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DEVELOPING A DECISION SUPPORT SYSTEM USING THE COGNITIVE FIT APPROACH: AN EVALUATION

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ABSTRACT

Decision support systems play a more and more significant role in today's business. Consequently, many important decisions at several levels within a company are based on the output of such systems. The objective of this study is to improve our understanding of the impact of this output on both decision accuracy and time, taking a practical point of view. In order to follow a scientific and structured approach towards this understanding the theory of the cognitive fit is used. Applying the theory, two of the most important output formats of decision support systems, notably tables and graphs, are compared within an existing business context.

1. INTRODUCTION

Information systems play an increasingly important role in today's business activities. At any hierarchical level within a company people use information systems to support their work and, maybe more important, their decisions. Information systems intended to support decisions are called decision support systems (DSS). The ultimate goal of such systems is to improve decision accuracy and to accelerate decision processes. In order to achieve this goal DSS summarize massive amounts of operational data and visualize this summarized data in various ways. The two most important visualization formats for numerical data are graphs and tables. Nowadays, due to advanced graphical user interfaces, a lot of attention is going towards the use of graphical representations. In the early days, data visualization was limited to tabular formats due to textual user interfaces.

Because it is our primary concern to improve decision efficiency, one of the main questions who comes to mind is which of the two visualization formats is preferable and under which circumstances. Clearly, the optimal display format will depend on the nature of the decision to be taken. To determine this optimal format we have to analyze the relation between characteristics of the decision on the one hand and the characteristics of the data representation format on the other hand. In order to understand the theoretical approach towards this key relation we have to take a closer look at the scientific domains called 'human computer interaction' (HCI) and cognitive ergonomics.

The HCI studies the communication between human beings and computer systems (Long & Whitefield, 1987). The goal is to optimize this communication in order to increase the efficiency at which men work with computer systems. It is important to see that men-computer interaction is not isolated but takes place in the context of the tasks that people have to accomplish. Task requirements such as execution time and accuracy determine the requirements for the men-computer interaction. Consequently, the optimization has to be done in the context of the tasks to be executed. This is a key point which can also been seen from Figure 1.

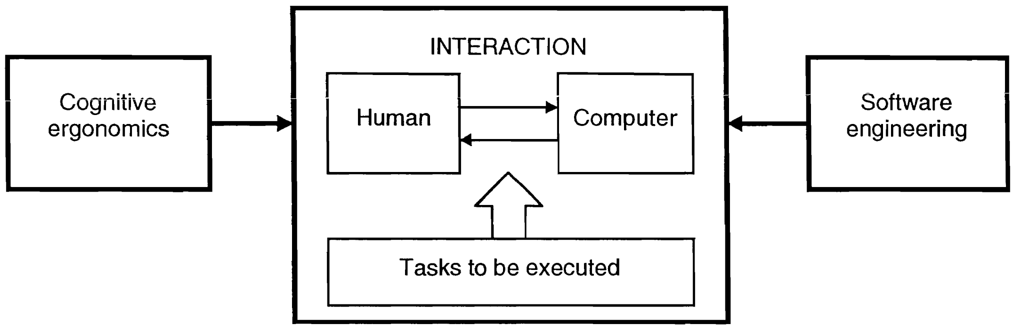

Figure 1. Elements of human computer interaction

As can be seen from the figure HCI can be considered as the intersection of two domains, software engineering and cognitive ergonomics. In fact, both domains look at the same human-computer interaction from a different, but complementary, point of view. Cognitive ergonomics studies the mental aspects of the interaction and specifies the representations and processes needed for an optimal interaction between the computer system and the users. In the context of cognitive ergonomics, representations refer to the mental representation of the tasks and the information system. Processes refer to the processes needed to use the known representations and to accomplish the tasks. Similarity between the representations and processes required by the interaction and those required by the task leads to improved interaction and increased efficiency. This specific similarity is called cognitive fit. This criterion of the cognitive fit will be used throughout the study and applied to graphs vs. table decision-making. This application of the cognitive fit will be discussed in more detail in the following section.

2. GRAPH VERSUS TABLE DECISION-MAKING AND COGNITIVE FIT THEORY

Because the comparative study of graphs and tables has already build up quite a history over the past 20 years, we first take a brief look at this history and its most representative highlights. In the second part of this section the theory of the cognitive fit will be presented.

2.1 Graph vs. table studies

Already numerous studies have addressed the graph vs. table problem in different ways over a long period of time (Remus, 1987; Benbasat & Schroeder, 1977; Lucas, 1981; Jarvenpaa & Dickson, 1988). Remarkably, each of this studies finds different results. This diversity of results and conclusions is not caused by poor experimental design, but rather by the complexity of the problem being studied itself (DeSanctis, 1984). When comparing the performance of graphs and tables in a decision context, a considerable number of factors, such as decision complexity and time pressure, play an significant role. Because the state of these factors differed widely from study to study the researchers came to varying conclusions. Consequently, more and more researchers came to the belief that only an theoretical approach towards the problem could lead to meaningful conclusions.

Iris Vessey was one of the first researchers, who managed to give a plausible explanation for the variety of results in Vessey (1991) and Vessey (1994). In order to analyze the already known results concerning graphs and tables in a theoretical way, Vessey based her analysis on the cognitive fit theory. Because a similar approach will be followed in this study we will explain some elements of Vessey's most recent study in detail in the next section.

2.2 Cognitive fit theory

The basic starting point of the theory is the cost-benefit analysis as known in economic theory. The cost-benefit approach can also be applied to graph/table decision-making leading to the following conclusion: 'Decision makers change strategy so as to minimize the joint cost of error and effort'. Otherwise stated, also in decision-making exists a clear trade off between effort and accuracy. The effort required to make a decision is determined by a number of factors, including the representation of the information needed to make the decision. It is this particular factor which makes up our concern. If we can determine which display format, in our case graph or table, is most suited for certain decision tasks we are able to improve decision accuracy and/or speed. Concerning those last two variables it is useful to keep the study of Todd & Benbasat (1991) in mind concluding that DSS are only used to gain time, not to improve accuracy. Whether this statement be true or false, it emphasizes the importance of time in decision-making.
The general model for problem solving on which the cognitive fit theory is based is given as Figure 2. According to this model the solution to a problem is the result of a relation between the problem representation and the decision-making task. The arrows relating the different elements represent the required cognitive processes. The mental representation is the way the problem or the decision to make is represented in the human brain and this representation is created by both the process extracting information from the problem representation and the process required to solve the problem. If the problem representation and the decision-making task emphasize the same kind of information, the decision maker is able to use similar processes to build a mental representation. The use of those similar processes results in a more accurate and consistent mental representation. In case the decision-making task and the problem representation are comparable there is a cognitive fit, in all other cases exists a so-called mismatch. In case of a mismatch a transformation of the problem representation or the decision-making task will be necessary to generate a valid mental representation. Because this transformation leads to decreased decision performance a mismatch has to be avoided. Remark, cognitive fit is not required to find a solution, but can facilitate the problem solving process substantially.

Important in the context of DSS are two results from the field of behavioral decision-making which strongly support the cognitive fit theory as described above (Long & Whitefield, 1987):

- Decision makers have the tendency to use only the information which is explicitly displayed and only in the format in which it is displayed. Information which needs to transformed or converted is often ignored.
- Researchers found out that decision makers often adapt information processing to the problem representation, even if they are completely free to chose the way in which information is processed.

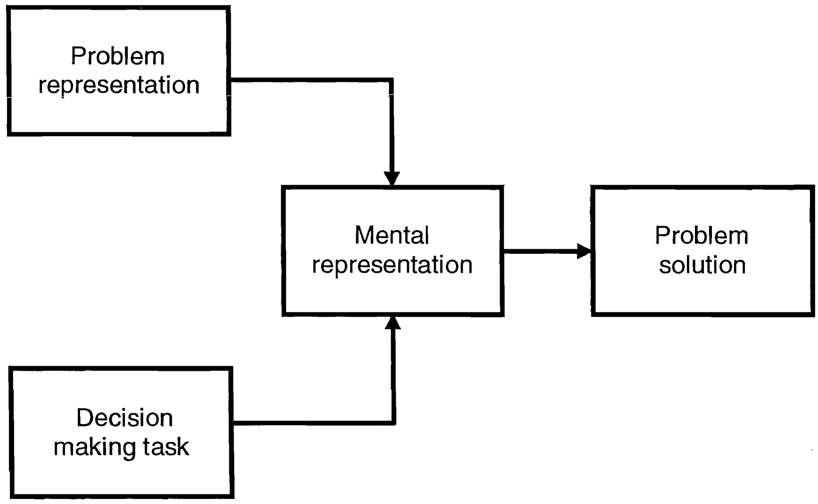

Figure 2. General model for problem solving with cognitive fit

2.3 Application to graph versus table decision-making

We now focus on the application of the cognitive fit to graph/table decision-making and determine the inherent characteristics of graphs and tables when used as information sources. These characteristics determine the nature of the cognitive process which is induced in the human mind and extracts the relevant information from the problem representation. Basically, a graph can be considered as being spatial and a table as being symbolic in nature. Graphs are spatial in nature because they relate spatially-related data elements. The emphasis is on the relationships in the data. On the contrary, tables emphasize discrete data values and facilitate extracting individual data values. Because of this different characteristics, different cognitive processes are used when extracting information from graphs or tables. Data in a graph are accessed using perceptual processes, data in a table are accessed using analytical processes. The three most important differences mentioned above are summarized in Table 1.

Graph	Table
Spatial in nature	Symbolic in nature
Emphasis on relations between data	Emphasis on discrete data values
Induce perceptual processes	Induce analytical processes

Table 1. Characteristics of graphs and tables

As can be inferred from Figure 2, the characteristics of the decision-making task are as important as those of the problem representation. If we are aware of the nature of the decision-making task, we can determine which display format, graph or table, will enable cognitive fit and lead to improved decision-making. So, in order to apply the theory of the cognitive fit, we have to know the characteristics of the decision-making task to be performed. In general the application of the cognitive fit theory is only possible if we can infer the nature of the decision-making task. Because the knowledge about the cognitive processes involved in decision-making tasks is still limited, the decomposition of decision-making tasks is very difficult. Consequently, the application of the cognitive fit theory is rather limited at the

moment and strongly depends on progress made in the fields like cognitive and decision sciences.
Because the goal of this study is to test the applicability of cognitive fit theory to real-world decisions the nature of these decisions has to be known. This requirement implies the experiments in this study will be limited to elementary tasks which involve only the acquisition of information. In the context of graph/table decision-making spatial and symbolic elementary tasks have to be identified. The difference between these two types of elementary tasks is clarified in Table 2.

Spatial	Symbolic
Problem area is viewed as a whole	Emphasis is on a specific aspect of the problem area
Making of associations and discovering relations in data	Finding precise data values
Comparison of sales trends in 1995 and 1996	Finding the sales amount of the first quarter of 1995
Via perceptual processes	Via analytical processes

Table 2: Spatial and symbolic elementary tasks

The reader undoubtedly notices the strong resemblance between the characteristics in the table above and those contained in Table 1. Taking in consideration this resemblance we obtain the following logical rule leading to cognitive fit in graph/table decision-making:

Spatial tasks are best supported using graphs.

Symbolic tasks are best supported using tables.

3. CASE STUDY

Before our findings concerning the usability of the cognitive fit during the development of a DSS will be presented in detail, a brief description is required of the context in which these findings were obtained and how they were obtained.

3.1 Decision context

The company chosen for the case study is a company active in the chemical sector developing products for both consumer and industrial markets. For both markets product quality is important and consequently a major goal for the company. In order to develop a new DSS, the context of quality control of chemical products was chosen. At a chemical plant quality control is done by an number of quality control labs. At our specific chemical plant we can distinguish quality control labs for the analysis of raw materials, intermediate products and finished products. In order to assure a high quality level these labs have to take a number of important decisions. The control lab responsible for the inputs for instance has to decide after a chemical analysis if a certain raw material will be used in production or not. If the quality of the product continues to be too low or unstable the lab has to initiate re-negotiations with the product deliverer. It is important that such decisions, however being rather simple in nature, are taken accurately and in time. In this context, the use of a DSS would certainly improve decision performance.

In order to build a useful DSS for the situation described above, information is needed about the decisions which are made in the area of quality control on the one hand, and about the data found in the operational databases of the quality control labs on the other hand. It is generally known that a good DSS can only be build on the basis of a well organized and maintained operational database because the data kept in the database should be transformed by the DSS in useful information. In our case the databases of the quality control labs contain the results of every single analysis done on raw, intermediate and finished products. This data is accessible by all staff involved in the quality control process and should enable them to take the necessary actions. The output of the database management system consists however of a number of reports containing a large number of figures in a format not suited for decision-making. The aim of the DSS will be to represent the data in graphs and tables adapted to the decisions to be made. Of course, a first and important step within the development cycle of a DSS is the identification and analysis of the decisions which have to be supported by the system.

3.2 Decision Identification and classification

In order to identify the information needs, the executives responsible of the three quality control labs were interviewed. The goal of these interviews was the identification of the current and future decisions vital to the quality control process. Not only the decisions were analyzed but also the circumstances in which they are made. As we will see further on, not only the nature of a decision but also the context in which the decision is made is important when determining the optimal information representation. In total about 15 important types of decisions were identified. Once the decisions are identified, the next step is to determine the best data representation format to support these decisions by applying the rules derived from the cognitive fit.

To make application of the cognitive fit theory possible, however, the identification of the sub-tasks and the nature of the sub-tasks which compromise the decision are required. This identification is most successful if the decisions are of middle or low complexity. Consequently, the decisions which will be supported by our DSS are situated at an operational decision level. More specifically, the set of decisions involving quality control contains decisions at the level of the individual control labs and decisions at the level of quality control in general. Because within the set of decisions some ones are similar, the number of decisions can be reduced to a number of relevant categories. There are a number of criteria to classify these decisions. Because we want to apply the cognitive fit, the best solution seems a classification on the basis of sub-task. The identification of sub-tasks is, as already been emphasized, not easy, especially in the case of complex decisions. So, if we are to apply cognitive fit during DSS development, we have to develop a comprehensible framework to classify decisions and, eventually, determine the optimal display format.

Looking at the previous graph/table studies, we can identify four important types of sub-tasks which we call elementary tasks. The characteristics of these elementary tasks can be summarized in the following way:

- Elementary tasks require one single operation on the data.
- Elementary tasks require the acquisition of information and/or the comparison of two data values.

- The nature of elementary tasks can be identified.
- Elementary tasks are the buildings blocks of more complex tasks.

Elementary task	Nature of task	Representation
Reading single data values	Symbolic	Table
Comparing data values	Symbolic	Table
Reading trends	Spatial	Graph
Comparing trends and patterns	Spatial	Graph

Table 3: Types of elementary tasks

The four types of elementary tasks listed in Table 3 constitute the base for the classification of decisions. Because all decisions within the same category require the execution of the same elementary tasks, the same display format will be used. The framework should enable developers to choose the most appropriate data representation, once the nature of the elementary task involved in the decision is known.

Reading single data values
The staff of laboratory raw materials checks daily the data entered in the database of all raw materials which have been analyzed by the lab.
Comparing data values
When a new load of raw materials arrives the lab staff decides if the product may be unloaded or not depending upon the quality of the product.
When a half-product does not meet the quality requirements the production lab has to decide if the running production batch will be discarded or not.
When the lab discovers that the quality of the finished products does not meet the quality standards, it has to decide if the product will be reprocessed.
Reading trends
It is the responsibility of the production control lab to correct the product formula if the quality starts to deteriorate.
At any moment the lab responsible for the raw materials can decide to re-negotiate conditions with the deliverer if the quality of the raw materials fluctuates heavily.
Comparing trends and patterns
The control lab has to decide which are the best performing deliverers comparing the quality of the raw materials over a certain time period.
An analyst may work for a number of control labs. The manager of the control labs wishes an overview of the performance to make decisions concerning the control team.
Complex decisions
The responsible for quality control has make decisions concerning the production process based upon the characteristics of the chemical input products.

Table 4: Classification quality control decisions

Note, the above reasoning is only valid in the case of simple decisions requiring one elementary task. Complex decisions require more than information acquisition and require the simultaneous execution of a number of elementary tasks. The next step is to classify each of the 15 identified decisions. A part of the resulting classification is given in Table 4 to give an idea of the nature of the decisions involved. Table 4 also contains an example of a somewhat more complex decision.

The classification of decisions as described above proved to be less straightforward than expected. In the following section a number of problems concerning the classification will be discussed.

3.3 Discussion of the classification

One of the problems encountered during the classification concerned the distinction between the reading en the comparing of data values. Because a comparison of values automatically includes the reading of those values, it is sometimes difficult to make the exact distinction. Note however, that it makes little or no sense to make a distinction between these two types of elementary tasks because both tasks are symbolic in nature and require the same representation format. The point we wish to prove here, is that the decomposition of a decision in elementary tasks if not a trivial exercise. Consequently, the question comes to mind whether we are obliged to analyze decisions at such a low level since we are solely interested in the distinction between spatial and symbolic tasks. Otherwise stated, are there classification criteria which are understandable to most system developers nature and whose state is readily identifiable? A possible answer to this question again can be found in the studies of Vessey.

In case of time pressure researchers noted that decision makers tended to prefer data representations which are less desirable in the context of the decision which has to be taken. This behavior is known in literature as a 'strategy shift'. In the case of a strategy shift, decisions are made without the existence of cognitive fit because of external factors in the decision environment such as time pressure. In other words, time pressure can result in a mismatch decreasing decision accuracy. In practice, it is sometimes more important to make a decision quickly instead of precisely. Whatever the effects of time pressure may be, the above empirical results emphasizes the importance of the factors time and accuracy. A classification only on the basis of elementary tasks would be naive. Generally speaking, if we want to determine the optimal data representation for a certain decision, the characteristics of the decision environment are as important as the characteristics of the decision itself. Of course the characteristics of the decision environment may vary from time to time. A decision which is not important today may be vital tomorrow, requiring a fast and a accurate response. Consequently the optimal data representation may change.

Also in our case study the importance of time and accuracy influenced the classification. During the interviews with the responsible for quality control it became clear that performance measurement was not an important issue for the control lab management. The responsible only wanted a quick overview of the performance of his team, not a detailed report. As a matter of fact, the exact number of analysis's did not matter. Consequently, the decisions concerning the control team were not classified as a comparison of values, but as a comparison of patterns. In this case, although contradictory to our intuition, the underlying elementary task is spatial in nature and a graph will be used to support these decisions.

3.4 Evaluation of the cognitive fit approach

Knowledge of the theory of the cognitive fit during DSS development is useful, but not a requirement. Application of the theory does not lead to a simplification of the decision analyses process because a large number of decision factors, such as time and accuracy, still have to be known. It is our belief, that a decision analyst who is aware of the factors playing a decisive role in a certain decision must be able to identify the optimal display format through logical thinking and without knowledge of the cognitive fit theory. This remark is possibly not valid anymore in the case of complex decisions, but neither brings the cognitive fit theory a solution when it comes to complex decision-making.

If we like to have a practical framework to select the optimal display format, we have to circumvent the analysis of decisions at a low level because at the moment we still lack to knowledge to do so. Generally, we can conclude that the application of the cognitive fit theory during DSS development is less meaningful if there is no simplification of the analysis and development process. A practical and useful theory should lead to a classification framework for simple and even complex decisions requiring little or no knowledge of elementary tasks or other elements which are difficult to identify and describe. Maybe, we can apply the cognitive fit at a higher level and drop the classifications baring upon elementary tasks.

4. CONCLUSIONS AND FUTURE RESEARCH

The aim of this study was to evaluate the theory of the cognitive fit in a more practical context. The theory of the cognitive fit was used to identify the optimal display format during the development of a DSS.

Concerning the development of DSS, we conclude the theory of the cognitive does not result in a simplification of the analysis process. The classification of decisions based on the underlying elementary task may be a useful starting point in determining the optimal display format. The identification of these elementary tasks stays however a problem. As suggested, this problem can be solved by applying the theory at a higher level. A classification based on more understandable and realistic tasks should be viable. Note that besides the underlying tasks, other factors such as time pressure and decision accuracy may play a significant role in determining the optimal display format. Some of these factors may even not be known at design time, only at decision time. It is appropriate, especially for critical decisions, to identify the value of these factors and to adapt the data representation correspondingly. This identification demands an accurate and extensive analysis of the decision environment. Consequently, the identification of the most appropriate display format requires besides theoretical knowledge still a great deal of common sense.

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