A framework for Group Decision Support Systems: Combining AI tools and OR techniques

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Abstract: Work on the implementation of Group Decision Support Systems has to exploit recent advancements of computer science. Existing frameworks for single-user Decision Support Systems, based on well-established Operations Research methods such as Multicriteria Decision Making techniques, have to be integrated with successful technical developments in electronic communication and computing. Starting from the presentation of the related Operations Research background, this paper proceeds by discussing challenges coming from the areas of Computer-Supported Cooperative Work and Information Systems on the World Wide Web platform. Based on this discussion, a framework for an "open", computer-mediated Group Decision Support System is proposed. The term "open" is related to a platform-independent system, which can efficiently support alternative types of goals and control protocols between its users.

Keywords: Group Decision Support Systems, Artificial Intelligence, Computer-aided decision making, Computer-mediated communication, Computer-Supported Cooperative Work.

1 Introduction

The introduction of Decision Support Systems (DSSs) in the 1970s and 1980s received great attention since these systems were heading to important developments, such as the integration of interactive systems for managers and professionals, the achievement of user-friendly environments, and the provision of a suitable framework for the handling of semi-structured and unstructured tasks. However, research on this area, having over-dealt with

technological and definition issues (e.g., the differences between a DSS and an Expert System or an Executive Information System), has de-emphasized other major issues in improving decision making (Alter, 1992). These issues include work structuring in order to improve coordination, use of communication technology to make decision making more efficient and effective, enforcing of rules and procedures for achieving consistency, and even automating the data processing in data intensive decision making situations. Only recently research on DSS design has acquired a strong organizational focus (Zuurbier, 1992). As highlighted in (Angehrn and Jelassi, 1994), the DSS community should further consider the conceptual, methodological and application-oriented aspects of the problem. *Conceptual focus* is associated with the consideration of the nature of individual and organizational decision making processes, *methodological focus* with the integration of existing computer-based tools, techniques and systems into the human decision making context, and *application-oriented focus* with the consideration of the real organizational needs by extending decision support to business teams.

The above criticism receives a growing interest in the context of Group Decision Support Systems (GDSSs). A GDSS is an interactive computer-based system that facilitates the solution of ill-structured problems by a set of decision makers which work together as a team (Kreamer and King, 1988). The main objective of a GDSS is to augment the effectiveness of decision groups through the interactive sharing of information between the group members and the computer (Huber, 1984). This can be achieved by removing communication impediments, providing techniques for structuring decision analysis and systematically directing the pattern, timing, or content of the discussion (DeSanctis and Gallupe, 1987).

Furthermore, group decision making in real environments has to confront conditions such as (Karacapilidis and Gordon, 1995):

- The decision making procedure has to be performed through a lot of debates and negotiations among a group of people. Conflicts of interest are inevitable and support for achieving consensus and compromise is required. Each participant in the discussion may adopt and, consequently, suggest his own strategy that fulfills some goals at a specific level.
- Reasoning is defeasible, that is, further information can trigger another alternative to appear preferable than what seems best at the moment.
- The coexistence of not enough and too much information; for some parts of the problem, relevant information which would be useful for making a decision may be missing, whereas for other parts the time needed for the retrieval of the existing information volume may be prohibitive for the participants to make a decision. Regarding the efficiency of the system, response time is often a basic issue.

- However much information is available, opinions may differ about its truth, relevance or value for deciding an issue. In addition, decision makers may have arguments supporting or against each alternative solution.
- Factual knowledge is not always sufficient for making a decision. Value judgements, depending on the role and the goals of each decision maker, are often the most critical issues.
- Last but not least, decision makers are not proficient in mathematics or computer science. The system should provide them appropriate tools in order to participate in the discussion in a "natural" way. This is in accordance with the DSS pioneers' vision, that is, by supporting and not replacing human judgement, the system comes in second and the users first.

The rest of the paper proceeds as follows: Section 2 gives an assessment of a group decision making environment, classifying design issues proposed in the literature. Section 3 summarizes development techniques and software coming from the OR discipline. Challenges coming from the area of Computer Supported Cooperative Work, the exploitation of the World Wide Web and AI approaches to reasoning and argumentation are presented in Section 4. Based on them, a framework for an "open" computer-mediated GDSS is proposed in Section 5.

2 An assessment of the group decision-making environment

Problems considered in a group decision making environment require the knowledge and expertise of a group of people. This group debates upon the problem aiming at achieving a common understanding of the issues revealed and arriving at a satisfactory solution. Usually, the group explores a variety of alternative solutions, using some tools for answering "what-if" questions. The participants (i.e., decision makers) may have different roles, depending on some predetermined organizational hierarchy or political power. Besides, it may be difficult for the interested parties to meet at some specific places and times. It may also be not possible for each party to have the necessary tools that would promote the discussion. In these cases, a technology-assisted group decision making environment, which will remotely support this type of activities, is needed. Tasks taking place in a group decision making environment can be categorized according to what the group must accomplish in the course of its meeting. Basic group goals in these settings include *generating* ideas and actions, *choosing* alternatives and *negotiating* solutions (McGrath, 1984).

The environment in which the group decision making procedure takes place sets different communication requirements and defines alternative types of GDSSs. Alternative

taxonomy schemes for these systems, justified across various dimensions of design issues, have been proposed in the literature (Jarke, 1986), (Jelassi and Foroughi, 1989), (Fisher and Ury, 1981). According to them, issues that have to be taken into account in the design and implementation of a GDSS are:

- The *spatial distance* between decision makers. This refers to whether full face-to-face communication among them is possible. This feature is certainly de facto provided in local DSS settings, but it must be compensated for with electronic communication facilities in remote multiperson decision environments. Depending on the group size and the proximity of members during a decision making procedure the following settings have been identified (DeSanctis and Gallupe, 1985), (DeSanctis and Gallupe, 1987): (i) the *decision room*, where an electronic version of a traditional meeting situation is established (smaller group, face-to-face meeting); (ii) the *legislative session* (as above but for a larger group and face-to-face meeting); (iii) the *local area decision network*, where group participants can communicate with each other and with a central processor through a local-area network (smaller group, dispersed), and (iv) the *computer-mediated conference,* where communication is provided between two or more remote groups by linking decision rooms together through audio and video facilities (larger group, dispersed).
- The *temporal distance* among the decision-making activities performed by the individual group members. This refers to whether decisions are made by meetings at a particular time, such as in conventional meeting or teleconferencing environments, or whether participants submit their input at different points in time, based on electronic mail, bulletin boards, newsgroups and computerized conferencing concepts.
- The *type of participants' goals* distinguishes between an environment in which a group wants to solve its common problem cooperatively, and another, in which bargaining takes place. Issues arisen in the first case, which has been mostly addressed by the researchers, are knowledge sharing, preference aggregation, and negotiation support. Beyond them, aspects from behavioral theory and Operations Research need to be exploited in bargaining environments. There are three modes of reaching a decision, depending on the degree of cooperativeness among the decision makers (Jelassi and Foroughi, 1989): (i) the *pooled mode*, where there is so much cooperation that the individuals act almost as a single decision maker; (ii) the *cooperative mode*, where decision makers may have difficulties in understanding and accepting each other's positions, and may need negotiations before taking the final decisions; (iii) the *non-cooperative mode*, where a series of negotiations must integrate the separate, often conflicting and incompatible, individual problem representations into a common solution.

- The type of *control* over the group decision making process: there may be cases where the participants follow a democratic process in order to reach a solution, and cases where the system is supported by a human group leader or mediator. In the former ones, communication and coordination are achieved by the users or directly by the system. The latter ones can be further distinguished in those where the human mediator cannot impose decisions on the participants, and those where there is compulsory arbitration from a group leader. Three levels of control have been identified (Jelassi and Foroughi, 1989): (i) *democratic, participative decision making*, (ii) *semi-hierarchical decision making aided by a mediator,* and (iii) *third-party arbitration.*
- *Separating people from the problem:* The system designer has to evaluate the individual and group characteristics of the participants, their motivations and approaches to conflicts and their possible disagreements in order to reduce (if not avoid) the negative impact that misunderstandings, emotions and bad communication may have. Behavioral issues of the problem are discussed in (Jarvenpaa et al., 1988) and (Zigurs et al., 1988). The use of Nominal Group Technique (NGT) (Delbecq et al., 1975) can facilitate the elicitation of common goals and help the participants to focus on the advantages of a negotiated settlement of their differences. Different approaches to conflict identified in the literature are (Lewicki and Litterer, 1985): (i) *contending or positional bargaining*, where a party is trying to convince the opponent(s) to accept its favorite position; (ii) *accommodating*, involving a party's effort to help another party meet its objectives; (iii) *compromising*, meaning a splitting of the differences between interested parties, that is satisfying but not optimizing; (iv) *collaborating*, involving parties working together to optimize their joint outcome, like in group problem solving settings, and (v) *avoiding* the negotiation process for various reasons such as fear of conflict, not worth bargaining issues, or intention of negotiations' postponement.
- The *type of communication* between the participants: group decision making environments can be based either on *point-to-point communications*, or on *broadcasting* of messages.

The negotiation procedure may ranges from a "soft" to a "hard" type (Fisher and Ury, 1981). The former type, also known as "integrative" or "win-win" bargaining, refers to problems addressed between friendly parties, heading for a jointly beneficial agreement. It is possible for both sides to fulfill their objectives, since their goals are not mutually exclusive. This type of negotiations is also common in the organizational context where, despite of the fact that there may be opinion differences, all parties are looking for a totally profitable solution. On the other hand, "hard" negotiation procedures, also known as "win-lose" or "distributive" bargaining, refer to situations where conflicting parties want to impose their own positions and "are not in a hurry to compromise" (Jelassi and Foroughi, 1989). These cases are

characterized by the fact that each party's goals are in direct conflict with those of the opponents, whereas each party wants to maximize its share of a fixed set of resources. Labor management debates, political disputes and nuclear test discussions are some examples of this negotiation type.

As proposed in (Jelassi and Beauclair, 1987), approaches for the development of GDSSs have to address both behavioral and technical aspects. Behavioral issues reported are the diffusion of responsibility, pressures toward group consensus and problems of coordination. A framework that integrates behavioral and technical perspectives may reduce the negative impact and enhance the positive effects of the former ones. Issues involved in the design of such a framework are: (i) support (or not) of anonymity depending on the type of the discussion (Connolly et al., 1990): the system may sometimes perform better if the participants don't associate their identification with their inputs; (ii) enforcement of participants' self-awareness; (iii) display of group inputs at any stage of the discussion; (iv) structure of the decision process: the actions the participants should follow may improve the efficiency of the system in terms of accuracy and response time; (v) ability to support communication, information sharing and democratic control: provision of communication and information sharing helps participants to create a "shared workspace", on which the discussion will be based; democratic control can be supported by specifying protocols depending on the type of the discussion.

3 OR and GDSSs

Multiple Criteria Decision Making (MCDM) methods and *Game Theory* have been the most used OR approaches in the development of GDSSs (Jarke, 1986). MCDM methods provide a means of integrating multiple views of a problem and support both quantitative and qualitative criteria. Most of these methods can be interactive, allowing for easy revisions of problem representations. Using MCDM methods, one can integrate formal tools for preference aggregation, negotiation and mediation in a variety of discussion environments. Game Theory (Von Neuman and Morgenstern, 1964), (Owen, 1982) uses mathematical models for the analysis of situations where there is a conflict of interest. Following this theory, when a conflict occurs, decision makers are free to select various alternative outcomes. So-called zero-sum games are used to represent cases where bargaining takes place (one party wins and the other loses), such as in "hard" negotiations. On the other hand, in cases where the interests of the "players" are in conflict, mixed-motive or non-zero-sum games are used (one, both, or neither party may win). Among other approaches we only mention here the Conflict Analysis method (Fraser and Hipel, 1986), Mathematical Programming (Kersten, 1985), Group Decision Theory (Eliashberg et al., 1986), Decision

Analysis (Quinn et al., 1985), Generalized Approach for Structuring and Modeling Negotiations (Kersten and Szapiro, 1986), and the Evolutionary Systems Design (Shakun, 1987).

In the rest of this section we highlight some representative GDSSs that have been developed following the OR discipline. Concerning cooperative group decision making contexts, we discuss Co-oP and MEDIATOR systems. *Co-oP* (Bui and Jarke, 1986) has been implemented on a network of personal computers. The discussion environment in Co-oP is democratic, remote and cooperative. The system offers a variety of communications facilities, ranging from e-mail to structured group communication tools (such as Delphi and NGT), and extended MCDM models for information exchange and preference aggregation. *MEDIATOR* (Jarke et al., 1987) is also a multicriteria-based micro-mainframe DSS. It can be applied in cases where the situation becomes less friendly. In such a case, access control to private data and problem representations and tools for negotiation support are needed. In MEDIATOR, the group of human and computerized problem solvers includes a human mediator. The role of the mediator is to aid the participants to establish a joint problem representation and, through compromise and consensus-thinking, find a mutually acceptable solution. Communication is achieved through the manipulation of database structures (this is similar to the concept of blackboard architectures in AI). The system proceeds following three phases, namely the *individual representation*, the *view integration* and the *negotiation phase*. In the first phase, each participant uses public and private DSS tools and databases in order to establish his individual representation of the problem. In the sequel, each one constructs his preference relations using an interactive MCDM method (all players use the same method), called *UTA* (Jacquet-Lagreze and Siskos, 1982), (Jacquet-Lagreze and Shakun, 1984). During the second phase, the human mediator tries to achieve a joint problem representation. There is a common database, where individual definitions of data sources, alternatives, criteria, utility functions and decision matrices are transferred. The third phase, negotiation, proceeds only with this joint representation. The mediator may perform negotiations by consensus seeking, through exchange of information, and by compromise, where consensus is incomplete. Participants are aware of the negotiation process, since it can be represented either graphically or, as relational data, in matrix form.

As made clear, the systems presented above are appropriate for cooperative group decision making environments. On the contrary, systems like *Conflict Analysis Program*, *DECISIONMAKER, NEGO, RUNE, DINE* and *DECISION CONFERENCING* are appropriate for situations where there is a strong disagreement on factual or value judgements. These systems are usually termed as Negotiation Support Systems (Jelassi and Foroughi, 1989). We briefly discuss these systems in the following, the target being to extract their pros and cons.

Conflict Analysis Program (CAP) (Fraser and Hipel, 1981) is an interactive, micro-computer based system intended to provide support for an external, third-party arbitrator, but only during the phase of the pre-negotiation strategy formulation. Its negotiation theory is based on meta-game analysis. The system can formulate and analyze the subjective alternative strategies and preferences of the discussion partners. Information from them is then presented to the arbitrator, which can eliminate unfeasible agreements, order the participants' preferences, and perform stability analysis on participants' inputs. Its main disadvantages are that the arbitrator is solely responsible for the creation of the model and participants are allowed to provide their inputs only once (at the beginning of the negotiation procedure). *DECISIONMAKER* (Fraser and Hipel, 1986) is the enhanced version of CAP. Further to the options provided in CAP, DECISIONMAKER can model a conflict as it evolves over time, forecast possible compromise solutions and optimize decision making. Major disadvantage of these systems is that they don't support interaction with other participants.

NEGO (Kersten, 1985) is based on the generalized theory of negotiations formulation (Kersten and Szapiro, 1986) and supports an interactive process of individual proposal formulation and negotiation. The iterative procedure allows decision makers to change their strategies, form coalitions, and compromise on the issues under consideration. Linear programming optimization methods are used for the analysis of goals and alternative objective functions. Advantage of NEGO is that it deploys multidimensional scaling graphs to show the negotiation process. Major disadvantage is that all decision makers should rely on the same set of criteria.

DECISION CONFERENCING (Quinn et al., 1985) can be basically used for pre-negotiation planning, but is adaptable to direct negotiations. To be used in direct negotiations, decision models should be developed separately for the two opposing parties, before they work together in order to derive a mutually preferred solution. It is based on decision analysis theory. The system is supported by three facilitators who assist the participants in structuring, refining and solving the problem. The discussion usually takes place in a conference room with a large-screen projector, a computer and terminals for the participants' inputs. Disadvantage of the system is that only facilitators are allowed to use the computer, while participants watch the analysis of results.

RUNE (Kersten et al., 1986) is a rule-based system, which can be used in order to help participants of a discussion evaluate their positions and model their negotiating strategies. The system follows a two-stage approach, the learning and the interaction stages. In the former, participants formulate their initial proposals, while in the latter, they exchange proposals and make concessions. The discussion may lead to a compromise decision or a deadlock. The system comprises tools for the analysis and representation of goals,

inconsistencies checking, a goal modifier that updates the content of the rule-base, and an inference engine for the elimination of deductions at the meta-rule level.

DINE (Bíró et al., 1992) supports simultaneous, multiple issue, independent, peer-to-peer negotiations. The model used allows the integration of various negotiation support techniques that may have been used to support the independent peer-to-peer negotiations. Negotiators may in fact use any tool, as long as it supports the same peer-to-peer information sharing protocol. At the same time, DINE is a generalized multiple criteria decision making model (where the alternatives to be ranked are compound subsets of negotiated offers). The system integrates intuitive judgement and knowledge-based techniques with asynchronous and synchronous communication facilities (usually electronic mail). Another advantage is that DINE is actually a distributed negotiation support shell which can be controlled by a higher layer system (e.g. by scripts or office procedures), or a human end-user implementing different scenarios of the negotiation process.

4 Challenges

Apart from the OR approaches presented above, advancements in electronic communication and computing should be also exploited during the design of a GDSS framework. For instance, Database Management has long been recognized as one of the key components of decision support systems, since it provides the most appropriate means of accessing and maintaining accurate and consistent data (Sprague and Carlson, 1982). This issue is extensively addressed in (Jarke, 1986) and is not the focus of this section. Instead, we discuss here challenges arising from the Computer Supported Cooperative Work discipline and the use of World Wide Web.

Computer-supported cooperative work (CSCW) has been defined as computer-assisted coordinated activity, such as communication and problem solving, carried out by a group of collaborating individuals (Greif, 1988), (Greenberg 1991). The multi-user software supporting CSCW is known as *groupware* (Ellis et al., 1991). Sometimes this term is broadened to incorporate the styles and practices that are essential for any collaborative activity to succeed, whether or not it is supported by computer. CSCW may also be viewed as the emerging scientific discipline that guides the thoughtful and appropriate design and development of groupware (Greenberg 1991). Key issues of CSCW are group awareness, multi-user interfaces, concurrency control, communication and coordination within the group, shared information space and the support of a heterogeneous, open environment which integrates existing single-user applications.

The most successful CSCW technology to date is undoubtedly the *electronic mail*. Other well-developed technologies so far comprise *computer conferencing*, *teleconferencing* or

desktop videoconferencing (the act of conferencing at a distance with the aid of audio and video links), *group authoring* (enabling cooperative writing with additions, revisions, comments and annotations), and *group decision support systems* (where problem solving is directed at the organization of the issues involved). The last category comprises mediating systems that support discussion, argumentation, negotiation and decision making in groups.

As illustrated in Table 1, most taxonomies of CSCW technologies distinguish them in terms of their abilities to bridge time and space (the table is a more elaborate version of the one appearing in (Baecker, 1993), page 3). As cited in (Baecker, 1993), groupware technologies of the future need to span all quadrants of this table. This is usually described as *any time - any place* groupware. Nowadays, CSCW is strongly supported and explored from both industry and academic research. Everybody speaks for the shifting role of computers. Computers show up in a different light from previous accounts of "information processing". They appear as tools for managing commitments and their fulfillment and as tools for producing and "listening to" the assertions and assessments that structure the organization (Winograd, 1992). Computers can make explicit the structure of human interaction in an organization, providing new operational means for generating and monitoring workflows, being a more effective observer in what is going on, determining what is needed for whom, when, and what is to be done.

	Synchronous communications	***Asynchronous communications***
One group site	*Electronic meeting facilitation,* *Decision rooms*	*Media spaces,* *Desktop conferencing*
Multiple individual or group sites	*Teleconferencing,* *Desktop Videoconferencing,* *Broadcast Seminars*	*Electronic-Mail,* *Voice-Mail,* *Collaborative Writing,* *Workflow Management,* *Group Decision Support,* *Cooperative Hypertext*

Table 1: *A taxonomy of CSCW technologies*

A principal aim for the designer of a group decision making system should be to apply state-of-the-art telematics and groupware technology to provide advanced support for the users over wide area networks, in particular the Internet. The leading commercial groupware products, such as *Lotus Notes* and DEC's *LinkWorks*, are generic tools for developing groupware applications within a single organization, primarily over local area networks. A GDSS environment requires support for communication and cooperation across organizational, or even national, boundaries. The primary advantages of the above

commercial systems are well-integrated tools for creating documents and messages. Unfortunately, they typically use proprietary formats and communications protocols. Conversely, the primary weakness of the Web as a basis for groupware concerns the present difficulty for ordinary users of creating, linking, indexing and storing new documents. Two developments make it easier for ordinary users to develop content which can be disseminated over the Web: (i) the increasing availability of HTML and SGML editors, often as extensions to popular word processors, and (ii) the use of Portable Document Format (PDF), which may be generated automatically from almost any document using a special printer driver.

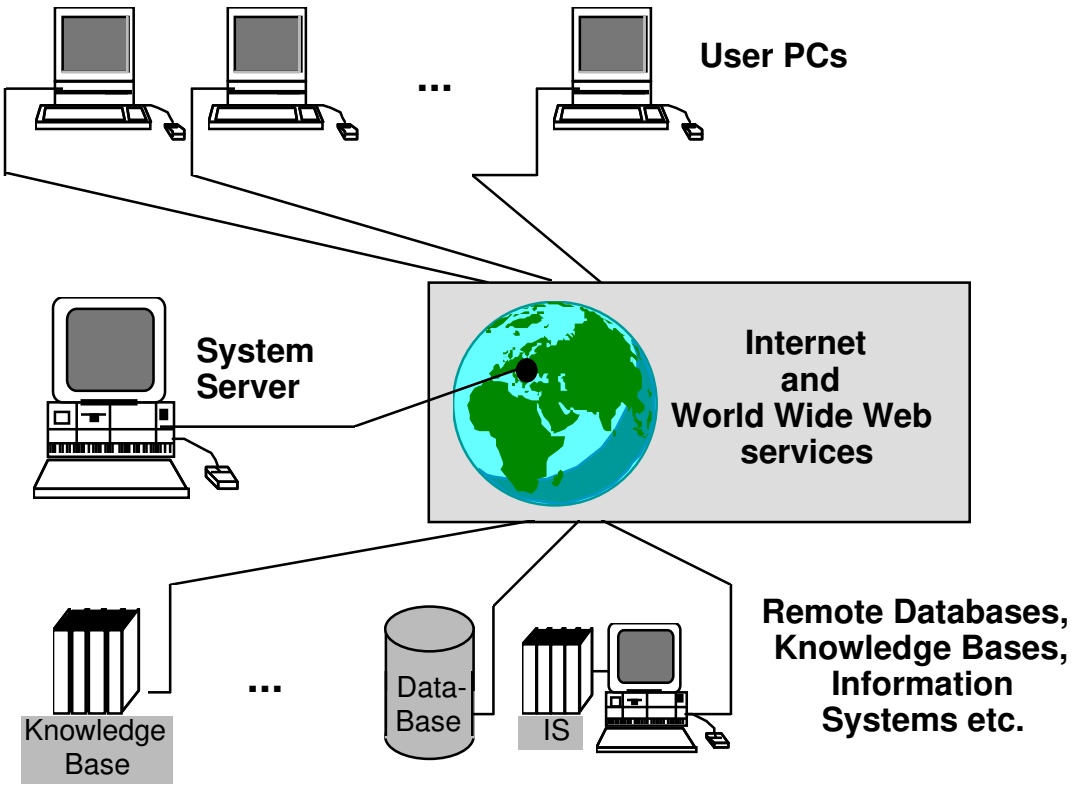

Figure 1: *Exploiting Internet and Web services.*

Furthermore, most decision makers will not want or be able to maintain a Web server. A way must be found to provide users with an opportunity to add information and assert their positions, which does not exacerbate the already difficult problem of later finding and retrieving information. Group decision support systems may alleviate this problem by using the discourse structure of a set of related messages. For example, messages may be organized by topic or *"thread"* in a hierarchy according to the *"reply"* relation. Existing groupware does not yet support this kind of interaction well. What is needed is a better integration of conferencing systems, such as the *Usenet news groups*, group decision support technology and the Web. There have been some experiments along these

lines, such as the *Web Interactive Talk* and the *Open Meeting* project in USA. As illustrated in Figure 1, decision makers will be connected to the server of such a system via Internet, using any Web browser. In addition, via the system server and appropriate intelligent tools for search and retrieval, they can have access to documents in distributed Databases, Knowledge-Bases and Information Systems. These issues will be further discussed in the next section.

Work coming from research areas such as reasoning, logic and argumentation, should be also taken into account in the specification of a GDSS framework. In the rest of the section, we give an overview of related concepts and theories. First, we mention the early work of Toulmin on a *theory of argumentation* (Toulmin, 1958). According to him, the mathematical orientation of "logics" is overemphasized and, although necessary, not of greatest practical significance. Instead, he views "logic" as a set of norms regulating practical discourse. The most interesting aspect in this theory is undoubtedly its structure of arguments. Briefly, a *claim* is a statement asserted by the proponent, who has to support it with a *datum*, if the opponent challenges it. If the opponent doubts that the datum supports the conclusion, the proponent is called upon to present a *warrant*, which is also defeasible and, in case of opponent's challenging, has to be supported by *backing*. Weaknesses of Toulmin´s theory are: (i) The cooperative only aspect of Toulmin´s argumentation; agreement is only possible if there is a certain willingness by both parties to agree. Instead, the GDSS framework required should be "open" and applicable to any kind of adversarial, or cooperative group decision making process; (ii) The lack of the appropriate formalism for ordering competing arguments; (iii) Its failure to fairly balance the interests of the proponent and the opponent; the proponent is obliged to face the opponent's right for limitless objection.

Pollock's *OSCAR* model of defeasible reasoning (Pollock, 1988) was one of the first attempts to base defeasible reasoning on arguments, influencing later work (see for example (Simari and Loui, 1992) and (Geffner and Pearl, 1992)). His model does not deal with resolving disputes, but with prescribing the set of beliefs a single rational agent should hold, under certain simplifying assumptions (throughout this paper, we use the terms agent and decision maker interchangeably). Following it, the initial *epistemic basis* of an agent comprises a set of positions which are either supported by perception or recalled from the memory, a set of *defeasible inference rules* and a set of *non-defeasible inference rules*. Belief on positions stands until defeated by new reasons, disregarding the original ones. OSCAR takes seriously computational limitations, such as memory and time, into account. Finally, the system does not make any distinction between roles of players, and there are no reasoning schemata provided for the validity of inference rules or for their relative weight and priority.

The work of Rescher on a *theory of formal disputation* (Rescher, 1977) considers disputation to be a three-party game, taking place with a *proponent* (asserting a certain position), an *opponent* (able to challenge proponent's position, i.e., through counterarguments) and a *determiner* (which decides whether the proponent's position was defended successfully or not). A more formal reconstruction of Rescher´s theory is presented in (Brewka, 1994), based on Reiter´s Default Logic. Brewka´s work clarifies Rescher´s concepts and goes ahead defining *elementary* and *legal moves* during a dispute, as well as *winning situations*. Nevertheless, both approaches are limited in that the players have no chance to disagree about defaults.

Finally, the *IBIS (Issue-Based Information System) rhetorical method* has addressed concepts such as *issues* (questions or problems), *positions* (possible resolutions of an issue), and *arguments* (the pros and cons of the alternative positions) (Conklin, 1992). The system has been developed at MCC and is based on the early ideas of Kunz and Rittel (Kunz and Rittel, 1970). Also interesting for our purposes is its "groupware version", namely *gIBIS* (Graphical Issue-Based Information System). It is a hypertext system, originally used for the software development process, which aids the structuring and documentation of the decision steps (Yakemovic and Conklin, 1990).

5 Towards an "open" GDSS

The framework proposed in this paper aims at supporting a new kind of conferencing and group decision support system. Services to be provided include management of the dependencies between argumentation elements (such as arguments pro and con, claims, positions and issues), users' awareness about their rights and obligations in a proceeding, and access to procedures for negotiation and conflict resolution. The task of such a system is to assist and advise the participants, and not to enforce the rules of the proceeding. Any Web browser (e.g. Mosaic, Netscape etc.) will be sufficient for a decision maker to take part in the system's mediated discussion. Exploiting the Web platform, issues related to any kind of spatial or temporal distance between the decision makers can be easily solved. Application scenarios may include that of a company or government trying to decide where to locate a new factory or agency, a community deciding how to partition the lots of a new housing district, or neighboring countries planning the path of a highway between two cities.

5.1 Services to be provided

By "open" GDSS we mean a system that makes information more accessible and affordable, and helps to open and democratize the decision making procedure. This would improve the

quality and acceptability of decisions and reduce the cost of delays. Services that should be integrated towards such a system concern the efficient retrieval and handling of the appropriate information. We classify these services in the following three levels (Figure 2):

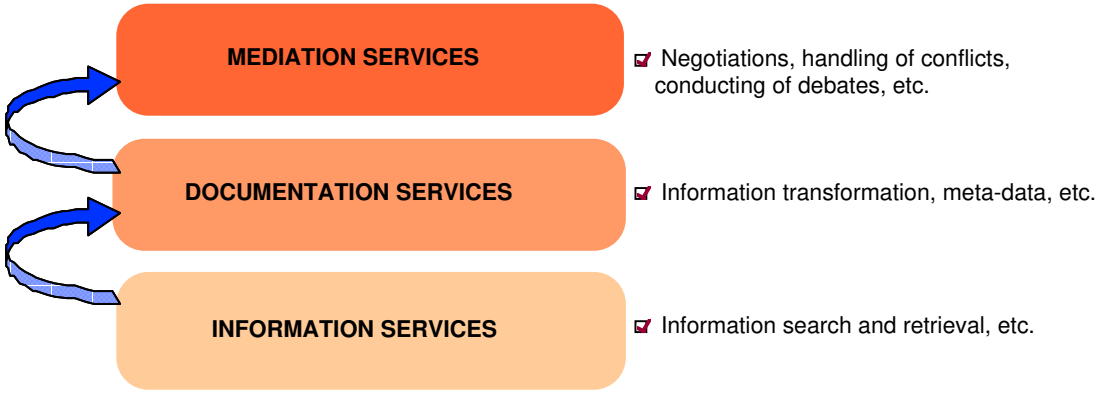

Figure 2: *Required services in a GDSS.*

- The *information services* will improve the interoperability of proprietary systems, providing efficient and cost-effective access to multimedia data in heterogeneous, distributed databases over wide-area networks. In particular, services should be included for finding relevant data and converting proprietary data to standard formats for data interchange. Additionally, these services should include ways of controlling remote servers from within compound documents and general purpose electronic mail, conferencing systems and hypermedia systems, such as the World Wide Web.
- The *documentation services* will provide a "shared workspace" for storing and retrieving the documents and messages of the participants, using standard document formats, such as SGML, OpenDoc, etc. Users will be enabled to add and retrieve information to the hyperspace of documents available on the network. Security and privacy issues should be also addressed here. Databases containing project documents may become part of the *collective memory* of a community, facilitating the design and re-use of plans.
- The *mediation services* will regulate the group's activities. Commercial workflow systems can be used to support well-defined, formal administrative procedures within organizations.

The mediation services of the system are based on the specification of the underlying logic, argumentation structure and actions (that is, duties and rights) of the decision makers. Extensive discussions on the number and contents of the associated levels are given in (Gordon and Karacapilidis, 1996) and (Prakken, 1995). Adopting the first approach, mediation services should consist of the following four levels (Figure 3):

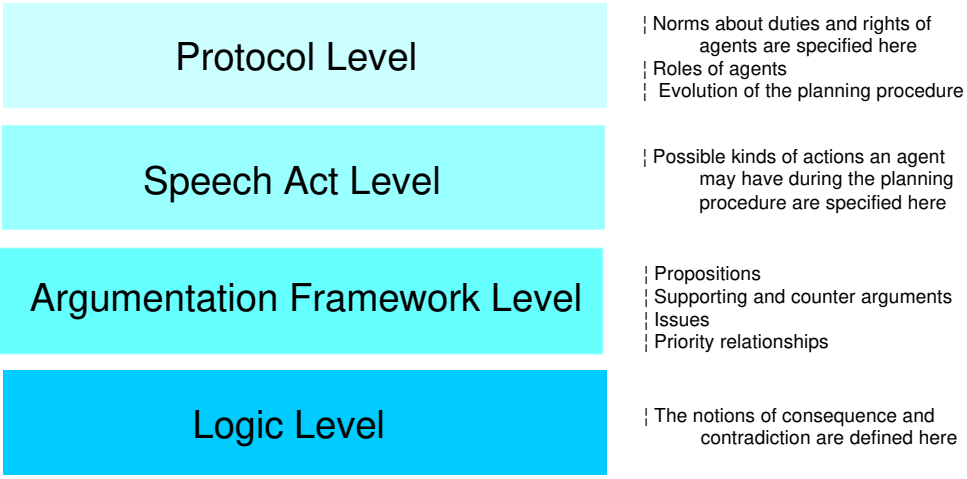

Figure 3: *Levels of mediation services*

- the *Logic Level*, where the notions of *consequence* and *contradiction* are defined. This level formally specifies the notions of theory that will be used and provides the appropriate inference relations. Formal models of argumentation have been built on various logics (see for example (Brewka, 1994) reconstructing Rescher's (Rescher, 1977) theory of formal disputation, (Prakken, 1993) based on Reiter's (Reiter, 1980) default logic, and (Gordon, 1993), (Gordon, 1994) using Geffner and Pearl's (Geffner and Pearl, 1992) nonmonotonic logic, namely, conditional entailment). Whether it makes sense to use nonmonotonic, inductive or analogical logics at the bottom level is extensively discussed in (Prakken, 1995). The formalization of the next levels does not assume choice of any particular logic. Related systems of defeasible argumentation have also left the underlying logic unspecified (see for example (Vreeswijk, 1993)).
- the *Argumentation Framework Level,* where the concepts of positions, supporting arguments, counterarguments and issues as well as linguistic constructs for arguing about priority relationships among competing arguments are defined. The argumentation concepts at this level result in a kind of nonmonotonic formalism, founded on argumentation principles. Both declarative and procedural models of argumentation, emerging from AI and Law, should be considered in the definition of this level (see also (Prakken, 1995)). The current state of any argumentation or negotiation procedure taking place in a dispute should be represented in this level. Such an argumentation framework for GDSSs, able to handle uncertain and incomplete information, is presented in (Karacapilidis, 1995) and (Karacapilidis, 1996).
- the *Speech Act Level,* where the space of possible kinds of actions a participant may "perform" during a discussion is defined (the term *speech act* has been introduced by the linguistic philosopher J.L. Austin (Austin, 1962)). Participants may alter the structure of

the Argumentation Framework at the second level by, for example, adding and deleting either claims or arguments.

- the *Protocol Level*, where norms and rules about duties and rights of the participants to perform actions defined at the previous layer are specified. The need for norms or *protocols* arises mainly from the conflicts of interest and goals each participant has during a debate. Protocols provide a means for structuring in advance demands for possible communication actions. They should promote *fairness*, *rationality* and *efficiency*. Ideas from similar structures in formalized public activities should be exploited together with methods from AI and Law, such as Deontic Logic and Argumentation Theory, as well as from Distributed AI. Protocols could also aid to the limitation of redundant communication (Campbell and D'Inverno, 1990). Following the above interpretation, any participant in a discussion should be "protocol-oriented", in the sense that he should be familiar with the existing protocol in order to make his contribution. Multiple protocols may also be defined, depending on the type of the debate. Protocols should take into account the roles of participants, the type of their goals (recall the pooled, cooperative and non-cooperative modes) and the type of control over the group decision making process (recall the democratic and hierarchical control levels). Finally, they should be "open", extensible, debatable, and not automatic or self-applying. The definition of efficient protocols in the Protocol Level will relieve argumentation of inadequacies similar to those of Toulmin's theory (recall that the proponent was obliged to face the opponent's right for limitless objection and a cooperative only aspect of the decision making procedure was supported) or Pollock's OSCAR model of defeasible reasoning (there was no distinction among roles of players). Additionally, like in OSCAR, computational limitations (i.e., memory and time) should be taken into account in this level.

5.2 Structure of the argumentation framework

Extending the set of argumentation elements defined for the Issue-Based Information Systems, we allow the argumentation framework of a GDSS to comprise positions, issues, arguments pro and con, and preference relations. *Positions* are considered to be the basic elements in our framework. Any kind of data an agent wants to assert during a decision making procedure can be used in order to represent a position. Those data may have been brought up to declare alternative solutions, justify a claim, advocate the selection of a specific course of action, or avert the agents' interest from it. A position can be (or become) true or false, important or irrelevant for the corresponding problem, and may finally become acceptable or not. *Issues* correspond to decisions to be made, or goals to be achieved. They consist of alternative positions and a set of constraints that hold among them. An issue can

be interpreted as which alternative position to prefer, if any. At any stage of the argumentation process, an issue may be either inconsistent (due to inconsistency in the associated set of constraints), able to recommend a solution (position) for its conclusion, or not. In fact, the last case indicates that none of the alternative positions of the issue is recommended. *Arguments* are assertions about the positions regarding their properties or attributes, which speak for or against them (multiple meanings of the term "argument" are discussed in (Prakken, 1995)). An argument links together two positions of different issues. Decision makers can put forward arguments to convince their opponents or to settle an issue via a formal decision procedure. We distinguish between supporting arguments (pro) and counterarguments (con). Besides, we assume that all arguments are refutable, and two conflicting arguments can simultaneously be applied.

In decision making environments, participants often want to express their preferences, e.g. that a position p is preferable than position q for some reason. *Preference relations* provide a means to weigh reasons for and against the selection of a certain course of action. Argumentation should then be viewed as a special form of logic programming. A sketch of an appropriate underlying logic for such an argumentation framework, namely *Qualitative Value Logic*, was first proposed in (Brewka and Gordon, 1994), aiming at relieving the users of the necessity of specification of exact cost values on alternative positions, while it offers them the possibility to reason about preferences. That logic is enhanced in (Karacapilidis, 1996), in order to enable it to address the following problems: (i) A complete preference ordering among statements is not always attainable. Formal properties such as transitivity and non-circularity may hold, but still a partial ordering is what one is able to achieve. (ii) There is not always complete information for each alternative position of an issue regarding the attributes asserted by the arguments. In other words, the known set of the criteria for each alternative position in an issue is not common.

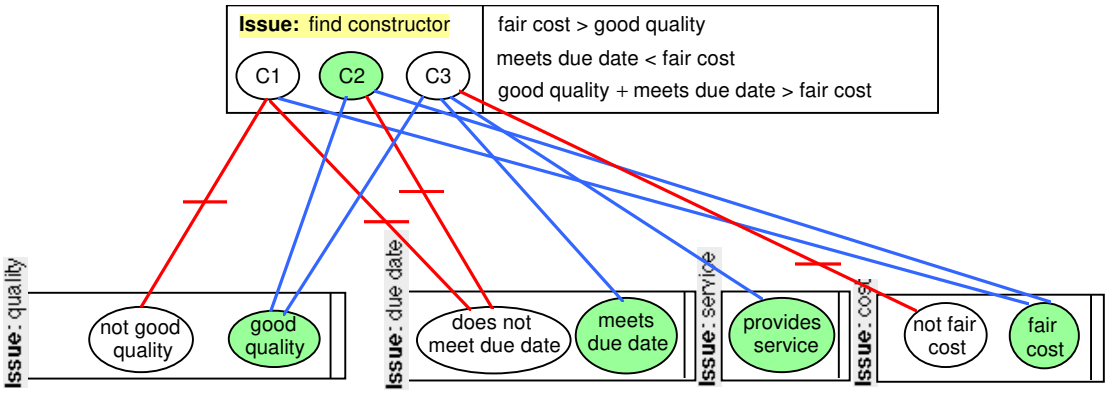

Figure 4: *An instance of the argumentation structure.*

Figure 4 illustrates an instance of the argumentation structure. Positions are denoted with ellipses, issues with rectangles and arguments with straight lines (counterarguments are distinguished with a small horizontal line crossing the diagonal ones). The shadowed position of each issue is the system-recommended one. The instance refers to the following example: Consider that the goal at some stage of a decision making procedure is to find a constructor for a part of a car engine. Let the following three, asserted so far, alternatives: *C1, C2* and *C3*. The asserted argumentation concerns the *quality*, *service*, *delivery time* and *cost* that each of the alternatives provides. For instance, it has been asserted that C1 "has not good quality", "does not meet the desired due date" and "provides a fair cost". As illustrated in Figure 4, there is no complete linking between each alternative of an issue and each asserted attribute. For instance, there is no argumentation at the moment about the *service* provided for the *C1* and *C2* alternatives. Therefore, disadvantages of systems like NEGO, where all decision makers should rely on the same set of attributes, are avoided with the proposed framework. In addition, preference relations on the attributes have been brought up (e.g., "coexistence of good quality and meeting of due date is considered to be more important than just the assurance of fair cost").

As mentioned in the Introduction, the argumentation framework of a GDSS should allow for defeasible reasoning. Decision makers can put forward new input at any time. Whenever that happens, the system should infer the respective consequences. Every preference relation adds a constraint in the associated issue. A constraint satisfaction problem is implicitly deployed and a constraint graph is being formed as the communication evolves. Each issue of the decision making procedure is actually a complete sub-graph of it. Applying path consistency algorithms the system should be able to refine the decision makers' knowledge about the preference relations and detect possible inconsistencies (this was an advantage of the RUNE system). Such a system, currently under development in Java aiming to deploy it on the Web, is presented in (Karacapilidis, 1996).

The framework discussed in this section retains the advantages of the MCDM methods and deploys a convenient means to express, clarify and negotiate preferences, which can be based on either quantitative or qualitative sets of criteria. In fact, any OR approach mentioned in Section 3 can give input to such a framework. Decision makers can modify the discourse graph by inserting new argumentation elements, or even consider alternative *decisions* in spite of the system's recommendations. *What-if* scenarios might be also tested before a user decides about what he finally wishes to assert (recall the phases provided in the MEDIATOR system, discussed in Section 3). Unlike Toulmin's theory, the above framework provides a means of ordering competing arguments (via preference relations), and unlike OSCAR model, there are reasoning mechanisms for the relative weight and priority of alternatives.

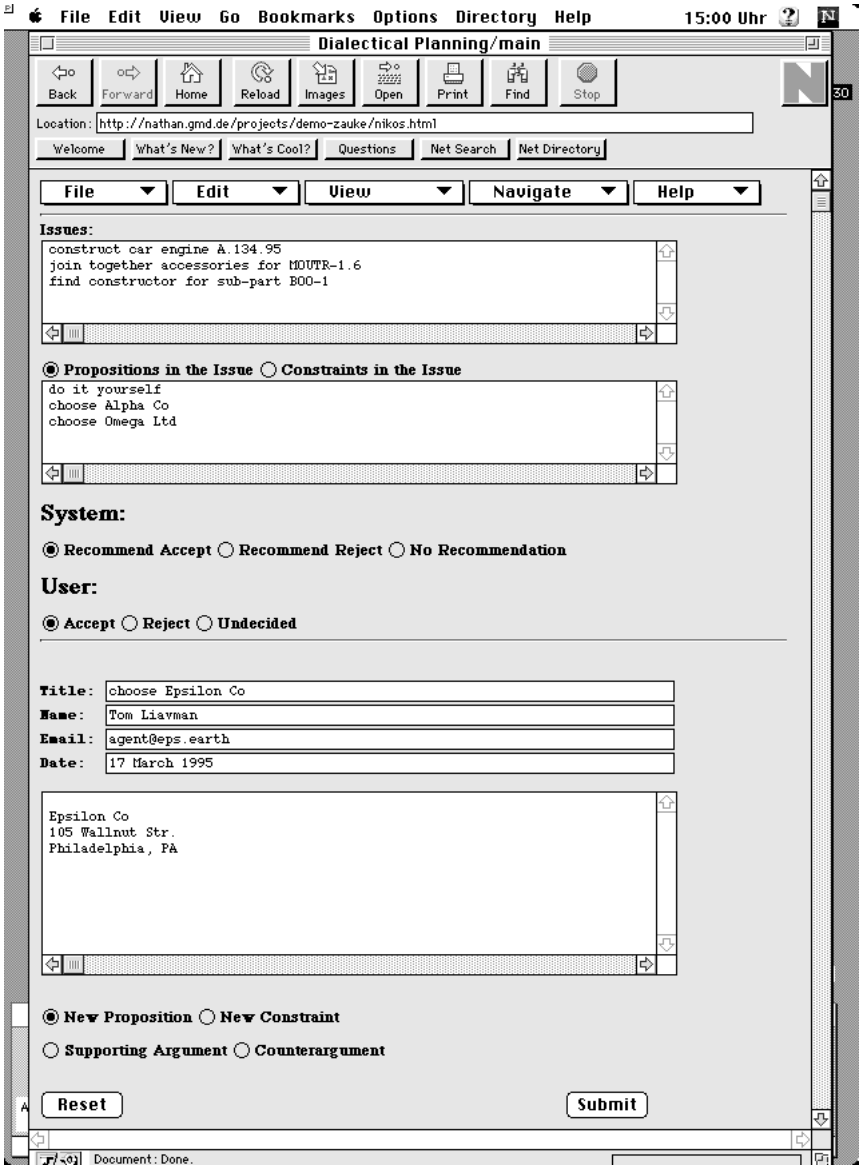

Figure 5: *The World Wide Web gateway.*

5.3 The World Wide Web gateway

Figure 5 illustrates a mock-up of a World Wide Web gateway through which each agent can assert its own positions and constraints in a planning paradigm. The File menu includes the usual commands such as New, Open, Close, Send, Save, Print or Quit a plan. Each paradigm contains all corresponding positions and constraints asserted so far via the system. Specification of rights and duties among agents at the Speech Act layer would affect their potential access to the list of available commands. Several agents can open and modify the same plan simultaneously. An agent can modify the dialectical graph by asserting new positions, and consider alternative decisions in spite of the system's recommendations. "What-if" scenarios might be tested before an agent decides about what he finally wishes to

assert. The Edit menu includes the usual Undo, Cut, Copy, Paste, Clear, Select, Find and Replace commands. Similarly, the View, Navigate, Options and Help menus include well-tried commands from Web browsers adapted in our formalism.

The instance illustrated in Figure 5 is related to the decision making example given above. The corresponding discussion file has been retrieved and its asserted issues are listed in the first scrollable pane under the main menu bar. Each agent can select any of them and click either on the “Propositions in the Issue”, or on the “Constraints in the Issue” button to see what has been asserted (second scrollable pane). Automatically, he would find out the system's conclusion for the issue by observing for which proposition the “Recommend Accept” button is on. Possible weakness for solving the issue will be represented by the “No Recommendation” button being on. “Recommend Reject” for a proposition, indicates that the system has identified a better alternative in this issue. Preserving the mediating role we intend for the system, an agent would be able to select an alternative, and assert its own opinion by clicking on the User’s “Accept”, “Reject” or “Undecided” buttons. Working in this way, agents would be able to observe the consequences their decisions cause at the higher levels of the decision making tree, and evaluate alternative plans. The procedures of concluding an issue are illustrated in (Karacapilidis, 1995) and (Karacapilidis, 1996).

The bottom part serves for the commitment of new positions or constraints in a plan. The scrollable pane would include the description of the position. The linking of a new-asserted position with an existing one can be made by clicking on one of the "Pro" and "Con" buttons (declaring intention for a supporting or a counter argument, respectively), after the selection of the corresponding position. The Navigate menu provides the usual commands for the tracing of the dialectical graph. For instance, the "Top" command leads to the prime goal of the plan, and the "Up" and "Down" commands trace the issues at the various abstraction levels. "Next" and "Previous" commands cycle through the other arguments of a selected proposition. Finally, the View menu provides suitable decision-making graphs and options for overall representations of a plan. For instance, other views of the dialectical graph, such as a temporal list of past messages will be also useful.

The framework described can provide easy display of group inputs at any stage of the discussion in a structured form. This can be achieved just with a set of related Web pages. Weaknesses of systems mentioned in Section 3 (participants were allowed to provide their input only once in CAP, there was no support for interaction among participants in CAP and DECISIONMAKER, only the facilitators were allowed to use the computer in DECISION CONFERENCING while participants were watching the analysis of results) do not exist in this approach.

6 Conclusion

A computer-mediated system for group decision making should be efficient, fair and rational. Key issues discussed in this paper are the communication and coordination between the participating decision makers, shared information space and support for a heterogeneous, "open" environment which can integrate existing single-user applications and handle any spatial or temporal distance, and various types of goals and communication protocols between its users. Starting from an OR background, and presenting challenges coming from the area of Computer Supported Cooperative Work, a conceptual framework for such an "open" computer-mediated GDSS has been proposed, which can support decision making in cases where conflicts of interests are inevitable and support for achieving consensus and compromise is required. The integration of such a system could be a research shift for the GDSS area, in that it emphasizes on a *human-human* coordination, communication and problem solving, rather than on a *human-machine* one.

A related concept is that of *Dialectical Planning,* embracing integrated hypertext and groupware technologies, smoothly applied on the amalgamation of a rhetorical model and classical planning algorithms (Karacapilidis and Gordon, 1995). *Hypertext* systems feature machine-supported links, both within and between documents, that have opened exciting new possibilities for using the computer as a communication and thinking tool (Conklin, 1987). The *rhetorical model* can enhance the quality of the dialogue process within a conceptual organization by providing the structure for the discussion of complex problems. Dialectical Planning is performed via a mediating system, built on a normative model of limited rationality. Thus, the implementation of a fair, efficient and rational rhetorical model plays a key role in such a system.

Artificial Intelligence techniques should be further exploited towards the implementation of a more advanced system. We mention here techniques coming from the area of Computer-Mediated Collaborative Learning (Alavi, 1994), Decision Analysis in AI (Dewhurst and Gwinnett, 1990), Agent Theory (Jones and Edmonds, 1994); (Peña-Mora et al., 1995); (Kraus and Lehmann, 1995), Truth Maintenance Systems (Karacapilidis and Papadias, 1995), and Workflow Systems (Klein, 1995). There is also extended literature advocating the joint exploitation of AI and OR areas in building such systems. A variety of supporting arguments for that appears in (Grant, 1986), (Grünwald and Fortuin, 1989), (Karacapilidis et al., 1994), (Dewhurst and Gwinnett, 1990) and (Phelps, 1986).

Acknowledgements: *The authors thank the anonymous referees for their useful suggestions and comments on the structure and contents of the paper.*

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