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Communications Design for Co-oP: A Group Decision Support System

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Decision Support Systems (DSSs), computer-based systems intended to assist managers in preparing and analyzing decisions, have been single-user systems for most of the past decade. Only recently has DSS research begun to study the implications of the fact that most complex managerial decisions involve multiple decision makers and analysts. A number of tools for facilitating group decisions have been proposed under the label Group Decision Support Systems (GDSSs).

One of the most important functions of a GDSS is to provide problem-oriented services for communication among decision makers. On the basis of an analysis of the communication requirements in various group decision settings, this paper presents an architecture for defining and enforcing dynamic application-level protocols that organize decision group interaction. The architecture has been implemented on a network of personal computers in Co-oP, a GDSS for cooperative group decision making based on interactive, multiple-criteria decision methods.

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1. INTRODUCTION

The term Decision Support System (DSS) characterizes a class of end-user-oriented systems intended to assist managers in making decisions about complex, ill-structured problems [27]. DSSs are distinguished from traditional management information systems by their emphasis on decision models in addition to

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databases. They differ from operations research methods in their stress on interactive usability by computer-naive decision makers and in their intention to support rather than automate decision processes.

Although there were a few mainframe-oriented organizational DSSs in the 1970s, the real breakthrough occurred only when user-friendly DSS tools, such as spreadsheets, enhanced database management systems, idea processors, and even expert systems, became a major selling point for microcomputer vendors. The success of these systems is largely based on their effective man–machine interface, as well as on their ability to work uniformly with model bases (e.g., collections of spreadsheet formulas) and databases. Correspondingly, a fundamental DSS architecture integrating dialogue manager, model manager, and data manager components emerged [48].

This development may have overemphasized the personal support nature of DSSs. Organizational decision making is often a group activity. Communication with subordinates, superiors, and peers inside and outside the organization occupies most of a manager's time [32, 33]. Reduced communication, possibly caused by preoccupation with a personal DSS tool, may lead to incoherent environmental scanning and thus contradictory decisions in an organization [10, 37, 38].

The actual influence of a DSS on managerial communication is subject to much discussion [44, 53]. On the one hand, the reliance on personal support tools does not blend well with access to specialists (unless their knowledge is encoded in expert systems), group decision activities, and bargaining among interest groups. This problem is aggravated when the participants in a group decision activity reside in different locations or cannot meet personally because of time constraints.

On the other hand, DSS tools do offer some promise for enhanced managerial communication. For example, presentation tools, such as viewgraphs or tailored ad hoc reports, combined with analytical models, may focus a discussion on issues rather than on persons and thus improve managerial interaction. Moreover, research in office information systems has generated some clerical-level communications tools, such as automatic dialing, electronic mail, and computer conferencing, that could potentially facilitate, complement, or replace face-to-face decision meetings [26].

However, there is some evidence that these tools will reach their full potential only if they can be integrated into a DSS context, or, vice versa, if a DSS can be embedded into the office communication context. The result of this integration is called a Group Decision Support System (GDSS). Such a GDSS would complement a nice man–machine interface for access to data and model bases with a *man–machine–man* interface for mediation among decision makers.

A few pioneer GDSSs have been built over the last five years. For example, *decision room* GDSSs using personal terminals and a public screen have been shown to make certain types of decision meetings more effective [14, 16, 17]. Decision rooms are currently being used by a few companies for supporting boards of directors' meetings. At least one such system is also being marketed [21]. Behavioral group techniques, such as the Delphi method and the Nominal Group Technique, can be used more efficiently with electronic support [20, 51]. Experiments are being conducted with distributed GDSSs for personnel promotion decisions and long-term interdepartmental coordination in manufacturing companies [15].

There is one major difference between a meeting-facilitating (local) and meeting-replacing (distributed) GDSS. In a decision meeting, the GDSS provides *additional* channels for communication. Although these channels may enhance efficiency of interaction (e.g., speed and accuracy of communication) and degree of cooperation [12, 47, 54], the decision makers are not dependent on them; they can still talk to each other, point to things, and so forth.

In a distributed decision setting, the GDSS may be the *major* communication channel; other ways of communication may be cumbersome and not certain of acknowledgment in the group process. Again, when compared with face-to-face meetings [8, 26, 47], this may have certain advantages, such as enhanced group participation. But there is also the danger that much of the richness of human dialogue is lost. The careful design of a communication manager as a fourth DSS component, in addition to dialogue manager, data manager, and model manager, is, therefore, a crucial prerequisite of a distributed GDSS.

This paper provides an analysis of the communication types and needs in a GDSS and presents a generalized design for a GDSS communication manager. A version of the proposed architecture has been realized in the distributed GDSS Co-oP [6, 7].

Section 2 provides a taxonomy of GDSS architectures organized by the type of man–machine–man communication they offer. It is argued that a GDSS should offer components for individual decision support, as well as for establishing the group decision. In Section 3, an overview of the system Co-oP is given; the process of multiple criteria group decision making is also described, using the selection of a new faculty member as an example. In Section 4, requirements concerning the format, formalization, and evolution of GDSS communication are identified; major roles and functions of a GDSS communication manager are derived from these requirements. Section 5 describes the implementation of these roles by Co-oP communication control modules at the presentation and application layers of an open systems architecture.

2. GROUP DSS ARCHITECTURES

The design of a GDSS strongly depends on the kind of group decision setting to be supported, on the philosophy regarding the tools to be supplied, and on the available communication channels. In this section these aspects are briefly reviewed.

Group communication situations can be classified according to at least four different dimensions [24]:

(1) *Spatial distance* among decision makers distinguishes between decision making in the same location (e.g., in a meeting) and remote decisions (via teleconferencing, electronic mail, telephones, etc.).

(2) *Temporal distance* determines whether decision makers are convened in a (local or remote) meeting at the same time, or whether they submit their input to the decision process at different points in time.

(3) *Centralization of control* distinguishes democratic decision processes from those in which there is a group leader or mediator with more power than other

group members; in the extreme case the group leader could make the decision alone with just advice from other members (e.g., research staff).

(4) *Degree of cooperation* distinguishes a setting of cooperative group work from one in which (possibly hostile) parties are bargaining over some issue of common interest (e.g., seller–buyer negotiations).

There are also different classes of tools for which the communication manager provides a framework of usage. In the simplest case, these may be merely shared databases; even then, there is at least a need for novel transaction concepts, such as those used in design databases [19]. More complex methods include various artificial intelligence techniques (e.g., distributed problem solving, evidential reasoning, belief maintenance), multiple criteria decision methods (MCDM), game theory from operations research, and a large number of behavioral, process-oriented tricks (threats, promises, deadlines, etc.). In Co-oP, we concentrate on MCDM-based communications techniques [35] supported by rule-based advice for the users [6].

Basically, six architectures for man–machine–man communication in a GDSS are conceivable; each may be most suitable for different group decision settings and tools. These architectures are displayed in Figure 1 and briefly described, below.

Type 1 represents the traditional single-user DSS paradigm. The purpose of such a DSS is twofold. First, it should enhance the user's cognitive processing capabilities, for example, by reducing the problems of limited short-term memory through database access or graphics. Second, it should facilitate the learning process necessary for solving a complex problem, for example, by allowing what-if computations of multiple alternatives or even by suggesting new alternatives or decision perspectives. However, the only source of new information is the system itself. The bilateral relationship between user and DSS provides no support for communication with other people. As mentioned, this type of DSS has been criticized for its potentially isolating role.

In Type 2, a group of users has access to a traditional DSS, typically through an intermediary. The purpose of such a DSS is, in essence, the same as in a Type 1 DSS. The group decision-making process remains unsupported: The group has to decide outside the system what requests to submit and how to interpret the results, possibly from individual viewpoints.

Type 3 adds computerized group problem-solving capabilities to the capabilities of Type 2: The GDSS "knows" about the existence of multiple decision makers. For example, automatic computation of preference aggregation functions or analysis of individual differences can be performed. The relationship between the decision group and the GDSS remains bilateral, that is, the users share the same man–machine interface. This type of GDSS is exemplified by the single-user, multiplayer DSS of Licker and Thompson [31], as well as by the Geodata Analysis and Display System (GADS) [48].

Whereas the third architecture provides a mechanism for mapping and integrating application-level communication results, another generalization of the individual DSS framework addresses the need for knowledge sharing among remote individual DSSs, for instance, by exchanging data files or mail messages. Although similar to a Type 2 DSS, this Type 4 network of loosely coupled

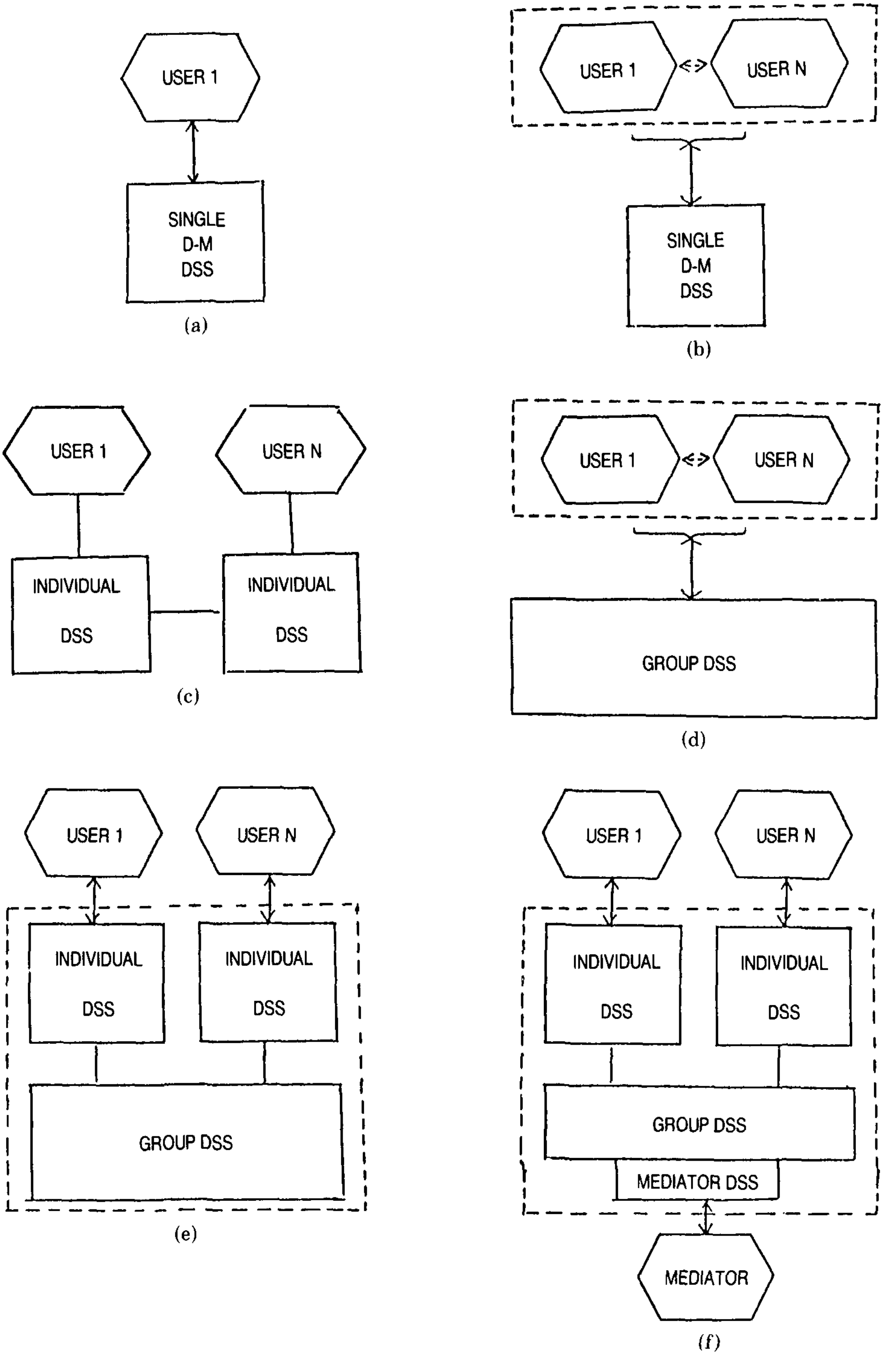

Fig. 1. A typology of Group Decision Support Systems: (a) Type 1, (b) Type 2, (c) Type 3, (d) Type 4, (e) Type 5, (f) Type 6.

individual DSSs lacks knowledge about the existence of a decision group; therefore, all group control mechanisms are left to humans. Examples of this architecture include networked Lotus 1-2-3 or Framework, which allow exchange of data but have no explicit group support.

Types 5 and 6 assume a multilateral relationship among group members via a network of individual DSSs and group DSSs. Such a network of DSSs is aimed at supporting both the decision maker who is a member of the group and the group itself. Nevertheless, only individual users interact with the system; the group as a whole is no longer an individual user. In other words, the fifth and sixth types of GDSSs represent a distributed problem-solving system composed of a decentralized, loosely coupled group of decision makers.

These architectures combine the advantages of knowledge sharing among individual DSSs (Type 4) with those of supporting group activities, such as preference aggregation and negotiation with high-level tools (Type 3). Additionally, the use of a GDSS as the communications component allows the flexible definition and enforcement of group decision-making standards and protocols. Whereas this is done automatically in the architecture of Type 5, the Type 6 architecture employs the services of a human group leader or mediator, whose efforts are only supported, not replaced by the GDSS.

The six architectures form a logical sequence; the capabilities of a Type 1 DSS are contained in Type 2 and Type 4, those of Type 2 in Type 3, those of Types 3 and 4 in Type 5, and those of Type 5 in Type 6. The remainder of this paper develops a communication architecture for the Type 5 GDSS that is implemented in the Co-oP system. (For further discussion of a Type 6 GDSS, see [25].)

3. THE SYSTEM Co-oP

3.1 Rationale and System Overview

Co-oP is a GDSS for cooperative multiple-criteria group decision making implemented in Pascal on a network of personal computers. An early version of Co-oP is described in [7]; the full system is presented in [6].

Cooperative group decision making is a problem-solving process in which (i) there are two or more persons, each characterized by his or her own perceptions, attitudes, and personalities, (ii) who have recognized the existence of a common problem and (iii) attempt to use the system to reach a collective decision. The current version of Co-oP does not consider a hostile environment. However, this version goes beyond computer-aided design (CAD) applications because different opinions can be explicitly expressed and traded off.

Co-oP's communication manager allows the dynamic definition, enforcement, and modification of protocols for structured, as well as informal, communications among decision makers. For structured communication, it relies on interactive *multiple-criteria decision methods* (MCDMs). MCDMs provide an elegant framework for the following important GDSS tasks:

(1) *Representing multiple viewpoints of a problem.* From a database perspective, the MCDM decision matrix can be viewed as a particular kind of derived relation whose rows represent decision alternatives and whose columns represent criteria or viewpoints by which the alternatives are judged.

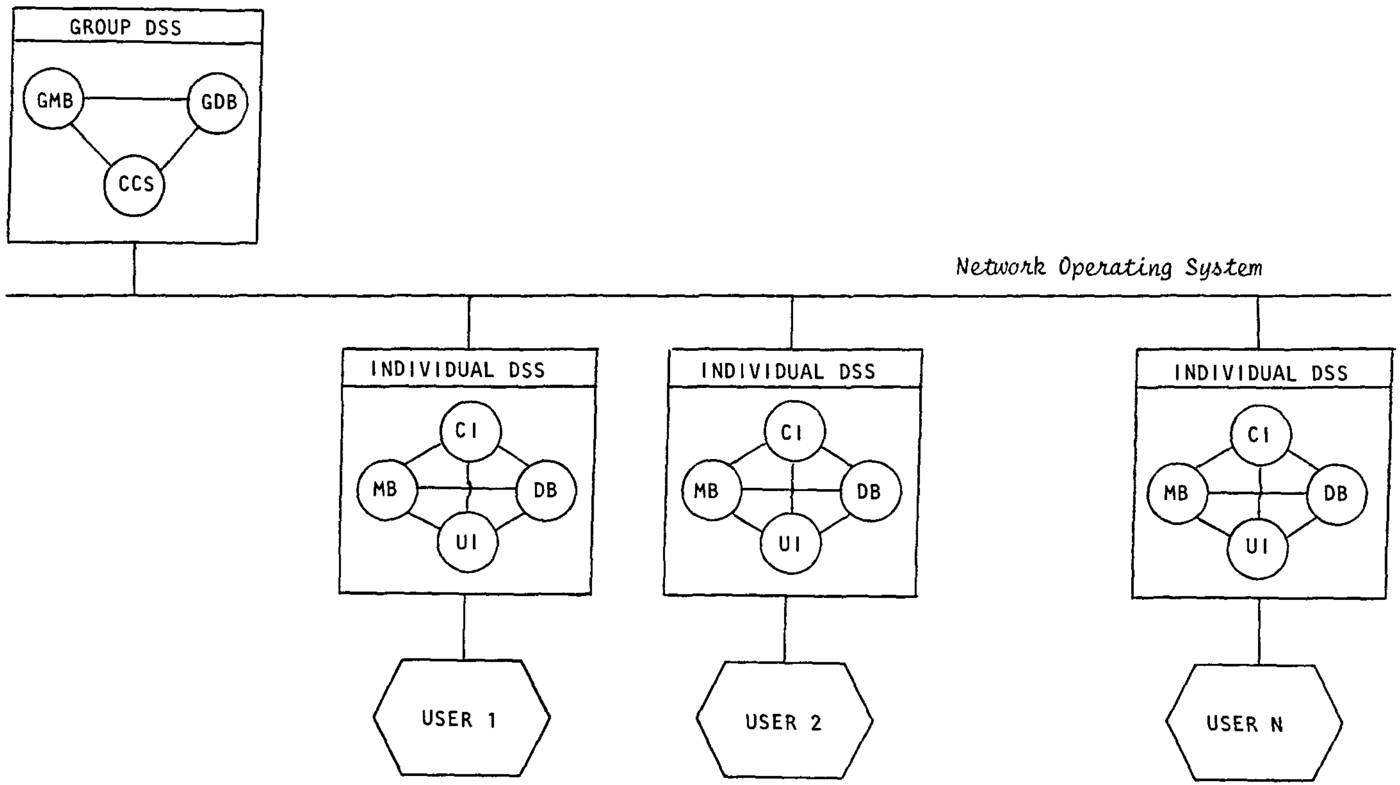

Fig. 2. The Co-oP architecture.

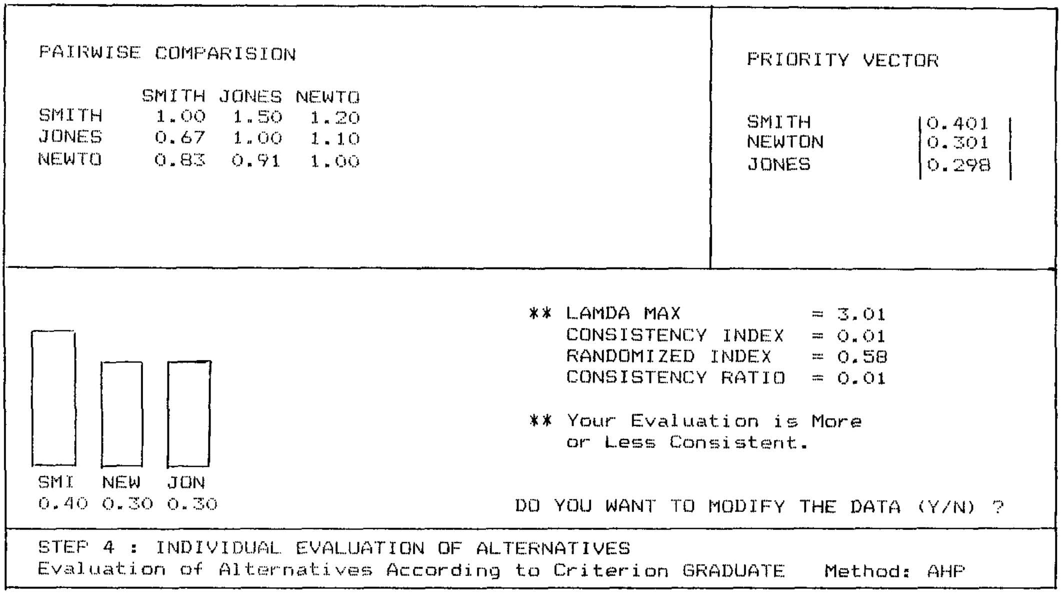

Fig. 3. An actual Co-oP screen showing the working window, solution window, and step window.

(2) *Aggregating the preferences of multiple decision makers according to various group norms.* MCDM and game theory have developed different weighting schemes for criteria and measures of fairness for multiperson decisions [28, 35, 36].

(3) *Organizing the decision process.* Dynamic game theory [9, 18, 45] and interactive MCDMs [23, 41] have recognized that preferences of decision makers are not necessarily rigid. They may not even exist a priori but are formed during the decision process itself; a typical procedure consisting of problem definition, group constitution, prioritization of evaluation criteria, determination of individual preferences, aggregation of individual preferences, and evolution of individual and group preferences through consensus seeking and compromise (negotiation) has emerged.

For these reasons, MCDMs appear to be good candidates for a structured application-level communication tool to facilitate group decision-making processes.

An overview of the Co-oP system is given in Figure 2. In each individual DSS, the Co-oP User Interface Component (UI) offers a menu-driven, window-based environment that allows decision makers to access the model base (MB) and the MCDM-specific database (DB).

The UI employs a standard screen format that guides the user by simultaneously displaying four different windows (see Figure 3): a step window (lower part of the screen) that identifies the current decision process step, a dialogue window for input/output (middle part), a working window for summarizing previous work within the current step (upper left), and a solution window for intermediate and final results of the decision process (upper right). In addition, an electronic notepad window [4] can be popped up at any time to conduct person-oriented and unstructured communication. Throughout the entire Co-oP process, the windows are recognizable by their colors. They vary, however, in size according to the amount of information displayed (i.e., number of decision makers, number of decision alternatives, and number of evaluation criteria).

Individual DSSs are linked by a microcomputer network system using a bus architecture and the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol. The group DSS contains a set of preference aggregation techniques and mediation tools that can be used in conjunction with certain combinations of the individual MCDM. During any phase of the group decision-making process, the Group Communication System (GCS) interface will connect individual DSSs to the group GCS upon request by using the pop-up notepad.

3.2 The Co-oP Group Decision Process

Co-oP follows the basic steps of a multiple-criteria group problem-solving process that is governed by norms imposed by the group. There are six steps:

(1) problem definition,
(2) group norm definition,
(3) prioritization of evaluation criteria,
(4) individual selection of alternatives,
(5) group selection of alternatives,
(6) consensus seeking and negotiation.

The decomposition of the group decision problem into steps permits users to interrupt their analysis temporarily at any point; they can log back into the decision process without having to repeat work. A group secretary must be chosen prior to system use to get the process started.

We now describe these steps, together with the tools provided by Co-oP. As a running example, we consider the process of selecting a new faculty member in a university department.

3.2.1 *Defining the Problem.* In this process, the group collectively identifies and defines a decision problem. Specifically, all group members share the same decision space, for example, alternatives and evaluation criteria.

In the faculty selection example, each member of the selection committee might scan his or her personal database of candidates, and the union of the candidate sets might be the common set of alternatives. Criteria may be hierarchically structured and would again be defined as the union of criteria proposed by individuals. Of course, more elaborate protocols for predecision could be defined, for instance, that a candidate must be named by at least three people to be considered. A simplified input screen of the problem definition phase for the faculty selection example is given in Figure 4.

During the problem definition phase, Co-oP is expected to support decision makers in communicating their opinions about the group problem-solving process. Teleconferencing and electronic mail are available to facilitate information exchange. From an individual DSS, the group secretary takes note of the discussion; Co-oP provides outline forms for this purpose.

3.2.2 *Defining the Group Norm.* The group has to identify its members and assign individual passwords. It also has to agree upon the way it handles data

NAME OF GROUP PROBLEM: *Faculty Selection*

IDENTIFICATION OF ALTERNATIVES:
Type ⟨*q*⟩ to end definition of alternatives:
1. Jones
2. Smith
3. Newton
4. *q*

ENTER HIERARCHY OF EVALUATION CRITERIA
Type ⟨1⟩ for first level,
⟨2⟩ for second level,
⟨3⟩ for third level, and
⟨*q*⟩ to end definition of evaluation criteria:

1. Education
   1.1 Undergraduate
   1.2 Graduate
2. Experience
   2.1 Teaching
      2.1.1 Undergraduate
      2.1.2 Graduate
   2.2 Research
3. Area of specialization

Fig. 4. An input screen of the Co-oP group problem definition process. (The underlined text is entered by the group secretary.)

transfers, interactive conversation, utilization of electronic mail, and group decision techniques. For example, the group can request automatic selection and computation of appropriate decision techniques. Group norm definition and enforcement is one of the main tasks of the GDSS communication manager and is discussed in detail later. Figure 5 shows a screen for defining a group norm for faculty selection. There are, at first, two decision makers, one of whom is the group secretary. Decisions are to be made by majority (assuming the group will become larger later on), and individuals are allowed to change their votes up to three times. Finally, there is a deadline by which individual opinions have to be submitted.

3.2.3 *Determining Priorities of Evaluation Criteria.* The third step deals with the prioritization of evaluation criteria. This process can be accomplished either by requesting the decision makers to directly assign weights to the criteria, or by using a hierarchical scheme based on pairwise comparisons of criteria importance (see Section 3.2.4). Co-oP can perform the prioritization process in three modes:

—*Pooled*: All group members collectively enter a common priority vector.

—*Sequential*: Group members, according to their expertise, assign priority to a subset of criteria.

—*Aggregated*: Each member assigns individual weights first; then individual priorities are aggregated using a predetermined computation rule.

3.2.4 *Selecting Alternatives Individually.* Given a defined problem, the fourth Co-oP process allows each decision maker to evaluate alternatives individually

ENTER THE NAME OF THE GROUP NORM: Norm1

1. IDENTIFICATION OF GROUP MEMBERS:
   1.1 Group Norm Builder Identification
   —Your Name : Chairman
   —Your ID : *******
   1.2 Number of decision makers : 2
   —Enter name of decision maker No. 1 : Faculty1
   —Enter name of decision maker No. 2 : Faculty2

2. GROUP DECISION TECHNIQUES:
   2.1 Weighted majority rule:
   —EQUAL Weights (*Y*/*N*) : *Y*
   2.2 Collective Evaluation Mode
   Choose one of the following modes:
   ⟨1⟩ Each group member will evaluate alternatives according to ALL criteria
   ⟨2⟩ Each group member will evaluate only alternatives according to his exclusive area of expertise
   Enter a number : 1
   2.3 If more than one individual decision technique is used by a group member, which individual outcome to submit for group decision making?
   ⟨1⟩ Last individual method used
   ⟨2⟩ Method chosen by individual group member
   Enter a number : 2
   2.4 Automatic selection of techniques of aggregation of preferences (*Y*/*N*) : *N*
   —R1 : SUM-OF-RANKS (*Y*/*N*) : *Y*
   —R2 : SUM-OF-OUTRANKING-RELATIONS (*Y*/*N*) : *N*
   —R3 : ADDITIVE RANKING (*Y*/*N*) : *Y*
   —R4 : MULTIPLICATIVE RANKING (*Y*/*N*) : *Y*
   2.5 Automatic computation of NAI (*Y*/*N*) : *Y*

3. INFORMATION EXCHANGE
   3.1 Broadcasting of individual outputs (*Y*/*N*) : *Y*
   3.2 Permission to modify individual analyses AFTER group analyses (*Y*/*N*) : *Y*
   3.2.1 How MANY times (max 10) : 3
   3.3 Time limit to submit individual results:
   3.3.1 How MANY days : 3
   3.3.2 Hour (1 to 24) : 12:00
   The deadline is: 3-12-1986 (*Y*/*N*) : *Y*
   3.3.3 Broadcasting of Group Results to group members who did NOT submit their analysis (*Y*/*N*) : *Y*
   3.3.4 Permission for LATE group members to perform analysis AFTER deadline (*Y*/*N*) : *N*

Fig. 5. The Co-oP group norm definition process for the faculty selection example.

using his or her preferred MCDM. To support this process, Co-oP provides each Individual Decision Support System (IDSS) with a model base (MB). The MB provides a technique-driven milieu for understanding, selecting, retrieving, and operating the decision models stored in a Content-Oriented Model Bank (COMB) and a Multiple-Criteria Decision Model Bank (MCDMB). The COMB offers a large set of explicative (e.g., linear programming, financial models) and time series models (regression models, smoothing techniques).

The main purpose of the MCDMB is to provide the decision maker with a set of interactive MCDMs for the most common types of decision problems. Currently, two MCDMs are stored in the MCDMB to support two types of decisions: the ELECTRE method [40] for selecting one, and only one, best alternative among many, and the Analytical Hierarchy Process (AHP) [43] for ranking all alternatives according to the decision maker's needs. The screen example from Figure 3 shows an almost completed individual decision process using AHP. Using a sequence of pairwise comparisons between the candidates, Smith, Jones, and Newton, according to criterion "graduate teaching" (defined in step 1 and prioritized in step 3), the decision maker has developed a weak preference for Smith; however, the pairwise comparisons are inconsistent and the user, guided by the system, may want to reconsider some choices.

3.2.5 *Computing Group Results.* The next phase of the Co-oP process is the computation of group results from individual MCDM outputs by using appropriate preference aggregation techniques and weighting user decision power as defined in step 2 (see also Figure 5).

The Co-oP group model bank contains four techniques for preference aggregation and some negotiation support modules. The former include additive ranking, multiplicative ranking, the sums-of-the-ranks approach, and the sums-of-the-outranking-relations approach [6]. Unless otherwise specified, the Co-oP group module automatically searches for all aggregation techniques compatible with the MCDM used by any individual decision maker.

For example, if AHP were adopted by every group member for individual assessment of alternatives, all four aggregates would be computed, since they are compatible with AHP in that they are based on cardinal preferences. By contrast, the ELECTRE method can work only with the sums-of-the-outranking-relations and, to a certain degree, the sums-of-the-ranks algorithms. When both available MCDMs are used concurrently, the Co-oP communication manager automatically searches for group decision techniques that can accept inputs from both AHP and ELECTRE.

3.2.6 *Seeking Consensus or Concessions.* If unanimity is not obtained, consensus-seeking algorithms can be invoked in the sixth and last phase. If an impasse still prevails, decision makers can attempt to revise their problem definition by going back to any of the previous steps [45].

Co-oP supports several methods for consensus seeking and concession making. In the ELECTRE context, it attempts to perform sensitivity analyses on the ELECTRE parameters. In the AHP context, it applies an algorithm, called the Negotiable Alternatives Identifier (NAI) (see [5]), that employs an expansion/contraction/intersection mechanism in order to search for possible negotiation clues.

4. COMMUNICATION REQUIREMENTS OF GDSS

Office automation research has placed substantial emphasis on the design of office communication systems. Originally, most of this work focused on the automation or intelligent support of clerical tasks. Although many of these tasks must be performed, directly or indirectly, by group decision support systems as well, there are additional requirements specific to the decision-making task. These result from the diversity of the users, from the need for multiple channels of communication, and from the evolutionary nature of group decision processes.

4.1 Diversity of Users

In a single-user environment (Types 1–3, Figure 1), a DSS user interface should (i) be easy to learn, use, and remember, (ii) be suitable for both novice and expert use, (iii) be efficient in the use of system resources, and (iv) promote effective usage and better decision making [49]. A distributed multiuser environment (Types 4–6) safe and mutually understandable communication among the users via the system must also be enabled.

It is necessary to convert heterogeneous information styles into standard message formats. Information related to group problem-solving techniques must be created and maintained. For instance, aggregation of preferences requires some standardized inputs from individual results that are represented in different formats.

Owing to the diversity of the decision makers' knowledge, the input/output formats for group decision techniques should be universally understandable or at least recognizable by every member of the group. If the group is small and homogeneous, the group DSS should be able to transfer detailed information between decision makers upon request (e.g., exchange of individual inputs, outputs, intermediate results). If the group is large or heterogeneous, a standardized form of group information should prevail. For example, simple voting procedures must be used instead of elaborate exchange of arguments.

4.2 Multiple Channels of Communication

Decision makers demand or generate information in a variety of formats ranging from unstructured notes to structured, numerical tables [3]. According to Pye et al. [39], the activities associated with group decision problems constitute a mixture of positive and negative reactions, problem-solving attempts, and "questions" (information search). Short et al. [47] classify negative and positive reactions as "person-oriented" communications, since they reflect the attitudes of one participant of the group toward another. The search for information and attempts at problem solving are classified as "non-person-oriented" communications, since they are primarily concerned with the content of the decision problem. In their studies on the effect of media on conflict resolution, Morley and Stephenson [34] found that formal communication tends to emphasize the object of the discussion at the expense of interpersonal exchange [46].

Taken together, these studies suggest a need for multiple channels for formal as well as informal communication in a decision group. If the GDSS is used as a facilitating tool in a meeting, the GDSS will have to provide mostly formal tools. Foremost among these are tools for *structured group communication.*

As the size of a group increases, it becomes heterogeneous, loses control of its norms for interaction, and is prone to undesirable interpersonal influences, such as the "surveillance effect," [2] which pushes people to go along with the group rather than specify their own ideas, the individual lack of confidence when facing group pressure [1], and the "leadership phenomenon," which prevents equal participation.

Thus, structured communication interfaces should promote independent generation of ideas or judgments, enforce mechanisms for assuring equal opportunity to participate in the discussion, and provide organized feedback for group discussion.

In addition to the MCDM-based methods, examples of such techniques that have been used in GDSSs include Delphi and Nominal Group Techniques [20]. The Delphi method is a technique that attempts to reach consensus among multiple experts on a difficult problem, following a cycle of anonymous individual statements and aggregated feedback. The method assumes that experts are locally distributed; it can therefore be very time consuming. GDSSs can substantially accelerate the Delphi process [51].

The Nominal Group Technique has the objective of ensuring equal participation in a group process. Each member is first asked to make suggestions; critiques are only allowed after the first round of statements is completed. Again, a GDSS can accelerate the initial suggestion phase by allowing concurrent initial statements and providing structuring tools.

In a *remote decision setting,* additional unstructured communication interfaces must compensate for some interpersonal communication needs that structured interfaces cannot provide. For instance, under a controlled environment, on-line and public notepads, electronic bulletin boards, and electronic mail may enhance interpersonal communications.

4.3 Evolving Patterns of Group Communication

In some group decision situations, it is conceivable that all shared information is public: Each member of the decision group has the right to access any information sent from any group member to another one. In other situations, only private message transfers are authorized. The creation, maintenance, and storage of message-routing activities [50] is crucial to enforcing group norms concerning the type of information sharing. Such norms can be consensually predefined by the group prior to the group decision-making process in a GDSS (Type 5) or monitored by the mediator (Type 6).

In addition, there are different tasks in group decision processes that must be supported:

—*Initiation.* How does the group start the collective decision-making process? Should the group elect a person who leads the discussion?

—*Information exchange.* How can a member request or disseminate information?

—*Analysis.* How does the group interpret the results of group discussions or decisions?

—*Consensus testing.* What decision technique(s) should be adopted, for example, democratic vote or weighted majority rule?

The requirements for information sharing evolve through the phases of the group decision-making process. For example, Walton [55] argues that a phase that emphasizes search and innovation requires more spontaneity and, therefore, open communication patterns. Bargaining activities, with their deliberate control of information exchange, would be facilitated by using individual-to-individual communication channels.

During the early phases of the collective decision-making process, encouraging information exchange between group members is an effective strategy for resolving individual differences. However, empirical studies have shown that, under certain circumstances, communication channels can escalate conflict [30]. In such situations channels should be eliminated to prevent the deterioration of interpersonal relationships. The decision whether to encourage or discourage communication depends on a number of situation-dependent factors. Therefore, the GDSS communications component should accommodate changing communication needs during the group decision-making process. In other words, no single communications protocol is sufficient for a GDSS; protocols should vary according to the dynamics of the group decision process.

4.4 Roles and Functions of the GDSS Communication Manager

To summarize the requirements analyzed in the previous subsections, the GDSS concept extends the DSS concept of creating an efficient man–machine interface to designing controlled man–machine–man interfaces that

—avoid misunderstanding and mistrust among group members by adapting the degree of communication to group size and decision situation;
—support structured group communication, in addition to informal exchange, for reducing negative group effects;
—adjust to formats and methods preferred by individual group members while preserving group consistency;
—monitor the degree and means of communication according to norms set by the group or its leader;
—evolve these norms during the various stages of group decision making.

On the basis of these requirements, one can develop a set of useful roles and functions for a GDSS communications manager. The roles of the communications component represent its potential impact on group decision making; its functions specify the services offered to the users. One can identify at least three specific roles:

(1) *Coordinator role.* The communication manager should coordinate the initial situation analysis and problem definition. Situation analysis is characterized by a (common) recognition that there exists an urgent and important problem to be solved. Once identified, a problem is formalized in the problem definition phase in such a way that solutions can be generated, analyzed, and selected. Eiseman [13] and Kolb et al. [29] emphasize that the success of situation analysis and problem definition depends on the ability of the group to eliminate mistrust and threat, which could cause group participants to withhold or distort information. Walton [52] suggests that by installing a communication medium that follows some norms of fairness (e.g., equality of participation, preserving autonomy), information exchange will be more abundant and accurate.

(2) *Detective role.* Problem analysis could be distorted by an individual's attempt to spy on others' activities or by the influence of some members who try to take over an individual's responsibility. The communication component should then serve as a detective that prevents unwanted data exchange or malicious modification of public data. Additionally, decision makers tend to delay sending their individual results. The communication component should press its users to

Decision Phases	Role	Function
Situation analysis/ Information gathering/ Problem definition	Coordinator	Provide support for information exchange
Individual decision analyses	Detective	Enforce communication protocols
Group decision analyses	Inventor	Search for data compatibility of group algorithms; sort data for diffusion

Fig. 6. The roles and functions of the GDSS communications component.

submit opinions before a given due date. Generally, the detective role consists of enforcing communications protocols, previously defined, to drive the collective decision-making process. In this sense, it is a generalization of concurrency control in databases.

(3) *Inventor role.* The inventor role is an extension of the coordinator role. Given the complex nature of a group decision problem and the diverse and unpredictable decision approaches of the participants, the communications component should detect incompatible information exchange and, if possible, propose alternative formats. The inventor role implies, on the one hand, a potential for tolerance of uncertainty in requests and needs for data transfers, and on the other hand, a continued search for communications operations that facilitate information exchange [11]. Thus, protocols for a GDSS should be able to analyze, evaluate, and determine the content of transmissible information, rather than simply perform a transport task.

The functions provided by the communication manager in order to play the above roles are at least twofold. First, it *monitors* a broad spectrum of data *transports* during a group problem-solving process. This transport function ranges from information exchange to information hiding, from selective and personalized routing to collective diffusion of data, and from public to private information. Second, the communications component coordinates various activities (i.e., initialization, consensus search, negotiation, and mediation).

Figure 6 summarizes the relationships between the roles and supporting functions of a GDSS communication component.

5. DESIGN OF THE Co-oP COMMUNICATION MANAGER

In its current version, the Co-oP communication manager fulfills the coordinator and detective roles but offers little in terms of inventor support. It consists of four modules that define and enforce protocols of interaction among the participants in a group decision process. In order to abstract from low-level details and to make the system compatible with other networking applications, it is embedded in the presentation and application layers of the Open Systems Architecture [22].

Figure 7 shows how the GDSS communication modules fit into the ISO open systems architecture layering concept. At the applications layer, three new systems components are introduced: a Group Norm Constructor for defining a group decision protocol, a Group Norm Filter for enforcing it, and an invocation mechanism to request protocol changes. At the presentation layer, an

IDSS-1 IDSS-2

← Layer 7—Application: →
- GROUP NORM CONSTRUCTOR
- GROUP NORM FILTER
- INVOCATION MECHANISM

← Layer 6—Presentation: →
- IDSS-to-GDSS FORMATTER

← Layer 5-4-3-2-1: Network, Link, Physical →
- TRANSMISSION PROTOCOLS PROVIDED BY SELECTED NETWORK OR LAN

Fig. 7. The GDSS communications modules and the ISO/OSI model.

IDSS-to-GDSS formatter supports the interaction of different individual problem representations, for example, the interaction of MCDM data formats with each other and with the group representation. In the following sections, each of these four modules is described, together with its role in the six Co-oP decision process steps outlined in Section 3. Figure 8 shows a summary of the interaction between the four modules (shown as rectangles), the six steps (shown as ovals), and the data files (small open boxes) that store intermediate results generated by the modules or steps.

5.1 Group Norm Constructor

The purpose of this module is to allow the definition of a flexible and adjustable mechanism for monitoring information transfer between individual DSSs. To fulfill the coordinator role, the Group Norm Constructor is used to define group members, communication channels, and group decision rules. Figure 9 is a checklist of major issues to be resolved in a GDSS group norm, generalized from the example in Figure 5.

The group norm is a set of structures and rules defined by a number of group choices for each of the issues in Figure 9, recorded by the group secretary. The notepad system is used for informal communication during this step (and later on, if allowed by the group norm). Identification of decision makers, that is, name and password, is necessary to coordinate group decision activities. The group secretary who defines the norms can enter his or her password during the group norm definition process. Other members of the group will be requested to provide their password from their individual workstations.

Parameters governing the nature of the information exchange must also be defined. If broadcasting of individual outputs is selected, individual outputs are public in that they are diffused to every group member's workstation. Otherwise, only group results are broadcast throughout the network; individual opinions are submitted anonymously to the GDSS method.

Finally, the group has to agree upon the methods by which group decisions will be computed, what negotiation support tools will be used, and if, and how often, to allow its members to modify individual analyses after diffusion of group analyses. Time limits can be set to press the group members to reach a decision.

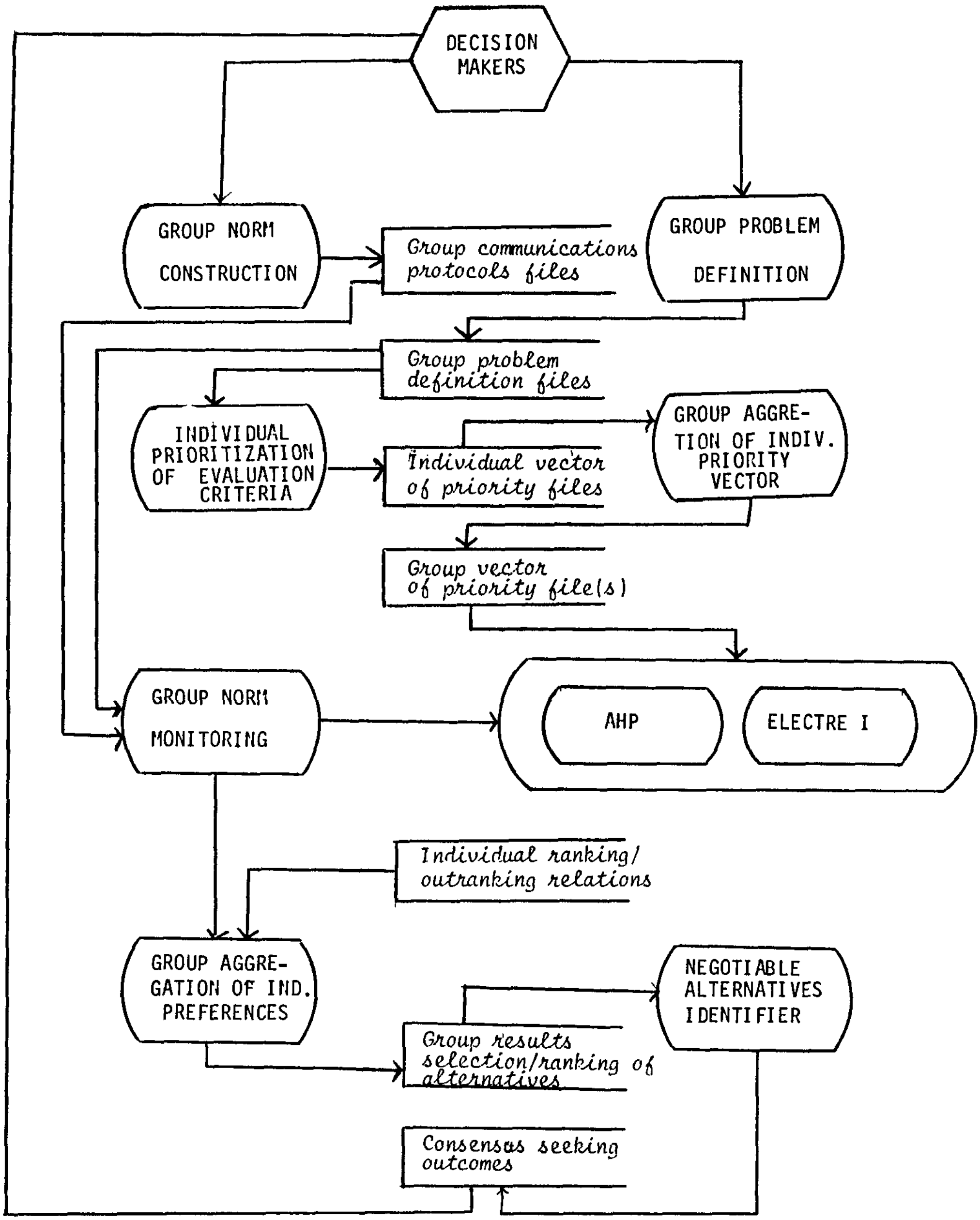

Fig. 8. Communications modules and Co-oP processes.

5.2 Group Norm Filter

The norm generated by the Group Norm Constructor is compiled into a set of enforcement routines called the Group Norm Filter. When a communication is requested, the Group Norm Filter will check whether the desired interaction

DATA TRANSFERS:

- Point-to-point or private data sharing .... ___
- Maximum number of shared files .... ___
- Maximum size allowed for each file .... ___
- File sharing allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___
- Public data sharing .... ___
- Maximum number of shared files .... ___
- Maximum size allowed for each file .... ___
- File sharing allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___

INTERACTIVE CONVERSATION:

- On-line talk .... ___
- Maximum number of talks .... ___
- Maximum time allowed for each talk .... ___
- Talk allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___
- Teleconferencing .... ___
- Maximum number of teleconferences .... ___
- Maximum time allowed for each teleconference .... ___
- Talk allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___

ELECTRONIC MAIL:

- Point-to-point communication .... ___
- Maximum number of messages .... ___
- Maximum time allowed for each message .... ___
- Mail allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___
- Bulletin board .... ___
- Maximum number of messages .... ___
- Maximum time allowed for each message .... ___
- Mail allowed only at the following phases:
  —Problem definition .... ___
  —Individual decision analyses .... ___
  —Group decision analyses .... ___

GROUP DECISION TECHNIQUES:

- Automatic selection of aggregation of preference techniques .... ___
- If NO,
  —Sums of the ranks .... ___
  —Sums of outranking relations .... ___
  —Additive ranking .... ___
  —Multiplicative ranking .... ___
- Automatic computation of the consensus seeking algorithm (NAI) .... ___
- Deadline for sending individual results .... ___
  —Date .... ___/___/___
  —Time .... ___:___
- Broadcasting of individual results .... ___

Fig. 9. Checklists for a Group Norm Constructor.

corresponds to the current protocols. Otherwise, the Group Norm Filter notifies the user of the violation and displays the current protocol pattern, if requested.

Specifically, the Co-oP Group Norm Filter performs three functions. First, it grants a user access to group DSS facilities only if identification and password are valid. It also warns the users if deadlines are coming up. Second, it keeps track of data transfers from an individual DSS to the group DSS. This allows Co-oP to deny unauthorized access to the group result. Finally, the Group Norm Filter monitors computation of group decision results in conjunction with the Co-oP model manager.

5.3 Invocation Mechanism

This module enables decision makers to request a modification of the communication protocols. The rationale of such a mechanism is to provide enough flexibility to deal with the inherently dynamic and nondeterministic nature of group problem-solving processes (see Section 4.2). Triggered by a group member's request, the Invocation Mechanism checks when and how it can convene the decision makers to debate and vote on the motion.

The Invocation Mechanism also permits creation of incremental changes and multiple alternate norms, for example, new group members, redistribution of decisional power, and extension of new due dates. Thus, many norms can be sequentially applied to a given decision problem, or a given norm can be used for various problem situations.

5.4 IDSS-to-GDSS Document Formatter

The formatter contains conversion protocols for information exchange between the IDSS Model Components and the GDSS Model Component. In Co-oP, it converts individual MCDM outputs to data formats compatible with the techniques of preference aggregation, as discussed in Section 3.2.5.

6. SUMMARY

A GDSS communication manager links decision support systems via a computer network to support group problem solving. Such an approach is a result of the increasing need to integrate communication support into a DSS. In a group decision situation, the communication facility must (i) reduce miscommunication among geographically dispersed decision makers, (ii) support formal and informal communication, (iii) simplify data transfer protocols, (iv) offer flexibility in setting levels of information sharing ranging from limited to free exchange, and (v) accommodate protocol changes during the group decision-making process.

The communication manager embeds a Group Norm Constructor, a Group Norm Filter, an Invocation Mechanism, and a method-oriented IDSS-to-GDSS Formatter in the application and presentation layers of the ISO Model. As opposed to the lower levels of the ISO model that attempt to provide reliable connections, the modules of the GDSS communications component help define and preserve group rules.

The implementation of Co-oP, a GDSS for cooperative group decision making, has demonstrated the feasibility of the proposed framework in the context of multiple-criteria decision methods. Informal experiments indicate that the combined service of the four communications modules satisfies many requirements regarding remote information exchange. In an extension currently under development, distributed knowledge bases are being added to the system to improve further the coordination of man–machine–man interaction and to strengthen the inventor role. As a long-term goal, we hope to contribute to office information systems that support collective managerial tasks with a quality similar to that available for clerical activities today.

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