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Context modeling for decision support

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Abstract

This paper addresses the issue of how one can model, represent and use context in a DSS. The modeling approach builds upon a decision making framework and concepts from sociology in developing five classes of decision support objects: interpretative scheme, facility (resources), norm (preferences), argumentation process, and task context (set of options). Specific instances of these five classes are iteratively adjusted in providing support to the decision makers. Additional support is provided by the use of formal procedures adapted from automated reasoning research. The result is a context sensitive DSS that supports decision makers in the communication of an argument for a particular course of action.

Keywords

Context, DSS, structuration theory, modal logic, object oriented

1 INTRODUCTION

The social environment is a context in which actions are taken. It provides cues as to what is happening. Social context is important because it binds people to actions that they must then justify and it provides norms and expectations that constrain explanations (Weick, 1995, p. 53).

Several concepts are expressed here that inform the goal of modeling context in order to provide decision support. The cues that the environment provides must be interpreted. Justifying actions that people take in a social interaction involves explaining the use of resources and the exercise of power by the actors in a particular situation. Context provides norms that are used in the justifications and, at the same time, constrain the choice of options. Therefore, any context sensitive decision support system (DSS) must explicitly include representations for (1) the

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cues that the environment provides, (2) the interpretative scheme that aids in communicating reasons for actions taken, (3) the norms (social preferences) that back an argument for actions taken, and (4) the use of resources in the execution of a plan of action. There are a number of contexts that need to be taken into account (e.g., organizational or task) depending on the purpose of the DSS. This papers identifies two types of *context* - a task context and a communicative context. It presents the concept of a context sensitive DSS in terms of all four representations, which interact and influence each other.

Section two of this paper builds on a decision making literature that is relevant to the design of DSS. It does this by reorienting a framework suggested in Nappelbaum (1997) by using concepts from sociology (Giddens 1993) as opposed to a more traditional DSS approach using psychology. This is followed by a review of an approach to automated reasoning with context based on modal logic. Although there are limitations, a modal logic of context that *supports* a decision maker is possible. Section four describes a conceptual architecture for a DSS that incorporates reasoning about context. The final section presents some conclusions and suggestions for future research.

2 DSS BASED ON SOCIOLOGY

A natural basis for decision support systems is decision making. The result is that many researchers draw upon concepts, methods, and tools from psychology in designing and studying DSS. Another basis for DSS research has been artificial intelligence literature, which also has a strong linkage to psychology (see Newell, 1990). A particular example of a line of research consistent with these areas is provided by Nappelbaum (1997), which serves as the starting point for this section. Next the theory of structuration (Giddens 1993) from the field of sociology is described. A mapping from Nappelbaum's set of concepts to a new framework for designing and understanding DSS is then presented. The result is a social interaction basis for designing DSS.

2.1 Logic of problem formulation and choice

Nappelbaum (1997) presents a logic of problem formulation and choice. His argument is based on three premises: (1) five components of the choice situation, (2) the idea of balance, and (3) no preferred starting point. Two conclusions are then reached: (1) a circular logic of choice and (2) a circular logic of problem solving. His general thesis is that 'any problem of choice reduces itself, in the final analysis, to a problem-solving kind, while the solution of any problem of the latter type depends crucially on the appropriate choice of the problem representation.' (p. 267)

The first premise is that the problem of choice can be represented in terms of the following five major components:

- *Alternatives* - the set of options that are available for choice
- *Scope* of these alternatives - the boundaries of the problem as conceived by the decision makers
- *Preferences* - valuations the outcomes in terms of costs, benefits, and risks
- *Logic of choice* - argumentation process for arriving at a decision
- *Instrumental intentions* - justification for the choice and decision execution planning

The second premise of the argument is that these five components are in a continual dynamic balance for the decision maker. 'Within this framework, in the process of choice, we do not choose only an option but, concurrently and interdependently, *all* the five components of the problem formulation ...' (p. 262). The idea is that, as the decision makers explore the options, they also start building their justification for why they chose a particular option. They are also exploring their preferences for different outcomes. This is consistent with the constructive nature of preferences and beliefs in the behavioral decision making literature where '... preferences for and beliefs about objects and events of any complexity are often constructed - not merely revealed ...' (Payne, Bettman and Johnson, 1992, p. 89).

The third premise of Nappelbaum's argument is that there is no preferred starting point in exploring the five components of the choice situation. The decision makers can start with an examination of the current scope that is a result of previous choices. They could react to criticism of their reasoning and justification for a particular choice for a failure in the planned implementation. 'Within the framework proposed here, it is essential to see that there are many entry points into the process of conceptualization, and none of them may claim the privileged role.' (p. 269)

Nappelbaum's framework involves a circular representation between the five components of choice. The scope, preferences and instrumental intentions are on the outside and the alternatives are in an inner circular. Within the set of options is the preferred choice. All of these components are linked by two way arrows. Given this, then 'The problem of choice, therefore, turns out to be reduced to the problem of problem-solving, that is, to the problem of finding a representation which balances out in the sense explained above.' (Nappelbaum, 1997, p. 264). Thus, there is a dynamic balance between the five components no matter which starting point is used in exploring the choice situation.

Comparison of Nappelbaum's circular logic of choice with his circular logic of problem formulation finds that (1) he equates the alternatives, set of options, with a problem solving search space and (2) he equates scope with a declarative representation, description of the problem solving search space. The set of options, as a problem solving search space, represents the task context that the decision makers consider. The scope could be referred to as the organizational context, but for reasons to be presented shortly, this is considered the communicative context. This pair of contexts is described after the second basis for context modeling is presented in the next subsection.

2.2 Structuration Theory

The particular sociological grounding that is used for context modeling for decision support is based upon the Structuration Theory of Anthony Giddens [note: undated 'Giddens' references are to the second edition (1993) of his book that was first published in 1976]. This subsection reviews the basics of his theory.

Adaptive Structuration Theory as described by DeSanctis and Poole (1994) and by Orlikowski and Robey (1991) is another example where concepts from Giddens are used in information systems research. Whereas they are using it as a conceptual basis for describing the adoption and use of DSS, we are using it to provide a basis for the design of DSS.

Giddens presents a framework for analyzing social interactions. It is based on the premise that 'social structure is both constituted *by* human agency and yet at the same time the very *medium* of this constitution.' (pp. 128-9) He refers to this as the *duality of structure*. This is a dynamic process and involves three modalities. The duality of structure can be represented as follows:

Table 1 The Duality of Structure (based on Giddens, 1993, pp. 129-30)

Interaction	Communication	Power	Morality
Modality	Interpretative scheme	Facility	Norm
Structure	Signification	Domination	Legitimation
Analysis	Semantic rules	Resources	Moral Rules

The concepts on the first line refer to properties of interaction that occur between members of a community, while those on the third line are characterizations of structure. The 'modalities' refer to the mediation of interaction and structure. They can be analyzed in terms of the items on fourth row of the table. The members of society draw upon the modalities as an integrated set rather than as three discrete components. The communication of meaning in interaction involves the use of interpretative schemes. These are cognitive schemes that depend upon a shared understanding by a community. The use of power in interaction involves the application of facilities whereby participants are able to generate outcomes through affecting the conduct of others. Finally, the moral constitution of interaction involves the application of norms. These norms are based on structures of legitimation. Giddens (1993, p. 130) states that 'Just as communication, power and morality are integral elements of interaction, so

signification, domination and legitimation are only analytically separable properties of structure.'

According to the notion of the duality of structure, the rules and resources (see the analysis row of the table) are drawn upon by the actors in the production of interaction, but, in doing so, they also reproduce the social structures. The analysis row provides a way of representing the modalities and, hence, a way of studying the modalities in understanding the structures of interaction.

A mapping is proposed between the three modalities of Giddens and the five components of Nappelbaum in the next section. The claim is that combining these two frameworks provides a sociological basis for designing DSS.

2.3 Social structure basis for DSS

The five components of Nappelbaum's framework are: (1) alternatives, (2) scope, (3) preferences, (4) logic of choice, and (5) instrumental intentions. Giddens' three modalities are: (1) interpretative scheme, (2) facility, and (3) norm.

What is missing from Giddens framework is a depiction of actions and the context in which those actions take place. He states that 'In the production of meaning in interaction, context cannot be treated as merely the 'environment' or 'background' of the use of language. *The context of interaction is in some degree shaped and organised as an integral part of that interaction as a communicative encounter.*' (Giddens, 1979, p. 83, italics in the original) Two types of context can be identified by taking these comments into account with Nappelbaum's five concepts and his circular model. There is a task context that represents the alternatives as a set of options. There is a communicative context that is represented by the interpretative scheme. The result is shown in Figure 1.

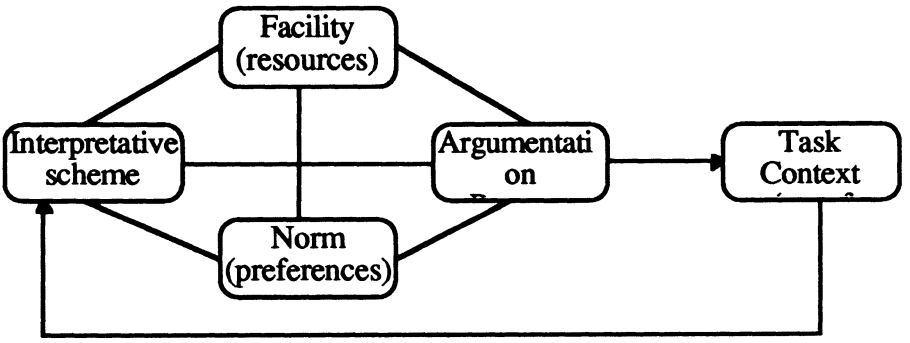

Figure 1 Feedback model for DSS

The figure shows five components, four of which are in a dynamic balance with feedback from the task context to the interpretative scheme. The intent of the drawing is to capture the continual operation and balance between the five factors in

the course of social interaction. Figure 1 is a synthesis between Nappelbaum's five factors and Giddens' framework.

Task context describes the set of options from which the decision makers can choose since it gives an indication of the features of the alternatives. It gives information that is used in deciding between alternatives (Tversky and Simonson, 1993). The interpretative scheme provides a way for understanding and communicating the scope of the alternatives in terms of the current state of affairs and the outcomes that can be expected from taking the decision. Norms provide the backing for an argument that supports the choice of a particular option from among the set of possible alternatives. The norms can be thought of as expressing the preferences of a community of individuals that are represented as moral rules. The logic of choice is replaced by an argumentation process that supports the making a of claim for a particular course of action (Toulmin, Rieke and Janik, 1979). Facility takes into account the resources that are available, the justification for using these resources, and impact on the social interactions of the community in using them. The comparison with Nappelbaum's five objects and the proposed framework is given in Table 2.

Table 2 Proposed objects for DSS

Decision making objects	*Social interaction objects*
Alternatives	Task context
Scope	Interpretative scheme
Preferences	Norm
Logic of choice	Argumentation process
Instrumental intentions	Facility

The interpretative scheme is a modality that uses declarative representations of the problem space. The norms draw upon pragmatic representations and the facility object uses representations of procedures. Giddens concept of the duality of structure means that these representations are both drawn upon and, at the same time, reproduced through the activities of participants in systems of interaction.

The five objects of social interaction and the framework in Figure 1 are intended to be consistent with the three premises of Nappelbaum (1997). There is a dynamic balance between the interpretative scheme, facility, norm and the logic of choice in arriving in an action to be taken. The task context of the decision situation is represented by the range of options. This range is available to all the participants in the community in so far as their interpretative scheme makes them available to

them. This view of the decision situation that needs to be supported by a DSS is sensitive to the context. Support is needed in building an argument for taking a particular decision and understanding the results of such action. This is a social process that occurs within a community that moves the design of DSS beyond individual decision making or problem solving.

A key feature of such a DSS is being able to support the reasoning about context. The next section sketches the design of such reasoning.

3 MODAL LOGIC OF CONTEXT

There is a significant literature on the logic of choice that provides many approaches and tools. There are many commercial products that can support the decision maker based on these tools, but there is very little software support for reasoning about context. Artificial intelligence research in the areas of knowledge based systems, truth maintenance systems, and natural language understanding address the concept of context (see Brézillon, 1996, for a review). This section presents an approach for reasoning about context based on the use of modal logic.

3.1 Modal logic

Classical propositional logic can be extended to include modal operators beyond the common one of negation ('$\neg\phi$'). A new modality ('$L\phi$') is introduced to express the sentence that ϕ holds in context κ. The notation '$L(\kappa, \phi)$' is used when it is necessary to identify which context ϕ holds in those cases where several contexts are involved in the reasoning. The modal logic of context concepts in this section are based on Buvac, Buvac, and Mason (1995). A general introduction to modal logic is provided by Chellas (1980).

The basis for a modal logic of context is as follows:

Primitive symbols

$\phi, \psi, \ldots$ [propositional variables]
$\neg$, L [monadic operators]
$\wedge, \vee$ [dyadic operators]
(,) [brackets]

Formation rules

A variable standing alone is a well formed formula (wff)
If ϕ is a wff, then so are $\neg\phi$ and $L\phi$
If ϕ and ψ are wffs, then so is $(\phi \vee \psi)$

Transformation rules

If ϕ and $(\phi \rightarrow \psi)$ are theses, then so is ψ. [*modus ponens* (MP)]
If ϕ is a thesis, then $L\phi$ is a thesis. [rule of necessitation (RN)]

Axioms

(D) $L\phi \rightarrow \neg L\neg\phi$ [or equivalently $L\neg\phi \rightarrow \neg L\phi$]
(K) $L(\phi \rightarrow \psi) \rightarrow (L\phi \rightarrow L\psi)$
(Δ) $L(\kappa_1, L(\kappa_2, \phi)) \vee L(\kappa_1, \neg L(\kappa_2, \phi))$
(ND) $\neg L(\kappa_1, L(\kappa_2, \phi)) \rightarrow L(\kappa_1, \neg L(\kappa_2, \phi))$ [Δ and ND are equivalent]

If there is only one context to be considered, then this formal system is identical to what is usually called the *normal system* of modal logic characterized by propositional logic with MP and extended by axiom K and the rule of necessitation (RN). An example of the use of the modal logic approach is given before describing the some of its limitations.

3.2 Example reasoning

Consider the problem of reasoning with two rules that may or may not hold in a specific context. This is an example of the type problem encountered in knowledge discovery in a data warehouse (Padmanabhan and Tuzhilin, 1997). The lower case letters - a, b, x, y - are used in this subsection to represent specific instances of the propositional variables ϕ.

Assume that the decision makers have two rules, one is $a \rightarrow b$ and the other is expressed in the form $x \rightarrow y$. Further assume that the following three conditions hold:

(i) b and y logically contradict each other
(ii) a and x are both true
(iii) the rule a and x implies b holds ($a \wedge x \rightarrow b$)

Since condition (i) constrains b and y to logically contradict each other, then it logically follows that the rule $a \wedge x \rightarrow \neg y$ holds. If the decision makers ask whether $a \rightarrow b$ or $x \rightarrow y$ holds, then they find that logically if one does then the other cannot and vice-versa. If they do not recognize this, then they introduce a logical inconsistency into their reasoning, which can lead to errors later.

If condition (ii) is contextualized - $L(a \wedge x)$ -, then they can derive $L(b)$ and $L(\neg y)$ as conclusion, but these only hold within a particular context. The decision makers are still faced with either accepting $L(a \rightarrow b)$ or $L(x \rightarrow y)$, but not both. They have encapsulated their problem within a limited context, but they still cannot accept both rules when continuing their reasoning. In a sense, they have pushed the problem down to a lower level and put a boundary around it. What they need to do is to consider two contexts.

Each rule can be true within a particular context - $L(\kappa_1, a \rightarrow b)$ or $L(\kappa_2, x \rightarrow y)$ - and reasoning with these rules can take place using axiom Δ and a specialization of the transformation rule RN, which is called context switching (Buvac, Buvac and Mason 1995). The key claim of this section is that a logic of choice based on a process of reasoning with context is feasible. The next subsection gives two limitations of this approach and the claim that these are not a serious impediment to its use in DSS.

3.3 Problems

Modal logic is used as a basis for a logic of knowledge and belief. There is a series of axiom schemata that can be included and Chellas (1980) identifies 15 distinct normal systems of modal logic by taking these schemata as theorems in all possible combination. The result is not a serial chain with 15 links in it but rather a network with about five layers in it. The McCarthy and Buvac (1997) formal logic of context modifies some of the axioms and rules of inference of normal modal logic for the specific purpose of reasoning about context.

As an example of the limitation of using modal logic consider two possible rules of inference:

RM. If $\phi \rightarrow \psi$ then $L\phi \rightarrow L\psi$

RN. If ϕ then $L\phi$

The difference between these two rules of inference is important. RM says that knowledge is closed under implication. If the decision makers have the proposition that $\phi \rightarrow \psi$ and also $L\phi$ then they accept $L\psi$. The proposition $\phi \rightarrow \psi$ can be thought of as a production rule in a knowledge based system (expert system). If this rule is in the system and by reasoning about the problem context results in $L\phi$, then we assume that the production rule 'fires' and the fact $L\psi$ is added to the knowledge base. The rule of inference RN is stronger than RM. It says that, if the system can, in some way, derive ψ, then it also has $L\psi$ in the knowledge base. The inferencing process can be much more difficult and involve many different production rules; it does not matter how much effort is used in deriving ψ, once this is obtained then $L\psi$ is also available.

The difference between RM and RN can be thought of as the difference between problem solving and decision making. Only if there are production rules of the form $\phi \rightarrow \psi$ can $L\psi$ be obtained from $L\phi$ if only RM is available. This is consistent with Newell's (1990) description of problem solving. It is only when there are no more productions rules to fire that a system must use a more powerful reasoning approach, which Newell (1990) refers to as the decision making phase. It is only in the decision making phase that we can use the rule of inference RN. Rather than using production rules, the decision makers may have consulted an outsider expert, gathered some more empirical data, or built and solved some mathematical model.

This is just a description of the type of support a DSS should provide. If we were trying to build a data processing system to *replace* the decision makers then there is cause for concern. Keeping the decision makers in the process and supporting their reasoning addresses this issue.

Another issue to be aware of is the impact of using axiom Δ. Intuitively, it states that a context is committed on what is valid in another context. Using the knowledge based systems scenario again, the schema Δ expresses that it is true in the κ_1 knowledge base that the formula f is actually valid in the κ_2 knowledge base

or that it is true in the κ_1 knowledge base that the formula f is actually not valid in the κ_2 knowledge base. In other words, the κ_1 knowledge base behaves as if it can see into the κ_2 knowledge base and decide for any formula f whether or not is valid in κ_2. (Buvac, Buvac and Mason, 1995, section 7.1). Buvac (1996) refers to this as *contextual omniscience*, which means that every context 'knows' what is true in every other context.

This is another issue for builders of automated reasoning tools where the goal is to replace the decision maker. A weaker form of Δ can be developed by comparing the schemata ND and D. The resulting system does not have all the desirable properties of an automated reasoning tool, but keeping the decision makers in the process and supporting their reasoning addresses this issue also. Therefore, providing a DSS with the ability to reason about context using the axiom schema D and the rule of inference RM does provide *support* for the decision makers.

There are different purposes for developing a modal logic of context. McCarthy and Buvac (1997) argue that context should be treated as a first class object with the goal of specifying properties that can be useful in artificial intelligence applications. Giunchiglia (1992) proposes that context be taken as the set of facts used locally to prove a given goal plus the inference rules used to reason about them. He sees a context as a partial theory of the world that encodes an individual's subjective perspective about it. The view developed in this paper breaks their concept of context into two parts - the task context as a set of options and an interpretative scheme (communicative context) that represents the semantic rules used in communicating about the options. Therefore, the subjective perspective of the world is captured in both the interpretative scheme and task context.

Task context, as represented by a set of options, is one object that needs to be included in a context sensitive DSS. The other parts of the problem situation such as norms and resources must also be represented. The next section starts an effort toward meeting this need.

4 SUPPORTING SENSE MAKING AND DECISION MAKING

An object oriented view based on Booch (1994) is adopted in this section to describe the characteristics of a context sensitive DSS. This is a conceptual description since a working system has not been developed that would test specifics of this approach; therefore, a descriptive example for the context and interpretative scheme objects is provided.

4.1 Five classes

An *object* is an instance of a class, while a *class* specifies the common structure and behavior of a set of objects. The structural properties are represented by data structures as defined by *variables*. The behavioral properties are represented by

processes as defined by *methods*. Each of the five social interaction objects listed in Table 2 are described in turn.

Task context

The task context is a class whose objects are sets of options, that is, a specific instance of this class is a set of options. Task context models the set of options under consideration in a choice situation and it provides information about the quality of the options. (Tversky and Simonson, 1993). The methods associated with task context include formal logical reasoning based on the modal logic of context from section 3 - propositional logic with *modus ponens*, the rule of inference RM, and axiom D.

Interpretative scheme

The communication of meaning in interaction involves the use of interpretative schemes by means of which sense is *made* by participants of what each says and does (Giddens, 1993, p. 129). Sense making, in its early stages, consists of people trying to discover the amount of agreement they have on cause-effect linkages and on preferences for outcomes and this is a precondition of decision making (Weick, 1995, p. 112). The preferences for outcomes is part of the norm class and the structures for the cause-effect linkages are part of the facility class. The interpretative scheme class has data structures and methods that model the communicative context for the social interaction.

Norm

A variety of preferences for outcomes are considered. These are both individual preferences and group social norms. In addition, social and legal norms that might constrain the range of actions are considered relevant in context sensitive DSS.

Argumentation process

The structures and methods for the argumentation process are based on the Toulmin framework for informal arguments (Toulmin, Rieke and Janik, 1979). The result is a claim for a particular course of action based on data and logical reasoning. This may include the use of mathematical models, but this is not a requirement. The reader is referred to the Toulmin et al. text for examples of their approach applied in a variety of disciplines.

Facility

The structures for the facility class represent the cause and effect linkages that the decision makers assume exist and the resources and plans for realizing a particular course of action.

These five classes can be divided into subclasses in the development of specific DSS as needed. A particular example of the context and interpretative scheme is described in the next subsection.

4.2 Task context and interpretative scheme example

Consider the problem of trying to specify the desirable characteristics of a web site for a bank. This is a problem for any organization that is trying to take advantage of electronic commerce opportunities. The decision makers at a specific bank do not approach this problem in a blank context. There are the strategies and current commercial capabilities that the bank has. There is also the current electronic commerce capabilities of both the bank and its competitors.

The problem can be approached by gathering data about the strategies and web sites of the bank and, for example, three competitors. The choice of the competitors determines the task context. The decision makers could include, in their selection, three banks that compete with theirs only in a particular country or in a particular market. They might choose three banks that represent the best, the median, and the worst in terms of features that they offer to a customer, however they might subjectively determine this. The characteristics of the strategy and web sites of the four banks represent a range of options that is the task context for the problem.

As the decision makers review the strategies and corresponding web sites of the four banks (theirs and the three competitors), they make use of various interpretative schemes. They may make use of a 'best practices' scheme whereby they try to extract from the range of options the best features along various attributes. Alternatively, they could look at how each of the four web sites supports different phases of a customer service life cycle. The result of their decision making with this scheme is the identification or creation of capabilities that supports each of the phases that a customer might be in. A third scheme might be based on levels of interactivity, e.g., information publishing versus transaction processing. The communication of their recommendations involves being able to explain the task context in terms of whichever scheme they choose. The success of this communication depends upon the shared understanding that the organization has when using each of the different schemes.

Therefore, a context sensitive DSS supports the decision makers in the communication of the arguments for a particular course of action. It involves representing the task context as a range of options in which the subsequent action is taken. Explicit representation of the task context and the communicative context by the interpretative scheme is a key feature of context sensitive DSS.

5 CONCLUSION

This paper addresses the issue of how one can model, represent and use context in a DSS. Task context is modeled as a set of options that provides cues about the features of the environment in which actions are taken. This is separate from the interpretative schemes that are used in providing different frames in which the task context is viewed. Each interpretative scheme aids in communicating reasons for

actions taken, and it is in this sense that a scheme can be considered to model the communicative context for the social interaction. This context interacts with social norms and also reflects the history of a social interaction among the decision makers. The communicative context, as modeled by the interpretative scheme, along with representations of the norms and resources are in a dynamic balance with an argument representation in supporting the decision makers. The five classes of decision support objects identified in this paper - interpretative scheme, facility (resources), norm (preferences), argumentation process, and task context (set of options) - are iteratively adjusted in providing support to the decision makers.

This research is based on mapping the three modalities of structuration theory (Giddens 1993) to the five component models of problem formulation and choice identified by Nappelbaum (1997). A second basis for this research is a logic of context (McCarthy and Buvac, 1997). Both of these areas require further elaboration and testing if they are to be useful in developing specific DSSs. In particular, the problem of developing a modal logic of context parallels efforts in developing a deontic concept of obligation. The same issues raised in section 3 about axiom D versus ND and rule of inference RM are present in deontic logic (Chellas, 1980), but this also provides a basis of previous research on which to build a modal logic of context.

DSS supports decision makers in developing arguments for a particular course of action. The design of such a DSS based on the five classes of decision support objects is only described in the barest of detail in section four. Specific data structures and methods need to be developed and explored. The view of DSS as being based on an iterative adjustment between the components of an architecture has a real implementation impact on any systems development. Also, the implementation of the argumentation basis needs further specification. All of these areas provide opportunities for future research.

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