Cognition-Driven Decision Support System Framework

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Abstract

Cognitive orientation has long been thought of as a very important consideration to decision support systems (DSS). Situation awareness (SA) and mental models, as two key concepts in cognitive psychology, are important for understanding ill-structured problems and making effective decisions. In many dynamic decision-making situations, especially those with high uncertainty, complexity and high personal stake, much research has proven that there is a close connection between SA, mental models and the performance of decision making: good SA and mental models are very likely to lead to good decisions and ultimately good performance. This research develops a conceptual information system framework for cognition-driven decision support system based on cognitive orientation, which is expected to be able to provide better decision support in ill-defined decision situations.

Keywords: Decision support systems; Situation awareness; Mental models; Decision-making

1. Introduction

Decision support systems (DSSs) are computer-based information systems, which are designed to aid people in decision-making process [18]. In everyday life, people, from the president of a country, the CEO of a company to each individual, need to make decisions. A decision can be very simple, say buying a book, or extremely complex, say a strategy underpinning the operation of an international organization. People make simple decisions simply based on their intuition, but for important ones, DSSs are often used in order to avoid intuitive errors of people.

DSSs, as a sort of information technology, have significantly contributed to society since its first emergence in the 1970s. However a big gap remains before computers will be able to perfectly support people's decisions. Three decades have seen the evolution of DSS, from personal DSS to group DSS, from data-driven DSS to model-driven DSS, but the majority of today's DSS research is still limited within the areas that emerged 30 years ago, and cognitive orientation, although it has long been recognized as a very important consideration for DSS, still seems absent from the latest DSS literature [3, 2]. Arnott and Pervan [2] criticize most of the current DSS research being conducted with inadequate professional relevance and with weak theoretical foundations. According to their observations, 'DSS research is simply focusing on the wrong application areas' (Arnott and Pervan 2005).

Decision support systems are information technology solutions that can be used to support complex decision making and problem solving. The original DSS concept was defined by Gorry and Scott Morton [11]. Gorry and Scott Morton used the terms structured, unstructured, and semi-structured, rather than programmed and non-programmed for the description of decision-making problems. A DSS was defined as a computer system that dealt with a problem where at least some stage was semi-structured or unstructured. A computer system could be developed to deal with the structured portion of a DSS problem, but the judgment of the decision-maker was brought to bear on the unstructured part, hence constituting a human–machine, problem-solving system.

A classic DSS is comprised of the three components: database management, modeling functions, and (3) user interface. Current DSS research has been primarily concerned with the behavioral aspects of decision-makers' managerial work. Seven typical stages are included in a decision-making process [18]. The emphasis comes to be on model development and problem analysis. Once the problem is recognized, it is defined in terms that facilitate the creation of models. Alternative solutions are created, and models are then developed to analyze the various alternatives. The choice is then made and implemented. Of course, no

decision process is this clear-cut in an ill-structured situation. Typically, the phases overlap and blend together, with frequent looping back to earlier stages as more is learned about the problem, as solutions fail, and so forth.

This paper is mainly concerned with incorporating some cognitive psychology concepts into the design of decision support systems and the corresponding application in business strategic management process. The main objective is to build appropriate theories, methodologies and information system techniques to support the senior decision makers' strategic management process (SMP) through combing decision support system theory, cognitive theory as well as business management theory.

2. Naturalistic decision-making

2.1. Naturalistic decision-making and classical decision-making

Naturalistic decision-making (NDM), a kind of decision-making theory, is under the umbrella of decision theory. The major concern of NDM is to model how proficient people make decisions in familiar decision situations. [14]. NDM is a descriptive decision theory. Another end of the spectrum is normative decision theory, e.g. classical decision-making (CDM). In CDM, decision makers are regarded as 'rational', i.e. it is assumed that they will not select a course of action, an option that is inferior to some other options. The rational choice model is the basic idea of CDM. Compared with normative decision theory, NDM is based on the context-specific descriptive models which are built through observations on the behaviors of specific decision-makers. There are five essential characteristics of NDM: proficient decision-makers, situation-action matching decision rules, context-bound informal modeling, process orientation, and empirical-based prescription.

According to NDM, people make decisions based on their past experience or knowledge as well as on their concurrent observations of the decision situations, which is closely connected with two cognitive psychology concepts: situation awareness (SA) and mental models (MM).

2.2. Situation awareness

Situation awareness is a relatively new psychological concept. This concept initiated from military aircraft domain extended to air traffic control, nuclear plants, and other tactical and strategic [8]. Situation awareness is thought of as important and essential prerequisite for decision-making in any dynamic system with time pressure, uncertainty, ill-defined goals and high personal stakes [8, 19, 7].

Situation awareness has been recently plenty of research in different application areas which directly leads to different understanding and definitions of SA. Hamilton [12] , from perspective of military aviation, define situation awareness as the knowledge of current and near-term disposition of both friendly and enemy forces within a volume of airspace. Similarly Reising and Britten-Austin [4] refer to SA as the crew's knowledge of both the internal and external states of the aircraft, as well as the environment in which it is operating. Compared with investigations into SA from specific aspects or components. Vidulich [20] thinks of SA as the pilot's cognitive understanding of the current situation and its implications. More abstractly, the definition of situation awareness by Sarter and Woods [17] is following: "ituation awareness refers to the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments." Sarter and Woods (1991) argue that SA is distinct and unique phenomenon with temporal dimension, i.e. the operator's SA is changeable and updated over time. More recently Endsley [7] describes SA at three levels. Level 1 SA is the perception of elements of current situation; Level 2 SA is the comprehension of current situation and level 3 SA is the projection of future status.

2.3. Mental models

Mental models are psychological representations of real, hypothetical, or imaginary situations [13]. Mental models are commonly referred to as deeply held assumptions and beliefs that enable individuals to make inferences and predictions. The concept of mental model was defined by Rouse and Morris (1985, p. 32) as 'mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states'. A mental model is useful in that it provides a mechanism for [7] (1) guiding attention to

relevant aspects of the situation, (2) A means of integrating information perceived to form an understanding of its meaning, and (3) a mechanism for projecting future states of the system based on its current state and an understanding of its dynamics.

Mental models can be represented in many forms such as tokens, spatial relations between entities, temporal or causal relations among events. In general, mental models are built based on an individual's understanding of external objects.

Decision makers' mental models are important for the decision making. Mintzberg [16] identified 10 roles of top decision makers. He argues that decision makers use the information they collect to develop a series of mental models of the internal working of their organizations, the behaviors of their subordinates, the trends in the organization's environment, and so on. When dealing with complex issues, decision makers use their mental models to simplify the decision process and test alternatives.

3. Cognitive-driven DSS framework

Based on above analysis, we proposed a cognitive-driven DSS framework (Figure 1).

In this framework, the basic idea is to aid decision makers' decision-making through enriching their SA and mental models in terms of information systems. Because human decision-making has a strong relationship with SA and mental models, DSSs under this framework we believe will be able to thoroughly support decision makers' strategic planning work Compared to traditional DSSs, three characteristics shape this system framework:

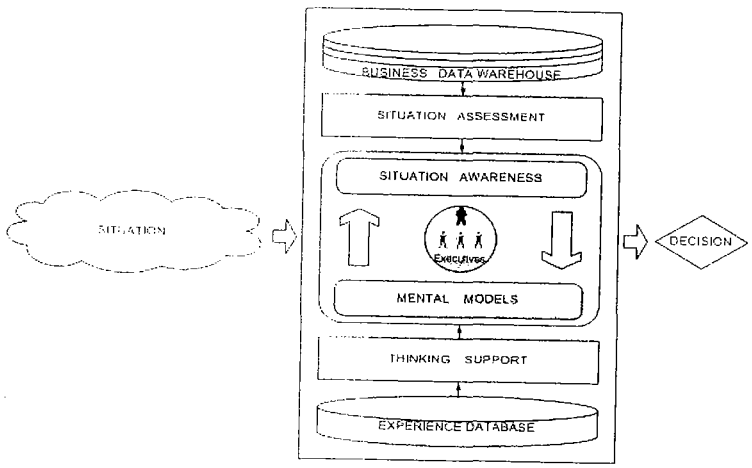

Figure 1 User-cUser-centered DSS with cognitive orientation

User-centered

The concept of user-centered is used for systems design. This concept means to put the user in the heart of all other considerations, such as decision information understanding, data analysis, decision-making etc. All the other theories, methodologies and the system development will be researched, developed with the purpose of serving the user's requirements. The opposite end of the spectrum is technology-centered concept, where users need to adapt themselves to the data extracted by information system from the environment.

Cognitive orientation

Rather than emphasizing behavioral support to decision makers' work, we focus attention on cognitive aspects of management: SA and mental models. Based on Anthony's [1] categories of management activity, we model decision makers' SA in three levels: operational, management, and strategic. The operational situation awareness (OSA) looks at the specific tasks usually conducted by frontline personnel as the basis of the operation of the organization. The management situation awareness (MSA) is concerned with middle managers' work assuring the acquisition and usage of the organization's resource in accomplishment of the organization's objectives. At the highest level, strategic situation awareness is about the top decision makers' strategic planning activities. In the strategic management process, strategies are

developed and implemented, which translate the organization's objectives into pre-determined outcomes.

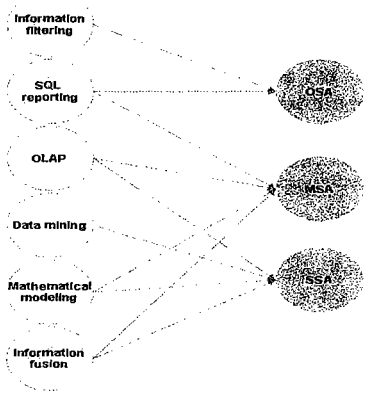

Figure 2: The support of data analysis techniques to situation assessment.

The three levels of decision makers' SA are developed or enriched through situation assessment module in this framework. Endsley [8] proposed a conceptual model of situation assessment, whereby the operator's SA is developed through three steps: perceiving, comprehending and projecting. We also define three sub-modules of situation assessment with respect to three levels of decision makers' SA in our framework. Our framework has somewhat similarities with Endsley's model. Nevertheless, the three situation assessment sub-modules in our framework are not necessarily reflective of Endsley's three-step model. More importantly, the situation assessment module in our framework is designed from information systems perspective which we believe is more applicable to specific system development.

The functionality of situation assessment is fully supported by different data analysis techniques. Currently, six kinds of data analysis techniques are employed in this framework: information filtering, SQL reporting, OLAP (online analytical processing), data mining, mathematical modeling, and information fusion. Each of them contributes to different situation assessment sub-modules (Figure 2). The environment information data store is the source that data analysis module processes. The environment information consists of internal environmental data (e.g. product R&D, financial, engineering, and marketing) and external one (e.g. technological, political, and socio-cultural). Both are important for decision makers' environmental scanning in strategic management process [21].

Another cognitive aspect of this framework is thinking support through modelling, fusion and simulation of decision makers' mental models. We use cause mapping technique to represent decision makers' mental models. A cause map is a semantic network that consists of concepts (nodes) that are linked together by casual relationships (linkages). It helps decision makers to order their thinking process in strategic management process [10]. Mental models are a sort of mental construct within decision makers' minds reflecting their past experience. After represented as knowledge (information), multiple pieces of knowledge can be aggregated through fusion module in this framework, which makes it possible to facilitate the integration of different views from multiple board members. Mental models and SA are working together as the mechanism whereby decision makers are capable of anticipating future status of the environment. The simulation module in this framework is designed to enhance decision makers' abilities of projection. It includes the creation of business scenarios, what-if analysis, and the possible mental model simulation. Thinking support module is based on management experience store, which consists of decision makers' past strategic management experience in difference cases.

Situation-strategy matching

In model-based DSSs, a typical decision-making process consists of intelligence (identification of problems), design (generation of alternatives), and choice (analysis of alternatives). During this decision-making process, A computer system is mainly developed to deal with the structured portion of a DSS problem, but the judgment of the decision-maker was brought to bear on the unstructured part, hence constituting a human-machine, problem-solving system [18].

The decision-making process based on this framework is a situation-strategy matching process. In the strategic decision-making, the decision situation comes often with ill-defined goals, uncertainty, high stakes, and time pressure. And the decision problems are always too implicit and complex to be identified explicitly. In this case, model-based DSSs seem ineffective. In our framework, proficient users (experienced decision makers) are playing the major role in decision-making process and computers are only used to help decision makers to enrich their SA and mental models. Because human decision-making has a strong positive

relationship with SA and mental models, the experienced decision makers, equipped with richer SA and mental models, will be likely to perform better in strategic decision-making process.

4. Discussions and further study

Compared to traditional DSSs, this framework reflects a new DSS paradigm. However, some challenges emerge during the development of this framework.

Firstly, how to evaluate decision makers' SA? SA evaluation is important to systems design. Without effective evaluation methods, the decision maker's mind remains a black box for us and we are not able to be confident to declare that SA is supportted. Endsley [6, 5] evaluates the pilot's awareness of the aircraft using so-called situation awareness global assessment technique (SAGT). In the SAGT, the pilot is flying a scenario in a simulation. The simulation system is frozen and the pilot is asked some questions concerning the current system status. The pilot's answers are then analysed to probe into his/her SA. SAGT is an intrusive assessment technique for SA evaluation. There are also some after-the-fact methods such as debriefing, e.g.,[15]. These SA evaluation methods are applicable to different domain, but are less likely to be effective in business SMP domain. In today's business environment, every company is focused on developing different competitive advantages. Each company is shaped by different goals, structures, processes, marketing share, and many other factors. The population of senior decision makers within each company is significantly small. Therefore, new SA evaluation methods need to be developed for business strategic decision-making domain.

Secondly, to what extend, situation assessment can be supported or partially supported by information systems? Situation assessment is the process in which the decision maker's SA is developed. Present situation assessment models are mainly proposed in terms of cognitive psychology not from information systems perspective. One of our next research tasks is to develop relevant theories and information technologies which can be used to aid decision makers' situation assessment.

Thirdly, how to facilitate an effect interaction between decision makers' SA and their mental models? The psychological mechanism on which SA and mental model are affected by each other has been researched and modeled from the perspective of psychology (Section 2.2). Based on this framework, we will examine the relationship between SA and mental models in terms of information systems. Put simply, mental models look at the past, and SA looks at the present and the near future. Decision makers are able to achieve an overview understanding (big picture) of the company based on their SA; and then they identify the potential opportunities or threats based on their mental models. Therefore, to be successful eventually in strategic planning, decision makers will heavily rely both on SA, mental models, and their interaction.

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