Chapter VIII

On the Ontology of a Decision Support System in Health Informatics

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ABSTRACT

A decision support system can be approached from two major disciplinary perspectives, those of information systems science (ISS) and artificial intelligence (AI). We present in this chapter an extended ontology for a decision support system in health informatics. The extended ontology is founded on related research in ISS and AI, and on performed case studies in health informatics. The ontology explicates relevant constructs and presents a vocabulary for a decision support system, and emphasises the need to cover environmental and contextual variables as an integral part of decision support systems development and evaluation methodologies. These results help the system developers to take the system's context into account through the set of defined variables that are linked to the application domain. This implies that domain and application characteristics, as well as knowledge creation and sharing aspects, are considered at every phase of development. With these extensions the focus in decision support systems development shifts from a task ontology towards a domain ontology. This extended ontology gives better support for development because from it follows that a more thorough problem analysis will be performed.

INTRODUCTION

Our current information society makes extensive use of information systems and technology. In the field of health care, information technology has been applied as long as computers have existed, and many types of information technology applications have been developed. The early applications in health care were restricted in scope, and they had an impact on only a few professionals. They were mostly targeted at automation of existing routines, rationing resources and ensuring quality. The shift to an information society has brought a qualitative change in this respect: The focus is now on the development of new information technology service products that can improve health care processes and their outcome. Current health care information systems and networks are large and they have wide ranging impacts on people and organisations (Lorenzi et al.1997).

An example of information technology applications in health care is decision support systems. Since the 1960's decision support systems have been developed in health care for such purposes as interpretation of findings and test results in patient care, selection of treatments, choice of tests or protocols for the patient case at hand, management of data and information, control of work flows and monitoring of patient care processes and their outcomes. Despite of the long history of availability and the type and amount of resources used, the results achieved have been rather low and dissemination of systems into health care practices has progressed slowly (Reisman 1996, Barahona and Christensen 1994). Numerous prototypical decision support systems exist, but very few of them have entered routine use. Some studies (Wyatt 1987, Lundsgaarde 1987, Pothoff 1988) showed that little more than 10% of medical decision support systems developed so far had been sufficiently developed to enter clinical use. In 1992 the 600 subscribers to the 'artificial intelligence in medicine' mailing list reported only six systems to be in routine use (Heathfield and Wyatt 1993).

This chapter deals with decision support systems in health care context. We are searching for answers to the following research questions:

- What are decision support systems (DSS) in a health informatics context? Are they somehow different from information systems (IS) or knowledge-based systems (KBS)?
- Do we need a special conceptualisation for a decision support system in health informatics as compared to those presented in related research areas?
- Is health informatics a special field for application of decision support systems? Do we need special approaches and methodologies to develop and evaluate decision support systems in health care context?

To find answers to the questions above, we analyse our case studies with decision support systems, and we use in the analysis conceptual definitions of a DSS and a KBS as presented in information systems science (ISS) and in artificial intelligence (AI). The purpose of this analysis is to identify relations between the theoretical approaches applied and practical implementations that could help to explain the successes and failures of decision support systems in health care.

ANALYSIS OF DSS CONCEPTUALISATIONS

Decision Support Systems - Information Systems

As early as 1970 Little described a decision calculus as a model-based set of procedures to assist a manager in his decision-making (Little 1970). He wanted to utilise better management science models through effective computer implementations. Little was even then able to list the requirements for a successful decision support system: Simple, robust, easy to control, adaptive, complete on important issues and easy to communicate with.

Scott Morton developed in 1971 a pioneer DSS for marketing and production planning (Scott Morton 1971). Together with Gorry he gave the first definition for a decision support system in (Gorry and Scott Morton 1971). Their DSS framework maps the potential for computer support in management activities along two dimensions: Structuredness of the task and level of managerial activity. Gorry and Scott Morton saw that, based on this framework, decision tasks could be divided between a human decision-maker and a computer system in many ways. In a structured situation all phases of decision making are structured and potentially automatable, and therefore the resulting systems are decision-making systems. In a semi-structured case one or more of the intelligence, design and choice phases are unstructured. The unstructured case corresponds to the Simon's unprogrammed situation (Simon 1981). In semi- and unstructured situations there is need for decision support in order to extend the decision-maker's capabilities or to improve the quality of the decision-making process. Some researchers see that a DSS is useful only for the structured parts of decision problems, but humans must solve the unstructured parts. The line between structured and unstructured situations moves over time when problems are understood better, and this understanding brings structure to them.

From the early 1970's decision support systems research has grown significantly, and many definitions have been presented. Mostly definitions have paid attention to the task structuredness and the problem of distinguishing decision support systems from other management information systems or operations research models. Sprague and Carlson brought into the discussion the organisational context of a DSS (Sprague and Carlson 1982) by providing a practical overview on how organisations could build and utilise a DSS.

A major goal of decision support systems research is to develop guidelines for designing and implementing systems that can support decision-making. Decision support systems can be designed and developed using different approaches and methods. A life cycle development methodology is often used and user-participation in the development is emphasised. There are, however, problems with life cycle development methodology, because it does not support well the typical design situation where users do not quite know their needs at the beginning and developers do not quite understand the users' needs. Adaptive design or incremental design using an evolutionary prototyping approach is often more suitable for DSS development because it supports learning during the development process.

Functionalism with a positivist epistemology has been the major approach applied in information systems science, also with decision support systems. Research has been largely focused on the DSS systems and models themselves rather than on the contextual aspects of the decision-making processes in organisations. Development has been based on hard quantifiable data and information rather than on soft qualitative information. The goal has often been to find generic solutions by matching the type of the problem and the task of the system. Support has mostly been offered for individual decision making; only quite recently support has been offered to enterprise-wide or group decision-making.

DSS research has been criticised for putting the major effort to the study of the choice phase in decision-making and much less effort has been put to the intelligence and design phases. Winograd and Flores (Winograd and Flores 1986) claimed that focusing on the choice phase in decision-making is dangerous because it may mean selection of a solution without really thinking what the right solution might be. They advised to pay more attention to communication as a central element in organisational decision-making.

Concepts Used in Defining a DSS in Information Systems Science

In Table 1 we summarise the definitions of a decision support system as found in information systems science textual sources.

Table 1: Concepts used to define a decision support system in information systems science (further elaborated on the basis of Turban 1988).

Source	DSS defined in terms of
Little 1970	System function, interface characteristics
Gorry and Scott Morton 1971	Problem type, system function
Alter 1980	Usage pattern, system objectives
Sprague 1980	Task, users (knowledge workers), means (information technology)
Moore and Chang 1980	Usage pattern, system capabilities
Bonczek 1981	System components
Keen 1980	Development process
Turban 1988	Problem type, usage pattern, system capabilities, system objectives
Sprague and Watson 1989	Problem type, problem occurrence
Klein and Mehlie 1990	System capabilities, system function (support), application tasks
Eierman et al. 1995	Environment, task, system capabilities, implementation strategy, system configuration, user, user behaviour, performance

In many of the definitions in Table 1, the problem type as well as system function and user (e.g. through usage pattern, interface or user behaviour) are explicitly included, but some definitions focus only on problem type and problem occurrence. Effects of interface characteristics on system design were emphasised early on, in 1970 (Little 1970). Sprague noted (Sprague 1980) that a DSS is developed for a specific task in a knowledge worker's environment, and that information technologies are a means to develop a DSS. Moore and Chang noted that the structuredness concept in the Gorry-Scott Morton framework cannot be general because structuredness is always in relation to the specific user (Moore and Chang 1980). In Keen's definition (Keen 1980) a DSS is seen as a product of a process where a user, a developer and a system itself exert mutual influence through adaptive learning and evolution. Eierman et al. (Eierman et al. 1995) pay special attention to the environment construct, which refers to the organisational context of the system's development and its use. This is a noteworthy addition to the Gorry-Scott Morton framework. Eierman defines eight constructs and 17 relations between the constructs. These constructs attend also to the social and organisational aspects of system use, such as attitudes and motivation of the user as well as actions taken by the user. However, the focus in Eierman's analysis has been on two issues: System implementation and system use.

Table 1 shows that DSS approaches in ISS have been closely focused on development and implementation and on hardware and software issues rather than on decision-makers and on decision processes. Keen has noted that the system, but not the decisions or the support, has been the focus in building the DSS's (Keen 1997). DSS technologies should not be the focus, but rather taken to be as means to develop better contexts for decision-makers and DSS's.

Decision Support Systems - Knowledge Based Systems

The goals of artificial intelligence are to study human intelligence and to build computational models that can simulate intelligent behaviour (Nilsson 1974, Lenat 1975, Newell and Simon 1976). AI can be seen as a science that studies solutions to complex or ill-structured problems using heuristics (Aliferis and Miller 1995).

In many AI projects the goal has been to develop a model of a specific expert's expertise and to implement this model as an expert system. The object of such study has mostly been an expert task at individual level decontextualised from the environment, in most developments the social and organisational contexts of decision-making have not been considered.

Discussion on AI-based decision support systems, knowledge-based systems (KBS), or expert systems (ES), has largely concentrated on methodological aspects of decision support, asking such questions as: Is it better to use model-based or data-driven approaches to model and implement decision making algorithms?

Concepts Used to Define a KBS in AI

Concepts used to define a KBS in AI are presented in Table 2 as derived from textual sources.

We have included in Table 2 primarily the knowledge level abstraction paradigms (Newell 1982), because knowledge level modelling has been the major approach applied in KBS to generalise and structure domain and task knowledge. These paradigms have made strong assumptions about domain knowledge, and therefore developers often had to select first the problem-solving paradigm and then define domain knowledge in terms of the method. Slowly, there has emerged the need to capture general concepts independent of what problem-solving method would be used. These efforts have gradually led to scalable architectures where reusable problem-solving methods and domain ontologies can be used. This kind of approach makes a distinction between the foundational domain concepts, inferences and problem solving that might be applied to those concepts (Musen 1999). A good example of this approach has been the KADS model for knowledge engineering (Schreiber et al. 1993).

Additionally, we present in Table 2 the epistemological model (Ramoni et al. 1990) and the development philosophy approach (Heathfield and Wyatt 1993). In the epistemological model the term knowledge level has been replaced with epistemological level, because inference structures, problem-solving methods and task features are also seen as elements at the knowledge level, in addition to domain knowledge. This approach proposes that a KBS contains two types of knowledge: Knowledge about the domain (ontology) and knowledge about inference structures that are needed to execute a task to exploit the ontology. Therefore, in building a KBS we need to focus on the definition of the domain ontology and on the definition of the underlying inference structure.

Table 2: Concepts used in AI to define a KBS

Abstraction paradigm or approach	KBS defined in terms of	Source
Heuristic classification	Feature abstraction, heuristic match, solution refinement	Clancey 1985
Deep and shallow knowledge	Deep knowledge, causal relations, shallow knowledge	Keravnoe and Washbrook 1989
Problem-solving method	Problem decomposition, domain independent strategies, sequencing inferences	McDermott 1988
Generic tasks	Problem type, problem decomposition, task, ordering of tasks	Chandrasekaran 1986
Epistemological model	Ontology, inference model, medical tasks	Ramoni et al. 1990
Development philosophy	Need, development methodology, methods, metrics, tools, integral evaluation, professional approach	Heathfield and Wyatt 1993

The development philosophy approach is a pragmatic view covering the phases of DSS development, from requirements analysis to evaluation, and includes values and beliefs.

The concepts detailed in Table 2 indicate that in AI a knowledge-based system or a decision support system is mostly understood to be a system that supports an individual's cognitive processes. The major focus in development has been on mimicking individual human intelligent behaviour by modelling tasks, knowledge and reasoning processes. The development philosophy approach aims at utilisation of software engineering approaches and experiences in KBS development in such a way that a professional, systematic methodology is used. However, the domain problem is still seen as an isolated and decontextualised one.

The object of a knowledge-based system has been construed as an expert task at an individual level decontextualised from the environment. Medical knowledge based systems have mostly been expert systems developed to solve isolated medical decision making problems. The decision-making context, i.e. the social and environmental variables, has mostly not been considered at all in the systems developed. The focus in the decision making process has been on the choice phase, and this has resulted in that problems have been matched to available tools. This way of proceeding puts the focus on the choice instead of on intelligence. The choice phase problems have been challenging for AI researchers and developers, but these choice phase problems may not have been driven by the interests and needs of health care professionals.

ANALYSIS OF OUR DSS CASE STUDIES

Support for Thyroid Disorders

Our first case study is a DSS developed for the interpretation of thyroid disorders (Nykänen and Nuutila 1991). The decision model considers the clinical hormone tests, the clinical features and the genetic background of the patient as well as medication and the non-thyroidal illnesses of the patient. The combinations of the

Table 3: Simplified combinations of hormone assay results

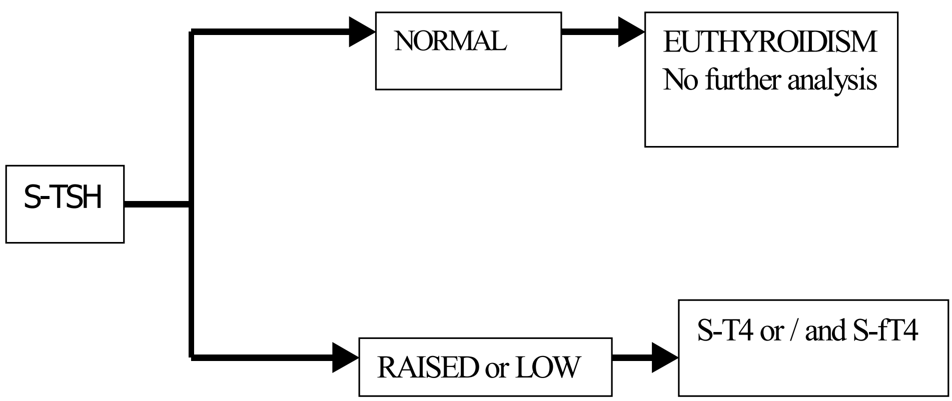
	S-TSH	S-T4 / S – fT4
Primary Hypothyroidism	↑	↓
Secondary Hypothyroidism	↓	↓
Primary Hyperthyroidism	↓	↑
Secondary Hyperthyroidism (rare)	↑	↑

hormone assay results used are presented in Table 3 and the decision model for interpretation is presented in Figure 1.

From the ontological viewpoint the thyroid DSS case study covers aspects of development and evaluation and decision-making process. The applied four-phase development and evaluation methodology is an AI-based approach for a knowledge-based system. The contextual aspects of the DSS were not considered and covered by the ontology applied.

In evaluating the DSS the preliminary exploration phase showed that the documents specifying user requirements worked well as a frame of reference in qualitative terms, but not well quantitatively. The specifications were incomplete; system performance, documentation and maintenance requirements were not documented at all in these specifications. Feasibility of the specifications was poor because of the lack of practical mappings from user requirements to software specifications. Neither cost-effectiveness nor viability of the system were considered at all.

Figure 1: Decision model for interpretation



Validity in application did not rate highly in this case study. The system classified correctly 98.6% of the test cases with suspected thyroid disease. This was less than the target correctness rate (99%). The failures were due to errors in data, in data entry and in definition of too broad diagnostic categories for classification. Broad categories were used because we would have required more detailed data and clinical information from the patient to be able to proceed to a more qualified classification. As a result, all those cases that could not be classified correctly were assigned to the class of non-specific thyroid disorders. A commercial expert system shell was used in the development of the system, and the knowledge base was not checked for its validity. Functionality and usability of the thyroid system turned out to be poor, and the user acceptance of the system was also poor. The reasons for poor usability were the lack of navigation, inspection and updating options for the knowledge base. The system was very brittle, transferable for use only to an organisation where the same fixed strategy was in use for thyroid diagnostics. In the impacts phase it was found that a training effect was the major positive impact caused by the system. The training effect was seen in improved diagnostic accuracy in primary care and in the accumulation of knowledge on thyroid diagnostics in secondary care, especially in borderline and difficult cases. The training effect was caused by interpretative reports, which were sent by normal mail or email to the primary care organisations. From these reports primary care physicians learnt more about thyroid diagnostics and became more knowledgeable in the selection of tests to be performed. When the test selection strategies gradually became more accurate, the number of tests performed could be reduced. This resulted in better cost-effectiveness because the costs of tests were rather high and resources could be saved when only those tests were performed that were useful in the specific clinical situation.

The four-phase development and evaluation methodology proved not to function well in this case, because the problems with the system's development were detected only in later phases. Errors should have been detected earlier; it would have saved time and resources. The methodology was not well suited for the development of knowledge-based systems because the knowledge acquisition phase and its validity checking were not explicitly included in the development life cycle. The system was connected with the laboratory information system in the hospital but the connection was very slow, difficult to use for the health care professional, and it worked only in one direction, from laboratory system to the KBS. The connection was used only to transmit the measured laboratory test results from biochemical analysers to the thyroid system for analysis and interpretation.

To summarise, the thyroid system helped users in primary care to deepen their understanding of thyroid diagnostics and to select better the tests to be performed. It also helped the specialist in the laboratory to concentrate on the borderline and difficult cases because the majority of the samples were normal and were correctly classified by the system. Though the acceptability of the system to the laboratory specialist was poor, the acceptability of the interpretative reports by the general practitioners was good. Our other study (Nuutila et al. 1991) on the clinical value of the system showed that in health centres 99% of the users read interpretative reports regularly and 60.4% considered these reports useful. In comparison, of the internists 79.5% read the reports regularly and 55.9% considered them useful. For these reasons clinicians considered the system a valuable support in their work.

Support for Post-Analytical Functionalities

In our second case study three DSS modules were developed for interpretation of laboratory test results and for alarming in the intensive care environment (Nykänen et al. 1993). The modules were integrated with an open laboratory information system architecture.

The thyroid decision model used in this second case study is described in Table 4. Both qualitative and quantitative variables were used. Quantitative data were classified into mutually exclusive decision ranges, which were locally modifiable; i.e. they were user-defined, fully revisable and age-specific. Qualitative data could be entered into the system in any combination by selecting the appropriate finding from the user-defined expandable lists of options. After data entry, the program obtained an interpretation from the observer and linked it to the data-derived rule so that an appropriate interpretation could be provided automatically whenever similar data were encountered (Nykänen et al. 1993).

Table 4: Qualitative and quantitative variables used in the thyroid decision support

Qualitative	Patient's sex
	Clinical details
	Drug therapy
Quantitative	Patient's age
	Serum total thyroxine concentration
	Serum thyrotropin concentration
	Serum free thyroxine concentration
	Serum free triiodothyroxine concentration

Evaluation of the developed thyroid system with more than 3000 requests in a 4-month period found that interpretations could be generated by the system for at least 90% of all requests. The remaining requests needed to be interpreted by a human expert.

With the intensive care DSS, interpretation of acid-base disorders was based on utilisation of the laboratory measurement results together with data recorded in the intensive care unit. Evaluation of the accuracy of the system resulted in 92.8% correct classifications with a test set of 194 cases. Two independent experts also tested the accuracy; levels of agreement between the independent expert, the system and between the different experts were found to be similar.

From ontological viewpoint these intensive care case studies were ambitious attempts to cover contextual aspects of the decision-making situation. We tried to build a model where information from patient data monitoring system, electronic patient record, laboratory information system and human visual examinations were combined. This ontology was planned to represent the essential concepts and relationships in an intensive care decision-making situation. Part of the ontology were taxonomies to bring order to the model and to present limited views of a model for human interpretation.

Generation of alarms and alerts in intensive care using laboratory data and clinical information proved to be a complex task due to the many variables that need to be included, due to the temporal aspects of the recorded data and due to high safety requirements. Two prototypes were developed and interfaced in a hospital with the laboratory information system, but the systems were used only in an experimental setting.

These developed DSS modules provided users of laboratory services, both in a specialised hospital unit and in primary care, with interpretations and suggestions on how to proceed with the specific patient case. The interpretations served as high quality decision support for users. The modules were integrated with a telecommunication network, though they were originally designed as stand-alone systems. Integration was done using standardised components and open architecture specifications. An important aspect of these specifications was the standardised definitions for data and information exchange messages. When integrated with the laboratory information system, the developed systems did not add to the laboratory workload, but showed promise of improving laboratory efficiency (Nykänen et al. 1993).

Discussion on the Case Studies

User's Problems

The developed, and to some extent evaluated, decision support systems in our case studies can be classified as knowledge-based systems, and they were targeted to support clinical decision making. They proved to be successful for the users in the management of information overload and in the interpretation of information so that it could be better utilised in clinical practice. Various users at different levels of health care were served through these systems. Specification of the systems' function was based on the users' needs in the problem at hand. The major function of the developed systems was to enhance information from data, and to transfer information to other health care units or primary care where expertise for interpretation was not available.

The evaluations performed in these case studies were restricted and were not reported to the users. No special attention was paid to how the evaluation studies and their results were documented so that users could understand them. In this respect users' needs were not served. On the other hand, users were involved in evaluations to some degree, and they received information and could give feedback for system developers on identified failures and needed improvements in the systems' functioning. Users, however, got no training or guidance for the future on how to evaluate decision support systems and which criteria and methods of evaluation to use, though there was a real user's need for that.

Developer's Problems

Developer's problems were mostly methodological. First, in developing decision support systems the planned use environments determined the constraints for software and methodological choices. Use of a research-oriented, combined evaluation and development methodology and use of commercial expert system shells as software environments were not quite successfully combined. We were in a situation where problems were matched to tools and not vice versa, as it should have been done. Problems were especially encountered in interfacing the developed systems with the existing health care information systems environment.

Second, developer's problems were related to the problem of how to integrate evaluation with the selected development methods. The used four-phase methodology integrates two different types of heuristics: That of sequential development and that of iterative development through prototyping. Checkpoints were defined at different phases of development to measure pre-specified success or failure variables, and these measures were compared with the determined reference criteria in order to decide on how to continue with the development.

As developers we faced problems in this kind of situation. Although there were many technical and methodological possibilities and alternatives to choose from, the use environment imposed strict requirements and constraints for the selection of software and technology options. These requirements were in some degree even conflicting. Additionally, development was done in an evolving world, and emerging technologies were available and new modalities were arising. Therefore, we tried to apply as much as possible conventional approaches and standards so that the modules could be integrated with traditional legacy systems. This was not, however, always successful.

Remaining Problems

Though user's and developer's problems were in the main quite successfully served in our case studies, there still remained some problems which needed attention, but which were not recognised as problems while we were carrying out these case studies.

The first problem is that a decision support system was only implicitly conceptualised in these case studies. There was no explication of the concept. The contents of the concept 'decision support system', particularly the type of system and the requirements for this type of system were not explicated. This means that the essential variables, the task of the system and the role of the system in supporting decision-making remained undefined.

The second problem is a natural consequence from the first, and it is also the same as with many early expert systems: Decontextualisation of the system from its environment. While developing the system, the focus was on modelling the specific expert's expertise, or a few experts' expertise, in a defined task and that model was then implemented as an expert system. In the modelling and implementation processes, the decision-making context and its social and environmental variables were not considered. From this it followed that the resulting system functioned well when seen as a problem-solver for the specific problem, but when seen as a system in real environment used by a human user, the system did not function well. This was because those system characteristics that would consider the environment and use contexts of the system, as well as the organisational context for knowledge and its use, were missing.

The third remaining problem is related to the evaluation and development methodologies. One essential feature for the development methodology is the possibility for evaluation during all development phases. Developing decision support systems for semi- and unstructured problems puts strenuous demands on development methodology and may even, depending on the type of the system, make it necessary to bring in additional developmental phases like knowledge acquisition, knowledge modelling, knowledge management, and knowledge validation. Also, another big problem is the lack of a generally accepted evaluation methodology. In these case studies, we did not have theoretical assumptions on how to connect evaluation and development successfully in the health care context.

EXTENDING A DSS ONTOLOGY WITH NEW VARIABLES

These case studies highlighted the need to consider the contextual aspects of decision support systems. In health care, decision support systems are developed and used as part of the health care environment and as part of the knowledge environment of the user. Therefore, we need such conceptualisation for a DSS that it covers the contextual aspects in system's development, evaluation and use.

As contextual variables have not been considered during the development of decision support systems, the resulting systems have been brittle: They have functioned only in their development environment, and they have not been transferable to other organisational environments. On another level, this has also been a problem with DSS's in general, as the contextual variables are mostly lacking from the DSS definitions (Tables 1 and 2). This is especially the case with medical expert or knowledge-based systems.

Reference Model for Information Systems Research

Ives, Hamilton and Davis presented in 1980 a model for information systems research in their article (Ives, Hamilton and Davis 1980), and they defined variables that need to be considered with information systems. In their model, three information system environments (operations, development and user environments) and three information system processes (use, development and operation processes) and the information subsystem itself are defined, and all these defined entities exist within an external and organisational environment.

This model has exerted a big impact on information systems research because it can be used to understand and classify research approaches and to generate research hypotheses. What is important about this model is that it showed that the environmental variables and their relations to development, use and operation processes need to be taken into account in information systems development. We use this model as our reference when discussing the relevant variables, and development and evaluation processes of decision support systems in the next subsections. The model, though it is abstract and has not been operationalised, helps us in identifying the relevant variables and in demonstrating the significance of environments and processes.

Decision Support System in Health Informatics

When comparing the Ives, Hamilton and Davis (Ives, Hamilton and Davis 1980) model with the DSS and KBS approaches presented in Tables 1 and 2, we see that in information systems science, decision support systems research and development has been development- and implementation-oriented, covering environment, process and information subsystem variables. The major focus has, however, been on development and user environment. In artificial intelligence, decision support systems research and development has been focused on IS development environment and on information subsystem variables.

As a result of our case studies and of the analysis of definitions we propose that the Ives, Hamilton and Davis framework be applied to the development of DSS in health informatics. And we propose to include some additional variables to the conceptualisation of a health informatics decision support system. These additional variables are presented in Table 5 and they are discussed in this subsection. From the variables of the Ives, Hamilton and Davis model we have left out the operation environment and operation process variables which are not today as essential to information systems. They are even less relevant in the case of decision support systems as their operation is included in user environment and use process variables.

The environment variables presented in (Ives, Hamilton and Davis 1980) are essential for decision support systems, as systems are used by decision-makers to support tasks and actions in a contextual situation, and they are developed with the express purpose of having effects and impacts on the environment. We propose to pay special attention to *user-system integrated behaviour* as part of the IS development environment. This variable emphasises the need to design and develop the system as part of the integrated knowledge environment of the user.

Environment variables have not been well covered in ISS-based DSS approaches. For instance, in the Gorry and Scott Morton framework for decision support systems (Gorry and Scott Morton 1971) only a user environment variable was explicitly included, and implicitly development and operation environment variables were covered. Eierman drew attention to the environment construct (Eierman et al. 1995) emphasising the need to consider the organisational and environmental context of system's development and use. Eierman et al., however, did not include designer's or developer's attitudes in the presented constructs, neither problem type nor the system function were included. Eierman et al. results strengthen our analysis results that environmental aspects like organisational environment and structure, task characteristics and context have to be considered in the DSS design and development.

In AI, task-specific approaches have been recently used in order to separate problem-solving methods and domain concepts, and to be able to represent domain

Table 5: Variable groups and variables for a decision support system

Environment variables	▪ ***External environment*** legal, social, political, economic, educational, resources, industrial environment of the system ▪ ***Organisational environment*** organisation's aims and objectives, tasks, structure, instability, management style and philosophy ▪ ***IS development environment*** development methods, techniques, development and design personnel with their assumptions and characteristics, organisation and management of the development work, user-system integrated behaviour ▪ ***User environment*** users and their environment, users' characteristics, users' tasks, organisation of users
Process variables	• ***Development process*** resources and costs, participation, support and satisfaction • ***Use process*** system usage, usage pattern, effects and impacts of system use on work performance and on productivity, on quality of decision making and work, user satisfaction
Information system variables	• ***Content*** information and knowledge achievable through the system, *Domain* describing vocabulary of the domain • ***Representation*** formalisms, media and visualisation techniques • ***Scale*** timestamps for representations • ***Knowledge*** types, sources, validity of knowledge ▪ ***Application*** specialisation of the domain and task in the specific application.

vocabularies and concepts as reusable ontologies (Musen 1999). However, these task-specific approaches have not paid much attention to the contextual and environmental aspects of the task. Rather, domain ontologies have been used to represent fundamental domain concepts like classifications and taxonomies. In Table 2, only the development philosophy approach (Heathfield and Wyatt 1993) drew attention to the context of domain problem and its modelling.

In information subsystem variables, the *content* should specifically consider the *domain* that describes the domain vocabulary not included in the other variables in that group.

Domain consideration is needed because from the DSS conceptualisations in ISS and AI we found that definition of the problem that the system is planned to support is essential for a decision support system. Each DSS has a problem to address, which represents the existing need for the system. The purpose of DSS development is to have a system that solves or supports the solution of the underlying problem. This problem is contextual and domain-sensitive and characteristics of the problem are reflected in the resulting system. The domain defines the purpose for developing the system and its use from the environmental perspective.

An awareness of domain allows for the possibility that the focus in DSS development should be moved from the task analysis more to the direction of the domain analysis. Guarino (Guarino 1997, Guarino 1998) has also raised the possibility that task ontology is an insufficient ontology for decision support systems in his studies of ontology-driven information systems. He concluded that there is need to cover the aspects of domain and application area: A clear implication of our analysis of AI approaches. A DSS should not be an implementation of an expert task that is decontextualised from the environment, or from the domain, as has been the case with most medical expert systems developed, as we also found in our case studies.

In the information subsystem variables group we propose to add two new variables: knowledge and application.

- The *knowledge* variable indicates the characteristics of knowledge, i.e. type, sources, validity and acquisition method. Knowledge aspects are emphasised in AI-based approaches as seen in Table 2. A health informatics decision support system is not only managing data and information, but also knowledge. Knowledge models are developed during knowledge acquisition and the quality of the system depends on the quality of knowledge, type of knowledge and validity of knowledge.
    - The organisational context of knowledge is important to consider in the health care environment as knowledge is created and shared through various communication, learning and conversion processes (Nonaka 1994, Boland and Tenkasi 1995). When concepts are created and made explicit, they can be modelled and shared, first at the domain level and further at the application level. In a health informatics context, decision support systems are often targeted to function as means or facilitators for organisational knowledge creation, sharing and accumulation in the decision-making context. A decision support system, developed through a development process in an environmental setting and used by users in their environment, should reflect through its characteristics, e.g. through an implemented knowledge model, its contextual and situational environment.
- As an information subsystem variable, the *application* variable specialises the domain environment in the specific application. The application variable is needed to take the contextual aspects into account at the system variables level. A DSS is an application which has a domain specified at a more general level, but the concepts relevant for this specific application need to be considered at the system level. For example, in our thyroid diagnostics case the environmental

domain and task is an internal medicine and interpretation task, and at the system level the application is thyroid interpretation.

- Without specialising the domain and task to the system level through application, we would not be able to use shared concepts from the domain in the application and thus we would not have enough information for successful system development.

The discussed extensions to conceptualisation of a DSS present an ontology for a health informatics decision support system.

DISCUSSION

We have presented an ontology for a decision support system in health informatics that takes into account the defined variable groups. It was necessary to extend variable groups, as the contextual aspects had not been sufficiently considered with decision support systems. Failure to attend to these aspects was identified as a major reason for failures in our case studies.

The need to understand the contextual aspects of health information systems has been emphasised very recently also by IMIA Working Group 13: Organisational aspects of medical informatics [see e.g. Lorenzi 1999, Aarts and Peel 1999, Berg and Goorman 1999). There is need to understand the context of clinical work as a prerequisite for successful implementation of information systems in health care. If such understanding exists, then it is reflected in the developer's work and, through his/her efforts, in the resulting system. Berg and Goorman emphasise (Berg and Goorman 1999), among others, that development of information systems in the health care context has a sociotechnical nature, and therefore successful development requires that developers understand the practises in the environment in which the systems are destined to function. Information in health care is in relation to the context where it is produced.

Also, a previous Delphi study (Brender et al. 1999) identified as an important future research area in health informatics the context for application of decision support systems, i.e. how to integrate knowledge-based decision support with the clinical process. We can say, that it is not only the clinical process, but the health care processes overall, that are related to decision support, depending on the case, and these processes we need to consider and understand.

On the Ontology

Does the presented ontology enable us to master such aspects of decision support systems that the other studied approaches are not able to cover? Does it provide us with better support for development, perhaps with better usability? And further, how valid and applicable is our ontology of a DSS?

We used as our reference the Ives, Hamilton and Davis model. This model has been largely applied on information systems science, and it has proven to be useful in understanding problems. It has been widely accepted in the ISS research community to classify past research and to give directions for the future, though it is rather abstract and not operationalised.

The presented conceptualisation of a DSS applying the Ives, Hamilton and Davis model gives us possibilities to cover those aspects of DSS's which have not been covered by earlier ISS-based or AI-based approaches. The contextual aspects of the domain, application and knowledge are covered. When the focus is moved to the direction of these issues, it means that domain and application characteristics, as well as knowledge creation and sharing aspects, are considered at every phase of development.

The presented conceptualisation gives better support for development because from it follows that a more thorough problem analysis will be performed. The environment and the domain are considered right from the beginning of the development. A more thorough problem analysis, on the other hand, means that more qualified resources may be required for development. However, with inclusion of domain, application and knowledge aspects, we are likely to be able to produce successful systems because their contextual environment is taken into consideration in system development, and the characteristics of the environment are reflected in the system qualities. One part of the development environment is the user-system integrated behaviour which puts the focus on the aspects of the integrated knowledge environment of the user.

When considering how valid and applicable our conceptualisation of a DSS is, we need to think about how the variables were found and how they were selected. The variables that have been selected for our conceptualisation of a DSS originate from three sources. First, they have been selected from the known variables of the Ives, Hamilton and Davis (Ives, Hamilton and Davis 1980) model. Second, variables have been selected on the basis of our analysis of how a decision support system has been defined in areas of information systems science and artificial intelligence, Tables 1 and 2. This analysis found that some variables that are not present in the Ives, Hamilton and Davis model should be included in the decision support system model in health informatics. Third, the results from our case studies confirm the need to include these additional variables. On this basis we have concluded that the environmental and contextual variables do have an influence on the phenomenon under study, i.e. on development and evaluation of decision support systems in health informatics. In this kind of decision, there is, of course, a possibility that we have forgotten some important variable that has not shown up during this experiment. We have classified this variable as unknown: It is interpreted as not having a big enough influence on the phenomenon under study. If the situation occurs that an unknown variable becomes known, then the conceptualisation should be modified on this basis, or new experiments carried out. This possibility would be a call for further research on the application of the ontology that we have presented on DSS development and evaluation.

Health Informatics Perspective

How does the presented ontology and framework contribute to health informatics research and practice?

Our DSS ontology builds a model of a DSS in health informatics and contributes to theory formulation in health informatics. When developing a decision support system in health informatics practice, important aspects to be considered are health care organisational context, and domain, application and knowledge aspects, as discussed earlier in this study. The ontology helps in drawing attention to these aspects during the problem formulation, development and evaluation phases.

Next, we look at our results in relation to the design science intent of information technology as discussed in (March and Smith 1995). They describe that in information technology artefacts are created that serve human purposes. Design science products are of four types: Constructs, models, methods and instantiations. Constructs or concepts form the vocabulary of the domain, a model is a set of propositions or statements that express relationships among the constructs or concepts. A method is a set of steps, an algorithm or a guideline, used to perform a task. An instantiation is the realisation of an artefact in its environment. Building, or development, is a process of constructing an artefact for a specific purpose. Evaluation is a process of determining how well the artefact performs.

In this study we have produced the following research findings, in the terms of (March and Smith): the DSS conceptualisation represents constructs. The DSS conceptualisation (ontology) represents also a model as it describes the relationships between the defined constructs. The DSS conceptualisation identifies relevant constructs and thus presents a vocabulary of a DSS in health informatics domain. Are the created constructs better than the old ones, i.e. those presented in conceptualisations in ISS and AI areas? Our DSS conceptualisation gives a wider and a more dense classification for concepts than the other conceptualisations discussed, and its application domain is health informatics. The DSS conceptualisation is also a model, which describes the situation as problem and solution statements. Is this model better than the other ones discussed, e.g. the abstraction paradigms of AI? The DSS conceptualisation represents essential concepts and gives a structure to the presentation. The model can be used to build instantiations. If the model helps both user and developer better understand the problem at hand, or the developer to develop better instantiations based on better understanding, and as a result, the user will have a useful and usable system at his/her disposal, then we can obviously judge that the utility is better than that of the model we are comparing with

The presented ontology for a DSS in health informatics contains more variables and viewpoints than those presented and discussed earlier in this study. Thus it may guarantee a more thorough analysis of the problem case, but it does have negative consequences, too. While forcing a deeper analysis, we increase the work of system developers and users. This might mean that system's development requires higher intellectual qualifications and a larger consumption of human resources. These requirements may not be easily met in a real-life situation. However, these results in their part support our additional finding that education and training in health informatics is an important issue to be covered.

CONCLUSIONS

The approaches for DSS research in ISS have been focused on development and implementation and on hardware and software issues rather than on decision-makers and on decision processes (Table 1). In AI based approaches a DSS has been mostly understood to be a system that supports an individual's cognitive processes. The major focus in development has been on mimicking individual human intelligent behaviour by modelling tasks, knowledge and inference processes, and the domain problem is seen as an isolated and decontextualised one.

The presented framework presents a research agenda and an integrated framework for decision support systems in health informatics domain. The earlier discussed DSS frameworks and approaches, presented in Tables 1 and 2, have been developed from particular viewpoints with focus on defined sets of concepts. The presented framework of this study gives us possibilities to cover those aspects of DSS's which have not been covered by earlier ISS-based or AI-based approaches. The presented conceptualisation applying the Ives, Hamilton and Davis model puts the focus on environmental variables and on domain ontology, and thus it contributes to the DSS research in general, too. When the focus is moved to the direction of these issues, it means that domain and application characteristics, as well as knowledge creation and sharing aspects, are considered at every phase of development. The presented conceptualisation gives support for development because from it follows that a more thorough problem analysis will be performed.

The results of this analysis have some implications on research and development of decision support systems in health informatics:

- Focus on decision support systems development is proposed to be moved from task ontology towards domain ontology.
- Systems development is seen as a sense-making process, where system designer helps the user to understand the system. This is needed to achieve an understanding of the domain problem and the purpose of the planned system.
- Consideration of environment, process and system variable groups during development and evaluation, and especially focusing on environmental variables, means that we are not any more developing isolated decision support systems, but systems that support decision making in health care organisational context, and in the user's domain, knowledge and application context.

Development and evaluation of information technology products, e.g. decision support systems, in health informatics requires information and knowledge on the domain and methods of health informatics. Research and practice are the essential components of health informatics, and dialogue between these two is needed, and they both should be included in health informatics education.

REFERENCES

Aarts J and Peel V (1999). Using a descriptive model of change when implementing large scale clinical information systems to identify priorities for further research. *Int J of Medical Informatics 56, nos 1-3*, 43-50.

Aliferis CF and Miller RA (1995). On the heuristic nature of medical decision support systems. *Methods of information in Medicine, 34*, 5-14.

Alter S (1980). *Decision support systems: Current practice and continuing challenges.* Addison-Wesley, Reading, Mass, USA.

Barahona P and Christensen JP (eds.), (1994). *Knowledge and decisions in health telematics*. IOS Press, Technology and Informatics 12.

Berg M and Goorman E (1999). The contextual nature of medical information. Int *J of Medical Informatics 56, nos 1-3,* 51-60.

Boland RJ and Tenkasi RV(1995). Perspective making and perspective taking in communities of knowing. *Organisation Science 6, no 4,* 350-372.

Bonczek RH, Holsapple CW and Watson AB (1981). *Foundations of decision support systems*, Academic Press, NY.

Brender J, McNair P, Nöhr C (1999). Research needs and priorities in health informatics – early results of a Delphi study. In: Kohol P (ed.), *Proceedings of Medical Informatics Europe 99 (MIE'99),* IOS Press, 191-196.

Chandrasekaran B (1986). Generic tasks in knowledge-based reasoning: High level building blocks for expert systems. *IEEE Expert,* 23-30.

Clancey W (1985). Heuristic classification. *Artificial Intelligence, 27*, 289-350.

Eierman MA, Niederman F and Adams C (1995). DSS theory: A model of constructs and relationships. *Decision Support Systems, 14*, 1-26.

Gorry GA and Scott Morton MS (1971). A framework for management information systems. *Sloan Management Review, vol 3, no 1*,55-71.

Guarino N (1997). Understanding, building and using ontologies: A commentary to "Using explicit ontologies in KBS development". *Int J Human and Computer Studies, 46*, 293-310.

Guarino N (1998). Formal ontology and information systems. In: Guarino N (ed.), *Formal ontology in information systems.* IOS Press, Amsterdam, 3-15.

Heathfield HA and Wyatt J (1993). Philosophies for the design and development of clinical decision support systems. *Methods of Information in Medicine, 32*, 1-8.

Ives B, Hamilton S and Davis GB (1980). A framework for research in computer-based management information systems. *Management Science 26, no 9*, 910-934.

Keen PGW (1980). Decision support systems: Translating useful models into usable technologies. *Sloan Managament review, vol 21, no 3,* 33-44.

Keen PGW (1997). Let's focus on action not info. http://www2.computerworld.com/home/cwlaunch.nsf/launch?RealForm&/home/print9497.nsf/ November 17, 1997.

Keravnoe E and Washbrook S (1989). Deep and shallow models in medical expert systems. *Int J Artificial intelligence in Medicine, 1,* 11-28.

Klein M and Mehlie LB (1990). *Knowledge-based decision support systems with applications in business.* John Wiley et Sons, UK.

Lenat D B (1975). The ubiquity of discovery. *Artificial Intelligence 9, 3*, 257-285.

Little JDC (1970). Models and managers: The concept of decision calculus. *Management science, vol 16,* 466-485.

Lorenzi N (1999). IMIA Working group 13: Organisational impact of medical informatics. *Int J of Medical Informatics 56, nos 1-3*, 5-8.

Lorenzi NM, Riley RT, Blyth AJC, Southon G and Dixon BJ (1997). Antecedents of the people and organisational aspects of medical informatics. Review of the literature. *JAMA, no 2*, 79-93.

Lundsgaarde H P (1987). Evaluating medical expert systems. *Social Science and Medicine 24, 10,* 805-819.

March ST and Smith GF (1995). Design and natural science research on information technology. *Decision Support Systems 15,* 251-266.

McDermott J (1988). Preliminary step toward a taxonomy of problem-solving methods. In Marcus S (ed.), *Automatic knowledge acquisition for expert systems.* Kluwer Academic Publishers, Boston USA, 225-254.

Moore JH and Chang MG (1980). Design of decision support systems. *Database, vol 12, nos 1 and 2*, 8-14.

Musen MA (1999). Scalable software architectures for decision support. *Methods of Information in Medicine 38,* 229-238.

Newell A (1982). The knowledge level. *Artificial Intelligence 18*, 87-127.

Newell A and Simon H (1976). Computer science as an empirical inquiry: Symbols and search. (1975 ACM Turing Award Lecture), *Comm ACM 19, 3,* 113-126.

Nilsson N (1974). Artificial intelligence. In: Rosenfeld JL (ed.), *Information Processing 1974*, North-Holland, Stockholm, 778-901.

Nonaka I (1994). A dynamic theory of organizational knowledge creation. *Organisation Science vol 5, no 1,* 14-37.

Nuutila P, Irjala K, Viikari J, Forsström J, Välimäki M, Nykänen P and Saarinen K (1991). Clinical value of the decision support system for the assessment of thyroid function. In: Adlassnig KP, Grabner G, Bengtsson S and Hansen R (eds.), *Proceedings of Medical Informatics Europe 1991, Lecture Notes in Medical Informatics 45,* Springer Verlag, Berlin, 389-393.

Nykänen P and Nuutila P (1991). Validation and evaluation of a system for thyroid disorders. *Expert Systems with Applications, vol. 3,* 289-295.

Nykänen P, Boran G, Pince H, Clarke K, Yearworth M, Willems JL and O'Moore R (1993). Interpretative reporting based on laboratory data. *Clinica Chimica Acta 222*, 37-48.

Pothoff P, Rothemund M, Schwebel D, Engelbrecht R and van Eimeren W (1988). Expert systems in medicine. Possible future effects. *Int J of Technology Assessment in Health Care, no 4,* 121 – 133.

Ramoni M, Stefanelli M, Magnani L, Barosi G (1990). *An epistemological framework for medical knowledge based systems.* Pavia University, Research report RIDIS-41-90.

Reisman Y (1996). Computer-based clinical decision aids. A review of methods and assessment of systems. *Int J of Medical Informatics, vol 21, no 3*, 179-197.

Schreiber A, Wielinga B, Breuker J (eds.)(1993). *KADS: A principled approach to knowledge based systems development.* Academic Press, London.

Scott Morton M (1971). *Management decision systems: Computer-based support for decision making.* Harvard University Press, Boston.

Simon HA (1981). *The sciences of the artificial*. MIT Press, Cambridge.

Sprague RH and Carlson ED (1982). *Building effective decision support systems.* Prentice Hall, Englewood Cliffs, NJ.

Sprague RH (1980). A framework for the development of decision support systems. *MIS Quarterly, vol 4, no 4,* 32-46.

Sprague RH and Watson HJ (eds.)(1989). *Decision support systems. Putting theory into practice*. Prentice Hall, USA.

Turban E (1988). *Decision support and expert systems. Management Support Systems.* Macmillan Publishing Company, First edition, USA.

Winograd T and Flores F (1986). *Understanding computers and cognition. A new foundation for design*. Addison-Wesley, USA.

Wyatt J (1987). The evaluation of clinical decision support systems: A discussion of the methodology used in the ACORN project. In: Fox J, Fieschi M and Engelbrecht R (eds.), *Proceedings of the Artificial Intelligence in Medicine, Lecture Notes in Medical Informatics 33,* Springer Verlag, Berlin, 15-24.