on system features relating to user interface design.

Figure 7 shows a section of a detailed fault tree for the problem recognition phase, in which we analyze causes which could lead to a deviation of planned and actual values remaining unnoticed. This can either be due to the actual deviation being overlooked or due to an error, either in retrieving the planned or actual data, or in forecasting. Failure to obtain the correct values can either be caused by a deficiency in the system's database capability, which causes the data to be unavailable or irretrievable, or by a problem in the user interface, so that the user is not able to obtain the correct values. Possible errors in comparison can be alleviated by automated comparison methods and also by a user interface which simplifies the task in question. Forecasting is also an important aspect of problem recognition, where several possibilities for errors exist. If forecasts are made using some formalized, model-based method, the system's ability to support the structuring task of model formulation, as well as to perform the required calculations and to retrieve the necessary inputs (possibly from external databases) are of importance. For intuitive forecasts, it is important to support the user in identifying trends or development patterns of variables over time and in obtaining exact values for making numerical forecasts.

Figure 7 indicates that the user interface is important for correctly performing several sub-tasks related to problem identification. These sub-tasks are the (precise) retrieval of single values, the recognition of patterns and trends, comparisons between values and patterns, recall of values and developments and structuring tasks. The effects of various design parameters in the user interface, most notably the use of graphics, have been the subject of considerable empirical research. Table 2 lists several empirical studies relating the efficiency and quality with which these sub-tasks are performed to user interface features, such as the types of graphs used, table formats, the use of color etc. It should be noted that this table contains studies with both positive and negative results concerning the suitability of a certain representation format for a given task. In most cases, the suitability of a certain representation for a certain task is also influenced by other context variables like characteristics of the user. It is therefore not possible to identify a "good" user interface for a given task in general terms. However, in the context of evaluating a specific MSS design in a specific environment, evidence like that collected in table 2 makes it possible to evaluate the features of the MSS in question. For example, consider the sub-problem of identifying trends for extrapolation in intuitive forecasting, which forms a part of the tree of figure 7. Table 2 shows that this area has been studied extensively. If we have to compare e.g. a system design which presents data in tabular form, with a system providing line graphs, the studies listed in the appropriate fields of table 2 indicate that for many users, line graphs will lead to better results. In this way, it is possible to relate system features to the overall quality of decisions and thus to estimate the decision quality effect of an MSS.

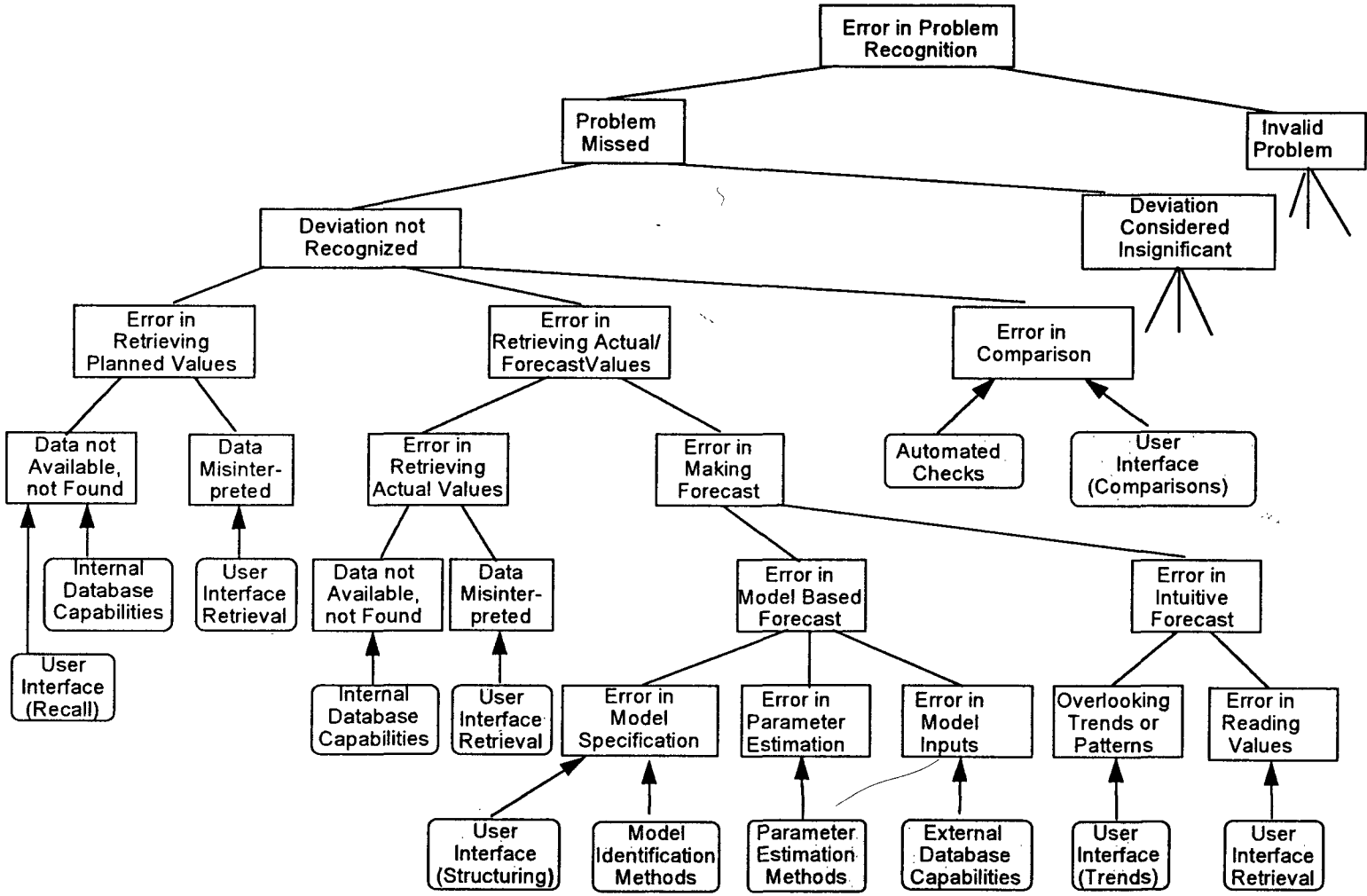


Figure 7: Fault Tree for the Problem Recognition Phase

Feature	Identification of patterns/trends	Retrieval of values	Comparison	Recall	Structuring
Tables	(Benbasat et al., 1986) (Dickson et al., 1986) (Casali/Gaylin, 1988) (Jarvenpaa/Dickson, 1988) (Sparrow, 1989) (DeSanctis/Jarvenpaa, 1989)	(Benbasat/Dexter, 1985) (Benbasat et al., 1986) (Dickson et al., 1986) (Jarvenpaa/Dickson, 1988) (Casali/Gaylin, 1988) (Sparrow, 1989)	(Benbasat/Dexter, 1985) (Casali/Gaylin, 1988) (Jarvenpaa/Dickson, 1988)	(Dickson et al., 1986) (Sparrow, 1989)	(Hauschildt, 1986) (Palvia/Gordon, 1992)
Bar charts	(Jarvenpaa/Dickson, 1988) (Casali/Gaylin, 1988) (DeSanctis/Jarvenpaa, 1989) (Sparrow, 1989)	(Dickson et al., 1986) (Casali/Gaylin, 1988) (Sparrow, 1989)	(Casali/Gaylin, 1988) (Jarvenpaa/Dickson, 1988)	(Dickson et al., 1986) (Umanath et al., 1990) (Sparrow, 1989)	
Line charts	(Dickson et al., 1986) (Benbasat et al., 1986) (Jarvenpaa/Dickson, 1988) (Sparrow, 1989) (Casali/Gaylin, 1988)	(Dickson et al., 1986) (Benbasat et al., 1986) (Sparrow, 1989) (Casali/Gaylin, 1988) (Benbasat/Dexter, 1985)	(Jarvenpaa/Dickson, 1988) (Casali/Gaylin, 1988) (Benbasat/Dexter, 1985)	(Dickson et al., 1986) (Sparrow, 1989)	
Pie charts	(Sparrow, 1989)	(Sparrow, 1989)	(Jarvenpaa/Dickson, 1988)		
3D charts	(Casali/Gaylin, 1988)	(Casali/Gaylin, 1988)	(Casali/Gaylin, 1988)		
Graphs in General	(Jarvenpaa/Dickson, 1988)	(Jarvenpaa/Dickson, 1988)	(Jarvenpaa/Dickson, 1988)		
Integration of graphs and tables	(Benbasat et al., 1986) (DeSanctis/Jarvenpaa, 1989)	(Benbasat et al., 1986)			
Color graphics	(Benbasat et al., 1986)				
Hierarchical Structuring					(Hauschildt, 1986) (Palvia/Gordon, 1992)

Table 2: Empirical Results to Evaluate User Interface

6. Conclusions and Topics for Further Research

In this paper, we have introduced a new methodology to evaluate the "soft" benefits of MSS's. Our methodology is based on several features which distinguish it from existing approaches:

- It is based on a prescriptive concept of the results of different stages in the decision process.
- It evaluates changes to the decision process induced by an MSS in terms of deviations from the prescriptively correct results.
- It provides a framework for incorporating empirical research on various aspects of system design into the evaluation process.

In the present paper, only a broad overview of our methodology has been provided. For actual application, the analysis has to be carried out at all stages of the decision process with a much finer level of detail. There is also a need for more empirical analysis, both in the construction of fault trees and in determining the effects of system characteristics on potential errors. The area of user interface design, which was used as an example in section five, has been studied quite intensively in the literature. Except for some empirical studies on analytical features and models (Aldag/Power, 1986; Sharda et al., 1988; Benbasat/Nault, 1990) and their user interface (Dos Santos/Bariff, 1988), other areas have received considerably less attention in the literature. Our framework provides an indication of the areas in which such empirical research is most needed.

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