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# Computer-Based Systems for Cooperative Work and Group Decision Making

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Application of computer and communications technology to cooperative work and group decision making has grown out of three traditions: computer-based communications, computer-based information service provision, and computer-based decision support. This paper reviews the group decision support systems (GDSSs) that have been configured to meet the needs of groups at work, and evaluates the experience to date with such systems. Progress with GDSSs has proved to be slower than originally anticipated because of shortcomings with available technology, poor integration of the various components of the computing "package," and incomplete understanding of the nature of group decision making. Nevertheless, the field shows considerable promise with respect to the creation of tools to aid in group decision making and the development of sophisticated means of studying the dynamics of decision making in groups.

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General Terms: Experimentation, Human Factors, Management

Additional Key Words and Phrases: Cooperative work systems, group decision support systems

## 1. AIDS FOR COOPERATIVE WORK AND GROUP DECISION MAKING

### 1.1 The Focus on the Group

A prevalent theme of modern industrial societies is that group activities are economically necessary, efficient as means of production, and reinforcing of democratic values. The necessity for group over individual activity has been assured by the modern industrial state, which could not survive on individual effort alone. As early as 1920, the power of the group to influence individual thought was shown experimentally, and the overall importance of group activity soon stimulated rapid growth in studies of group psychology [Allport 1920; Murphy and Murphy 1931]. The belief in the efficiency of group work was reinforced by research in the 1930s that showed groups could solve problems in larger numbers and with greater speed than could isolated individuals [Shaw 1932]. The democratic attributes of group work were demonstrated by studies showing that members of minimally organized work groups were just as productive as members of strictly organized and segmented work groups, but more content [Lewin et al. 1939]. Social organization was a hallmark of the U.S. effort in World War II, and for the first time substantial resources were invested in the systematic and scientific analysis of group activity. Since then, efforts to improve the

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functioning of groups have burgeoned, and a focused specialty of study in group performance, particularly performance in making decisions, has emerged [cf. Burlingame et al. 1984; Davis 1969; Gabarro 1987; Hackman and Morris 1975; Hogarth and Makridakis 1981; Huber and Delbecq 1972; Kraut et al. 1988; McGrath 1984; Quinn 1978; Quinn and McGrath 1982; Steiner 1972; Ungson and Braunstein 1982]. Increasingly, techniques and technologies have been proposed as instruments for improving group performance in the decision-making arena [Dalkey 1975, 1977; Huber 1980; Hulin and Roznowski 1985; Van de Ven and Delbecq 1971; Van Gundy 1981].

Over the past decade, computer-based systems have been proposed as tools for group decision support.[1] The result has been the creation of a new area of research in group decision support systems (GDSSs). GDSS efforts initially grew out of a desire to expand the concept of decision support systems (DSSs) to encompass group decision making [Bonczek et al. 1979; Huber 1980]. The challenge proved more daunting than the early visionaries imagined, and the subsequent development of the group decision support field was slow through the early 1980s. During that time, the GDSS efforts were paralleled by contemporaneous development in the allied fields of advanced electronic communications, including teleconferencing, computer conferencing, and electronic mail. In the mid-eighties a new paradigm began to emerge at the confluence of these fields. This new paradigm, known most commonly by the name computer-supported cooperative work (CSCW), maintains that facilitating the tasks of group decision making is just one of a broader set of challenges to using computer technologies to facilitate cooperative work [Begeman et al. 1986; Galegher et al. 1988; Greif 1986; Malone et al. 1987; Suchman and Trigg 1986].

This paper presents an assessment of GDSS development and use in the United States at present. The focus is limited to the United States because the issues to be explored are adequately accessible from domestic experience, although GDSS efforts are underway in other countries [Anderson 1987; Bodker 1987; Danielsen et al. 1986; Kersten 1985; Raman and Rao 1988]. The paper builds upon earlier work [Kraemer and King 1983] but also includes more analysis of the prospects of this emerging technology. It reviews the conceptual foundations for GDSS, describes exemplary systems that are in operation or under development, and assesses the experience with GDSS thus far. It traces the evolution of GDSS to encompass group activities other than decision making, including communication and information processing. The paper fits within the broader CSCW rubric by placing the GDSS movement within a tradition of research that collectively constitutes the CSCW domain and by drawing the broad implications for GDSS and cooperative work in the conclusion.

[1] It is interesting to note that the earliest proposals and experiments were not at the group but at the community level [cf. Rouse 1973a, 1973b, 1973c; Rouse 1974; Rouse and Sheridan 1973, 1975; Sheridan 1971, 1973, 1975a, 1975b].

### 1.2 A Definition of GDSS

There is little agreement in the literature about what constitutes a GDSS. In fact, the term is seldom defined explicitly. DeSanctis and Gallupe [1985] provide a useful start by defining GDSS as "an interactive computer-based system that facilitates the solution of unstructured problems by a set of decisionmakers working together as a group." This is an adequate introductory definition when coupled with an understanding of the reasons behind the perceived *need* for development of improved means of aiding group processes. Huber [1984] illustrates the need through the following dilemma: Decision makers find themselves faced with an increasing number of lengthy meetings needed to discuss information-laden issues, but decision makers are beginning to resist attending such meetings because they take time away from other critical activities. The solution to this dilemma is to make meetings more productive, which is the key concept behind the GDSS. Operationally, this means increasing the speed at which decisions are reached without reducing, and, it is hoped, enhancing, the quality of resulting decisions.

How can the GDSS accomplish these worthy goals? Huber [1982a] provides the following succinct assessment of the issue:

(1) Effective group decision making requires meeting the need of the situation, ensuring that members are satisfied with the process, and enabling members to meet and work successfully in the future.
(2) "Losses" of productivity in group decision making occur because discussions are dominated by certain individuals, low-status members defer to high-status members, group pressures lead to conformity of thought, miscommunication among members is common, and insufficient time is spent in problem exploration and generation of alternatives.
(3) GDSSs can help alleviate these problems by providing a personal computer terminal for each participant, a public display screen for all, computing and communication capabilities that allow for accessing databases and communicating with the group leader and the public display, and software for word processing, data access and management, graphics, and "controls" to permit communications with others or the group.

In other words, the primary problems of productivity loss in group decision meetings are from information loss, information distortion, or suboptimal decision making (i.e., not enough issues and alternatives are explored). GDSSs can reduce these losses by allowing anonymity of participants' contributions to the discussions, facilitating database searches and analyses in order to answer questions, and enabling individuals' inputs to be displayed on the public screen for open discussion.

As Huber points out elsewhere [1981a, 1981b], this view of the contribution of GDSSs to decision making is essentially a *rational* one. That is, the participants in decision meetings intentionally use information in a rational manner to benefit the organization or group as a whole; lack of success under this model is due to intellectual or resource constraints. Under this model the GDSS can provide the following information:

*Basic information.* What are the alternatives? What are the likely future conditions? What criteria are to be used in the decision?

*Elaborating information.* What are the probabilities that the future conditions will occur? What is the relative importance of the criteria for deciding? What payoffs accrue to what outcomes? What are the constraints on payoffs or costs?

Techniques such as return-on-investment analysis and break-even analysis can be used for these purposes. In the future, judgment-eliciting techniques may also be incorporated to glean members' judgments.

The basic concept is fairly simple: to reduce the losses inherent in group meetings by selected application of technologies that facilitate information access, analysis, and sharing. As we shall see, the simplicity is only apparent. Although progress has been made in the development of technologies that show the *potential* for facilitating cooperative work and group decision making, the promise has not yet been realized.

## 2. CURRENT STATUS OF GDSS ACTIVITY

### 2.1 The Context of the GDSS Concept

A review of the literature and the practice suggests that there is no established way of classifying GDSSs. It is most expedient to derive a classification of GDSSs from the array of possible technologies that can be brought to bear in situations in which groups must make decisions. These can be computer, communications, or decision technologies, or combinations thereof.[2]

We distinguish six technologies that form the context of GDSSs, as shown in Table 1.

### 2.2 The GDSS Package

As with many other technologies, it is useful to conceive of a GDSS as a sociotechnical "package" comprised of (1) hardware, (2) software, (3) organizationware, and (4) people. Typically, a GDSS involves a group of decision makers with access to a computer, viewing screen, database, decision model(s), and, in many cases, a "facilitator" who supports the group in use of the technology, instructs them on the use of the decision model, coordinates the group's activity, and documents the group's work.

*Hardware* includes the conference facility itself and the computing, telecommunications, and audiovisual equipment. At a minimum, the conference facility is a single room with a conference table and supporting equipment. In some cases the meeting room has space for observers of the conference (e.g., teleconferences, which usually are expensive and last only a few hours); in still other cases, the meeting room is accompanied by breakout, audiovisual, and lounge rooms for the staff and participants (e.g., decision conferences, which last several days).

The computing equipment includes a computer processor with graphics capability and an information display, usually a computer display or a large projection screen, accessible to the group as a whole. In more sophisticated systems, the computer equipment will include a computer terminal or personal computer for each group member, a large central processor for managing communications among members and storing common databases and models, a local-area network ("local" to the meeting room or the local work locations of the group) for communication among group members, a long-distance communications system for linkage with outside groups or databases, and several large viewing screens or one large screen with multiuser and windowing capabilities. These sophisticated systems also might include multipoint interactive communication capabilities for computer and/or video conferencing, shared files and displays that all group members can view and change, and private files and displays that only group members can view and change.

*Software* is the key distinguishing technological feature of GDSSs and may be used for the support of general information processing, decision modeling, or communications. General information processing software could be used for either individual or group work and includes database management systems and high-level programming languages, as well as generalized application packages such as those for graphics, spreadsheets, and statistical analysis. Decision modeling software is specifically aimed at supporting group decision making and includes modeling languages (e.g., SIMSCRIPT, DYNAMO), decision structuring techniques such as stakeholder analysis, brainstorming, nominal group technique, and Delphi technique,

[2] There are alternative classifications available. For example, GDSSs could be classed on the basis of whether they are single- or multipurpose, inside or outside the organization, and fixed (you come to them) or portable (they come to you) (see, e.g., Huber [1984]). DeSanctis and Gallupe [1987] provide a useful classification according to the context of application—group size, member proximity, and task type. We chose to classify GDSSs on the nature of their underlying technology because (1) they are easily differentiated this way, (2) the technology, particularly the hardware and software, remains the major content of a GDSS, and (3) the nature of the GDSS field is most readily traced by following the evolution of the technical developments that underlie it.

**Table 1.** Technology Basis of GDSS

| Technology | Description |
|---|---|
| Electronic boardroom | Computer and audiovisuals |
| Teleconferencing facility | Computer and communications |
| Group network | Computer network and interactive conferencing |
| Information center | Computer, databases, and retrieval tools |
| Decision conference | Computer and decision models |
| Collaboration laboratory | Computer and collaboration tools |

and specialized software for decision analysis techniques such as utility and probability assessment, multiattribute utility analysis, and multiattribute weighting analysis [Adelman 1984]. Communications software is specifically aimed at supporting the collaborative aspects of group work and includes tools for both local and long-distance text, data, voice, and video transmission (e.g., electronic chalkboard, electronic voting, networking, electronic mail, computer conferencing) among local and distant group members, between group members and the facilitator, and between group members and the central processor.

*Organizationware* includes the organizational data, group processes, and management procedures for collaborative group work. Some GDSSs generate their own data by polling the members for their ideas, opinions, weightings, and judgments; other GDSSs involve the use of organizational or outside databases as well. These databases might include strategic or operating plans, budgets, market or customer data, or industry data. Organizationware also includes group processes that vary, depending on whether relations among group members are authoritarian or democratic, consensual or conflictual, political or rational. Group processes direct the flow of events and discussion regarding the group's decision, such as whether there is a group leader, how the leader is chosen, how the group's agenda is chosen. Group processes are often implicit and shaped by the organizational context of participants. They might, however, be altered in the context of GDSS use. In addition to organizational data and group processes, there are management procedures for collaborative group work. These are aimed at the social versus the task aspects of group activity, such as developing participation, securing commitment to the decision, and maintaining support of the group.

*People* include the participants in the group and the support staff who facilitate the group's activities. The "facilitator" is the key distinguishing social component of GDSS, and his or her role can vary widely. At minimum, the facilitator operates the technology required to support the group activity. For example, the facilitator might perform calculations and produce displays and document group decisions. Alternatively, the facilitator may actually conduct the group meeting, leading the participants through each step of some specific decision making or other group process technique and directing the technological aspects as well. Although this role is often taken with new groups, the facilitator's role usually evolves into that of a trainer and troubleshooter, teaching the participants how to use both the hardware/software and the group process technology themselves and then remaining available for help as problems arise and providing advice and feedback to the group.

Table 2 summarizes the six kinds of GDSSs in terms of the four elements described. Each kind of GDSS is discussed and illustrated next.

#### *2.2.1 The Electronic Boardroom*

The electronic boardroom is the most elementary of the GDSSs and differs little from its nonelectronic parent except that the audiovisual technology is computer based, primarily in the form of computer graphics, computer "storyboards," or computer-controlled audiovisuals (e.g., slide projectors, video projectors, movie projectors) used for presentations. Here the

**Table 2.** Major GDSS Elements

| Element | Electronic boardroom | Teleconference facility | Group network |
|---|---|---|---|
| Hardware | Conference room; audio visuals; graphic displays; computer | Conference room; audiovisuals; audio, computer or video telecommunication controller | Offices; file server and computer work stations; telephone; computer network |
| Software | Interactive graphics | Communications | Interactive/asynchronous computer conferencing; terminal linking; real-time meeting scheduling; shared bit-map display |
| Organizationware | Audiovisuals; corporate reports; standard meeting protocols | Audiovisuals; teleconference protocols | Conference chair conducts meetings |
| People | Participants; audiovisual technician | Participants (in two or more locations); teleconference facilitator | Participants (in two or more *local* places), group leader |
| Examples | NA custom tailored for each site although some "modular" audiovisual rooms exist | Picturephone Meeting Service | MIT Lab for Computer Science RTCAL and MBlink EIES, NOTEPAD, PARTICIPATE CONFER II |

computer is a very indirect aid to group decision making. The capability provided by the computer is primarily used in relation to storage, retrieval and programming of previously prepared presentation materials. It is possible, however, for the computer to be used in a more interactive way in group meetings. For example, it is logically possible to use the computer to store audio-visuals such as slides, maps, charts, photographs, and drawings of areas of a city and to retrieve these on demand for a city planning commission or city council as a direct aid to discussions about problems and issues in a particular area of the city. But such applications are presently only possibilities; to our knowledge there are no organizational applications.

The electronic boardroom is the earliest type of GDSS, having been the topic of much discussion and construction during the early 1970s. Although we cannot verify this claim on a broad basis, from our field investigations we have come to believe that many of these early versions of the electronic boardroom have either disappeared from use (i.e., have been taken out of service or allowed to languish) or have been transformed into one of the other three types of GDSSs. Examples of the electronic boardroom were found in the City of Brea (California), Arthur Anderson and Company (San Francisco, Chicago, New York, Los Angeles), Chase Manhattan Bank (New York), First Chicago Corporation (Chicago), Transamerica Corporation (San Francisco), Aetna Life and Casualty (Hartford, Conn.), and Bank of America (San Francisco) [*Administrative Management* 1982; *Business Week* 1976; *City of Brea* 1982; Manilla 1980].

### 2.2.2 The Teleconferencing Facility

The teleconferencing facility is a GDSS designed primarily to facilitate meetings between groups at two or more locations. All of the conference rooms designed for teleconferencing have been designed to facilitate audio or video teleconferencing rather than computer teleconferencing, since the latter does not require a conference room. Computers seldom play a direct role in these teleconferencing facilities

**Table 2** (*Continued*)

| Information center | Decision conference | Collaboration laboratory |
|---|---|---|
| Conference room; large-screen video projector; computer; display terminals | Conference room; large-screen video projector; display terminals; voting terminals | Conference room; electronic chalkboard microcomputer workstations, electern |
| Database management software; statistical packages; retrieval, graphics, and text-processing software | Decision analysis software; modeling software; voting tally and display software | Multiuser interface; WYSIWIS; outlining (COGNOTER); evaluating (Argnoter) |
| Corporate and other databases; standard meeting protocols; standard meetings (e.g., annual report, market forecast) | Democratic decision-making protocols (e.g., one person one vote; all major interests represented; majority opinion rules) | Standard meeting protocols |
| Participants; computer specialists; modeling specialists | Participants; decision analysts; group process facilitators | Participants |
| HOBO System: SYSTEM W; EIS, EXPRESS, XSIM | Group Decision Aid; Decision Conferences of DDI; Decision Tectronics, SUNY, Albany; Planning Lab, University of Arizona; GDSS Lab, University of Minnesota | Colab Project, Xerox PARC; Project NICK, MCC |

since most of the concern is with trying to mimic face-to-face meetings.[3]

A modern two-way video teleconference facility is usually suitable for 6–12 active participants in a meeting and another 12–24 passive participants. The active participants sit around a conference table, which is surveyed by a video camera with zoom capability that is automatically directed toward the speaker (and one or two people around the speaker) by voice activation. Microphones in front of each speaker are also voice activated. A control panel in the center of the conference table, operated by the conference chair, permits the chair to override the automatic voice activation, to switch control between the two meeting locations, to focus the video cameras on presentation materials in the room, and to activate other presentation devices. Other hardware in the teleconferencing facility includes facsimile machines for transmitting hard copy between sites and conventional audiovisuals such as movies, audio recorders/players, blackboards or whiteboards, overhead projectors, opaque projectors, and flip charts.

The software in support of video and audio teleconferencing is primarily communications software for handling digital transmission of voice, data, and pictures. The organizationware used in teleconferencing involves special preparation and planning for each teleconference, including planning of the audiovisuals and meeting protocols designed specifically for teleconferences. The people involved in a teleconference include the meeting participants, background support people outside the meeting room, and a teleconference facilitator who provides an introduction to teleconferencing for the participants and hovers at the meeting in case assistance is needed. The meeting is chaired by a participant at one of the sites participating in the conference. Conference rooms built for video teleconferencing are being used increasingly for internal meetings, and some of them are being hooked up to

[3] Computer teleconferencing is discussed in Section 2.2.6, Group Network.

corporate computers and databases to provide the additional capabilities of a corporate information center.

Most of the private teleconference facilities currently in existence have been built for large business or government organizations that have need for frequent communication between two or more sites. Some of these systems have been built as organizational demonstrations to learn more about their feasibility and utility. Examples of such facilities include those at Atlantic Richfield, U.S. Department of Energy, General Services Administration, Jet Propulsion Laboratory, National Aeronautics and Space Administration, Union Trust, and United California Bank [Gold 1979; Kraemer 1982]. Picturephone meeting service is a "public" teleconferencing service of AT&T that once extended to 42 U.S. cities [Suenning and Ruchinskas 1984].

#### *2.2.3 The Information Center*

The information center is a portion of the data processing resources of an organization that is organized and dedicated to support the users of computer-based information systems in activities such as report generation and modification, data manipulation and analysis, and spontaneous inquiries. The assumption underlying the information center is that if users are given proper education, technical support, usable tools, data availability, and convenient access to the system, they may directly and rapidly satisfy some of their computer-based information requirements [Chastain 1983; Hammond 1982; Mau 1982; Youstra and Squire 1983].

The impetus for developing the information center stems from the fact that the project-oriented development environment for information systems in most organizations seldom meets the needs of managers and professional users. The development environment is usually characterized by long lead times and emphasis on stability, whereas the decision environment of managers and professionals is characterized by rapid change, short turnaround, and the requirement for flexible data-handling capabilities. Consequently, the aim of the information center is to provide users with computer power, databases, software, and technical support that enables them to directly control their information environment. The type of work intended to be supported through the information center is the short job, the one-time query, the simple report, the minor change, and the ad hoc analysis.

The kinds of software typically provided in an information center include packaged programs for data management, report generation, data retrieval and query, text handling, statistical analysis, and mathematical and simulation modeling. The information center usually has a manager and several technical staff who, in turn, are backed up by the organization's data processing staff. The center also operates on the organization's main computing facilities and accesses corporate databases as well as secondary data sources. It usually is part of the organization's data processing installation, with status equal to major divisions such as development and operations but physically separate from these to emphasize the relationship of the center to the users. The physical arrangement of the information center includes public areas with terminals that users can access, private cubicles or offices where center staff can work with individual users, and a conference facility with a large-screen display and terminals to serve small-to-medium-sized groups [cf. Kucia 1983].

As is apparent from this description, the information center started out as a way of distributing computing to managers and professional users throughout an organization. In many cases it continues to operate in that way—basically providing a smorgasbord of computer power, databases, software packages, and consulting to users. But in some instances the center and its tools have become tailored to serve a particular group of users, such as the marketing department, the planning staff, the corporate staff, and managers. And in such instances the center's activity has focused on honing the tools of the information center into aids specifically designed for decision making by a particular group (e.g., the marketing group). It is this group-oriented use of information centers that most properly falls under the GDSS label and that was the intellectual forerunner of the contemporary information center [cf. Robinson and Stidsen 1971].

Examples of the generalized information center abound in large organizations [Torgler 1983; Waltrip 1983]. But specialized information centers serving the information and decision needs of a particular group are as yet relatively few [Bode 1983; Moore 1983; Van Nievelt 1982]. Integrated software packages for information centers include Executive Information Services (EIS), EXPRESS, System W, and XSIM [Houston 1983; Sumner 1985].

#### 2.2.4 The Decision Conference

The decision conference facility is discussed in the literature under the labels of group decision support system, decision analysis, and group decision aid. What distinguishes the decision conference from the other GDSSs is its explicit focus on improving decision making by groups and its emphasis on the use of structured decision processes, mainly involving computer models but increasingly involving group process models as well.

The hardware for the decision conference consists of a medium-sized conference room furnished with a large-screen video projector, a computer, video terminals, terminals for voting or other input by the participants, and a control terminal for presenting participant inputs in graphic form and for accessing other sources of information (e.g., databases, general reference materials, results of previous conferences).

The software of the decision conference is usually some form of decision analytic technique: decision trees and influence trees, multiattribute expected utility models for single-stage decisions, hierarchical evaluation structures for multiattribute utility analysis, Pareto algorithms for two-party negotiations, cost–benefit models for resource allocation, and spreadsheet models [cf. Adelman et al. 1981; Allardyce et al. 1979a, 1979b; Amey et al. 1979a, 1979b, 1979c, 1979d; Weiss 1980; Weiss and Kelly 1980]. In some systems the data are collected and displayed at a fine-grained level, including expressions of preferences on a scale (say 0–100 points) or predictions involving ranges rather than point estimates. Software for graphics and vote tally and display also are part of the decision conference facility.

The organizationware of the decision conference primarily relates to meeting protocols regarding who participates, on what basis, with what voting rights, and with what consequences and commitments resulting from the process. Most of the decision conferences we examined emphasize "democratic" protocols rather than "authoritarian," "hierarchical," or "authoritative" ones. The primary reason for this fact seems to be that the decision conferences involve equals (e.g., scientists, managers at more or less the same level in the organization) or representatives of groups who insist they be treated as equals (e.g., community interest groups vying with one another and the city council on some policy issue, and labor and management negotiators).

The participants in the decision conference are the actual people in the organization who are involved in making a decision. The participants usually are assisted by decision analysts who explain the available decision analytic tools and work with the participants in modeling their decision problem. The participants also might be assisted by one or more group process facilitators—people trained in the behavioral dynamics of group meetings and in facilitating self-awareness of the group about its processes.

Illustrations of the decision conference in industry are provided by GROUP DECISION AID of Perceptronics, Inc. [Elfont 1982; Leal and Pearl 1977; Leal et al. 1978; Saleh et al. 1979; Steeb and Johnston 1981], and the Decision Conferences of Decisions and Designs, Inc. [Adelman 1984; Brown 1978; Buede and Waslov 1981; Fischer et al. 1978; Kelly et al. 1980; Patterson et al. 1981]. In universities, the decision conference is illustrated by the Decision Tectronics Laboratory at SUNY, Albany [Quinn et al. 1985], the Planning Laboratory at the University of Arizona

[Applegate et al. 1986a, 1986b, 1986c; Konsynski et al. 1984–85; Nunamaker et al. 1987, 1988a; Nunamaker et al. 1988b], the Cooperative GDSS at New York University [Bui and Jarke 1984], the SMU Decision Room [Gray 1983; Gray et al. 1981], and the GDSS Lab at the University of Minnesota [DeSanctis and Dickson 1986; DeSanctis et al. 1987].

Although most GDSSs focus on decision making and involve formal decision technologies of some kind, there are important variants, which begin with the notion of facilitating simple group collaboration around common tasks such as setting meetings, sharing information, outlining ideas, and evaluating proposals rather than only facilitating group decision making. The importance of these variants is that they bring new kinds of capabilities to support group work. Many of these capabilities, such as outlining, word processing, and spreadsheet analysis, already exist for individuals but generally have not been tailored for groups, nor has the supporting common infrastructure been developed. Although they are only in prototype stages, we believe these represent significant new types of GDSSs not uncovered in our previous survey—the Collaboration Laboratory and the Group Network.

### 2.2.5 The Collaboration Laboratory

The collaboration laboratory is focused on computer support for face-to-face group work. Although decision making and problem solving might be involved in group work, the laboratory does not involve the use of formal decision models and quantitative techniques. Rather, it focuses on writing and argumentation and involves verbal models and qualitative techniques through the manipulation of text-oriented data and graphical images, which are the most common forms of data used in group meetings.

Physically, the collaboration laboratory is similar to the decision conference. It consists of workstations that are built into a conference table to permit eye contact and that communicate with one another and with a shared electronic chalkboard. The electronic chalkboard is contrasted as follows with the conventional chalkboard:

> A chalkboard provides a shared and focused memory for a meeting. Chalkboards allow flexible placement of text and figures, and this complements our human capabilities for manipulating spatial memories. But space is limited and items disappear when their space is needed for something else. Rearranging items is inconvenient because they must be manually redrawn and then erased. Handwriting on a chalkboard can be illegible. Chalkboards are also unreliable for information storage. They are used in rooms that are often shared by many groups. Text and figures created in one meeting may be erased by the next group to use the room. If an issue requires several meetings to resolve, then some other means must be used to save the information between meetings. Many things that are awkward with chalkboards are easy with computers. Computers provide much greater flexibility for rearranging text and figures with window systems and drawing aids. Computers can create text in fonts that are crisp and reproducible. File systems for today's computers make it possible to redisplay information from previous meetings, to revisit old arguments, to show the history of a series of arguments, and to resume discussions. Computer displays can replicate the objects under discussion and place them where everyone can see them, point to them and change them. Participation can feel less like being a member of a committee, and more like being a member of a community barn-raising. [Stefik et al. 1987]

The collaboration laboratory also consists of text-oriented tools including a common human–machine interface, WYSIWIS (what you see is what I see) for presentation of images of shared information for all participants, public (shared) and private (not shared) windows on the workstations, and applications such as a group method of preparing outlines of ideas and associated text and a group method of evaluating plans and programs that have already been developed.

The group method for outlining is similar to individual tools for outlining such as ThinkTank,[4] but includes additional features to specifically aid group collaboration. For example, it works for multiple participants or a single user, it separates the brainstorming task of outlining from the ordering task, and it saves all ideas until the last moment, even if they do not fit into the outline.

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[4] ThinkTank is a trademark of Living Video Text.

As the name suggests, the collaboration laboratory is aimed at facilitating equal participation among essentially equal members of a work group. The multiuser interface is intended to discourage control over the group activity by any one participant by equalizing the access of all participants to displays and shared data. In reality, as is the case with all GDSSs, the technology requires taking turns, with only one person writing or editing shared text or speaking at a time. However, because taking turns is facilitated by the multiuser interface and because participants can work in either the shared or public spaces and easily move back and forth between them, the dynamic flow of collaborative group work appears highly supported by the technology.

There are two current illustrations of the collaboration laboratory: Colab at Xerox Palo Alto Research Center, California [Foster and Stefik 1986; Stefik et al. 1987] and Project NICK at the MCC in Austin, Texas [Begeman et al. 1986].

#### 2.2.6 The Group Network

The group network has its roots in computer teleconferencing but is also a response to its limitations. Computer conferencing is asynchronous, which means that "meetings" take place over an extended time period, usually around some prearranged topic. The conference chair usually initiates the meeting with an introductory statement and questions about the topic, which is then broadcast to all participants. The participants in turn join the meeting at their convenience, but within the prescribed "meeting time" (usually a week or two), read the chair's message and any responses from other participants, and then broadcast their own messages. Participants may respond to any and all messages and may join or exit the meeting at any time. When the appointed time to end the meeting comes or when message traffic drops off, the chair exercises the prerogative of summarizing the meeting and ending it.

There has been a great deal of experimentation with computer conferencing, and the results have been widely reported in the literature [Hiltz 1982; Hiltz and Turoff 1978, 1981; Johansen 1984; Johansen et al. 1979; Kerr and Hiltz 1982; Turoff 1972; Turoff and Hiltz 1982]. Computer conferencing has been widely used because it is relatively inexpensive (compared with face-to-face meetings) and because the technical platform is available through public and private networks (e.g., Internet, CSNET, BITNET, The Source, Tymenet). The only special requirements are a computing host and conferencing software to facilitate the meetings themselves. The software is usually located at one or more nodes in the network and is frequently a service provided in private networks (e.g., the conferencing system called "Participate" on The Source). Despite these positive features, most participants report that computer conferencing hardly feels like a meeting at all, and many are unwilling to participate in them more than a few times [Fanning and Raphael 1986; Kraemer 1982]. This has led to new efforts with interactive conferencing for small work groups in local settings.

The group network is focused on interactive computer support for small groups in geographically dispersed but nearby locations such as offices within a building or a building complex. It differs from asynchronous computer conferencing in that it is real time and interactive. In fact, it is the participant's ability to access and manipulate information dynamically by use of computer-based tools that is the distinguishing characteristic of the group network. Each participant can be seated in his or her own office at a microcomputer workstation with a keyboard, pointing device, and speaker telephone and can communicate directly with the other participants in the meeting by voice and shared information on the workstation displays. Each workstation has public and shared spaces, terminal linking, meeting scheduling, bit-map sharing, and shared applications, such as graphics, word processing, and spreadsheeting, which permit all participants to create, edit, or simply exchange graphics, text, or numbers (although only one person at a time can do so). The meeting scheduler application illustrates how interaction takes place over the network.

A meeting chair calls, conducts, and terminates meetings. The chairperson determines who has permission to enter calendar commands at any given time, when voting begins and ends, and when control of shared space is given or taken away. The meeting scheduler application displays who is part of the meeting and when they enter and exit the meeting. It allows each participant's public schedule to be viewed by all and their private schedule by themselves; the public and private schedules scroll up and down together. The meeting scheduler allows participants to vote for a preferred meeting time and displays the results at each workstation; when a time is agreed upon, each participant's public schedule is automatically posted with the meeting time.

The integrated group network exists only in prototypes and is illustrated by the work of the MIT Laboratory for Computer Science [Greif and Sarin 1986; Sarin 1984; Sarin and Greif 1985]. Stand-alone applications for group work exist in commercial form for graphics teleconferencing [Pferd et al. 1979], interactive word processing, and computer-aided drafting.

### 2.3 Examples of Existing Systems

It is almost impossible to inventory all existing GDSSs. There are hundreds of electronic boardrooms, each built more or less custom with new office construction or modification and designed by an architectural or engineering firm with technical consultation from an audiovisual provider. More are being created all the time. Video teleconferencing facilities are somewhat rarer, with no more than three dozen private teleconference facilities and probably only one-half dozen "public" facilities in existence in the United States [Kraemer 1982; Sticha et al. 1980; Suenning and Ruchinskas 1984]. Information centers are a relatively new phenomenon being promoted by the providers of large computer mainframes and currently are being developed in conjunction with established data processing installations in the United States. The providers of the information centers are in the first instance the data processing organization itself and, in the second, the computer vendor who supplies concepts, equipment, and software to the data processing organization. A recent study of such centers by Crawford [1986] suggests that, whereas many organizations have "information centers," fewer than 20% of these perform the functions of an information center as described earlier.

Only in the case of decision conferences do we have a GDSS that is relatively easily identified separate from its institutional context and provided to the market as a "product" that can therefore be inventoried. Table 3 presents an overview of major GDSS providers, their systems, and the functions performed by the systems.

Several general observations can be made on the basis of information about these systems. First, most decision conference GDSSs use three general functions: structured decision analysis, including decision trees, and multiattribute utility analysis; structured group process, including social judgment analysis, delphi technique, and nominal group technique; and collaboration support, including data management, graphic display, decision documentation, tutoring, decision analysis consultation, group process facilitation, meeting facility, and vote tabulation and display. Few systems in these examples constitute a complete package (i.e., hardware, software, organizationware, and people operating a system and providing most of the functions listed above). To date, only one is available for purchase as a "turnkey" package (Perceptronics, Inc.'s GROUP DECISION AID). The other systems are in-house decision conference facilities that are available for outside use on a fee-for-service basis or systems that have so far only been used for research. The University of Arizona's PLEXYS software is available for purchase and has been transferred to nearly a dozen universities and several corporate environments [Konsynski et al. 1984–85].

Second, there is a tendency toward greater integration within, between, and among the various functions provided in a GDSS. For example, information center products such as SYSTEM W are designed to integrate several software capabilities

**Table 3.** Features of Major GDSS Providers

| Provider | System | Functions |
|---|---|---|
| Applied Futures, Inc. | CONSENSOR (hardware/ software) | Vote tabulation and display |
| Compshare | SYSTEM W (software) EXPRESS (software) | Data management, modeling statistical analysis, graphics, report generation PC communications |
| Decisions and Designs, Inc. | Decision conference (complete package) | Interactive decision analysis (six models), conference facility, decision analysis, consultation |
| EXECUCOM | IFPS (software) | Interactive financial modeling, data management, graphics |
| Institute for the Future | NA—research | Research/consulting on teleconferencing |
| MIT Laboratory for Computer Science | MPCAL, CDS, RTCAL, MBlink research only | Support of geographically separated local group work, including calendar management, real-time conferencing, and collaborative document editing |
| Perceptronics, Inc. | GROUP DECISION AID (hardware/software package) | Interactive decision tree; analysis, tutor, documentation |
| SRI International | QUICKTREE and APLTYER (software) | Interactive decision tree analysis for individuals |
| SUNY, Albany Decision Techtronics Group | NA—public service (complete package) | Interactive decision analysis (six models), data management, graphics, decision and process consulting |
| UCLA Cognitive Systems Laboratory | NA—research (math models/ software) | Group decision theory and analysis |
| University of Arizona Planning Laboratory | PLEXYS software—research, public service (complete package) | Electronic brainstorming, stakeholder identification and analysis, organization analysis, knowledge management, graphics, report generation, PC network |
| University of Minnesota GDSS Laboratory | CAM—research only (software) | Snow card technique, nominal group technique, stakeholder analysis, spreadsheet and allocate analysis tools, data management tools |
| Xerox PARC | COLAB—research (complete package) | Computer support of face-to-face group work |

(data management, graphics, statistical analysis, modeling, report generation, and PC communications) in a single system. Traditionally, these functions have been provided through separate, or only partially linked, software products. Similarly, versions of GROUP DECISION AID include an array of decision models used by Decisions and Designs, and marketing plans call for greater emphasis on group processes in addition to the hardware and software of GROUP DECISION AID. And the University of Minnesota's CAM software and the University of Arizona's PLEXYS software are moving toward integrated systems to support both group decision making and research on such group activity [Dennis et al. 1988; DeSanctis et al. 1987; Vogel and Nunamaker 1988; Vogel et al. 1988].

Third, GDSSs can take a variety of forms. Generally, the more sophisticated the GDSS technology, the more dramatic the intervention into the group's work processes. DeSanctis and Gallupe [1987] have identified three levels of GDSSs, based on the nature of the intervention into the group's work processes, that fit nicely with our foregoing classification of GDSS.

We adopt those levels here but sharpen their distinctions somewhat.

At the simplest level, GDSSs provide features aimed at removing common barriers to group work and communication, such as unequal consideration of ideas, dominance by individuals, peer pressure, and loss of autonomy. These features include anonymous input of ideas and preferences, large screens for instantaneous display of ideas, and secret voting and compilation. The level is illustrated by the electronic boardroom or computer-supported conference room.

At another level, GDSSs provide specific group techniques aimed at structuring the group's work and decision processes. These techniques might include planning tools such as brainstorming, stakeholder identification and analysis, or organization analysis; modeling tools that support qualitative and quantitative decision analysis such as decision trees, risk analysis, social judgment analysis, or multiattribute utility analysis; and group process tools from the organization development field such as process observation, team building, and reality testing. Group members aided by a facilitator work together with these tools and simultaneously view both inputs and results, again using a large common screen. This level is illustrated by the decision conference above.

At a third level, GDSSs structure group communication patterns and select and arrange the rules to be applied during a meeting. There are no existing systems of this type, but teleconferencing and computer conferencing exhibit some features of such a system.

### 2.4 Current Status of GDSS Development

The clearest summary statement that can be made about the current status of GDSSs is that they are growing in use but at a rate far below what could be expected given their need and promise.

An assessment of the field conducted by Kraemer and King in 1983, for example, initially identified eight organizations said to be developing or employing GDSSs.[5] Subsequent investigations revealed that only two of eight organizations studied (Perceptronics and Decisions and Designs) had operational systems that were in use and available for purchase and that most of the systems had never come to fruition; that some systems were being considered for development (e.g., EXECUCOM's), and that one relatively new GDSS used by state government agencies had been developed and was in active use (that at the Institute of Government and Policy Studies at SUNY, Albany). Among the three operational systems, the hardware/software offered by Perceptronics and the software offered by Decisions and Designs were in the public domain and only marginally successful in that the companies were barely breaking even. Those developing the systems believed that GDSSs would do better in the following 5 years, but none could explain in detail why they felt that way. Five years later, the field has seen notable additions among university research organizations, particularly the systems at the University of Arizona [Applegate et al. 1986a, 1986b, 1986c; Nunamaker et al. 1987, 1988a; Vogel and Nunamaker 1988] and the University of Minnesota [DeSanctis and Dickson 1986; DeSanctis et al. 1987]. But growth has remained slow, and as yet no successful business ventures have evolved from the GDSS arena.

In short, outside of research environments, GDSSs currently remain more prospect, promise, and possibility rather than successful operations. Nevertheless, we believe that GDSSs, and particularly the hardware and software technologies that underlie them, will continue to receive public and private investments. They are a good idea. People who participate in the decision conferences are uniformly enthusiastic about the experience. The analytic tools are useful in structuring decision

[5] The organizations were CACI, Inc., Cleveland State University, Decisions and Designs, Inc., Execucom Systems Corp., Georgia Institute of Technology, K. R. Hammond Associates, Perceptive Decisions (Perceptronics), and Southern Methodist University.

problems, although sometimes overly complex for many participants. And the hardware both performs useful functions in support of the participants and adds futuristic imagery that participants enjoy.

## 3. EVALUATION OF EXPERIENCE WITH GDSS SYSTEMS

Despite enthusiasm for the concept of GDSSs, there is a shortfall in the actual deployment and use of such systems at this time. In this section we briefly trace the evolution of GDSS efforts, evaluate the benefits and problems with GDSSs to date, and assess the barriers to successful GDSS implementation as attempted thus far.

### 3.1 Evolution of GDSS Efforts

We identify two major streams of evolution in GDSS efforts. One is the study of decision making itself, both at the individual and group levels [cf. DeSanctis and Gallupe 1987]. This stream has had a research component that has concentrated on discovering the psychological or cognitive processes of individuals and groups involved in reaching conclusions and on the sociology of small-group interactions. It has also had a development component concentrating on finding ways of facilitating group interaction toward reaching decisions more quickly and with greater consensus and conviviality, mainly from the organization development perspective. Neither of these components of the decision research field has been particularly concerned with technology per se. Rather, the focus has been on how the people involved in the decision-making processes think and behave.

The other major stream has been the development of technologically supported means of collecting, managing, and displaying information that might be useful in decision situations [Sprague 1980; Steeb and Johnston 1981; Stodolsky 1981; Turoff and Hiltz 1982; Vogel and Nunamaker 1988]. This field has been dominated by an engineering perspective. The goal has been to make new discoveries in decision methods or decision technology and apply them in the creation of tools that people in decision-making situations might find helpful. The major areas of this work have been in decision analysis and other forms of decision modeling and human information processing through interactive use of digital computers, electronic storage media, electronic communications, and electronic information display.

The electronic boardroom and the teleconferencing facility have primarily developed from the technology perspective. These embody technologies that facilitate rapid collection and tallying of votes by participants, information sharing through video displays of computer-based information, and communication over distances among decision meeting participants in various locations. Organizationware for these technologies has generally been limited to protocols for using them for their specific purposes.

The information center and the group network have also been developed primarily from an engineering point of view but with the goal of making "friendly" technologies that users find genuinely helpful. They embody refined interfaces and nonprocedural languages to provide users with a means of easily conveying requests to the information system. These systems act as interpreters of the user requests, and build the appropriate system-level commands required for the information system to execute the requests. Organizationware for such systems includes information bases used in the analyses requested by users and protocols for using the system.

The decision conference and collaboration laboratory are the results of an attempted union of the psychosocial and technology perspectives. The technologies developed for other GDSS applications are brought together to facilitate information acquisition and sharing. Knowledge of group decision processes is applied to shaping technologies into systems that facilitate these processes. Decision analysis and modeling systems provide the means of utilizing available data and participants' input to deal with "what if" questions. These are the most ambitious of the GDSS efforts because they attempt to merge two perspectives that have been previously segregated. Organizationware for these applications embodies the values and ideologies inherent in the designers' views of what group decision making is (or should be) like. To date, efforts to create decision conference and collaboration laboratory facilities continue to be heavily influenced by the technology perspective, mainly because there is still uncertainty about the nature of decision-making processes. Although they embrace a broad view of psychosocial theory about group decision processes, they remain more influenced by the rational model of decision making than by the "political," "garbage can," or "program" models.

The strong influence of the technology perspective on the evolution of GDSSs has had two important consequences. First, most of the efforts to apply these technologies have affected decision processes either too much or too little to provide a good assessment of their effects. Electronic boardroom and teleconference facility technologies affect decision meetings only by speeding up certain common tasks (e.g., voting) or adding flexibility to meeting opportunities (e.g., teleconferencing that permits meetings without travel). Neither claims to improve the quality of decision making appreciably. Use of information centers and group networks might improve the quality of decisions, but they are typically used outside the actual decision meeting context to prepare for meetings. The decision conference and collaborative laboratory approaches attempt to improve the actual process and consequence of decision meetings, but they nevertheless impose the designers' views of the decision process on the participants. Despite recent empirical research [e.g., Applegate et al. 1986a, 1986b; Dennis et al. 1988; DeSanctis and Dickson 1986; Gallupe 1985; Gallupe et al. 1986; Nunamaker et al. 1987; Vogel and Nunamaker 1988; Vogel et al. 1988; Watson 1987; Zigurs 1987], the question of the qualitative impact of advanced GDSSs on decision meetings remains unsettled.

Second, the bias toward technological development makes GDSS efforts very "supply push" in their orientation. The designers of GDSSs usually develop technological aids that they presume will be needed by decision makers. This is in contrast to the "demand-pull" forces of innovation, in which demand lures developers into creating a supply that meets that demand. The question of whether supply or demand comes first is hard to answer, but it is easier to build technical aids to decision making than it is to paint a clear picture of what decision making *is*, so the technical orientation often takes precedence. Sometimes these new technologies are widely adopted and used, but it still is not always clear whether they really improve the condition of those who use them.

### 3.2 Perceived Benefits from GDSS Use

We identify three classes of benefits that appear to accrue from the use of GDSS.

#### *3.2.1 Affective Benefits*

GDSSs appear to bring "affective" benefits in the sense that they enliven meetings and in some cases help encourage a sense of group cohesion. Computer-supported systems for graphics, voting, communications, data analysis, and modeling appear to increase some participants' interest in the group activity. Some of these technologies are interesting and exciting to watch in action; for example, computer-generated color graphics can be fascinating. Similarly, hands-on data input systems, such as voting systems, seem to elicit group interest because they get users directly involved with the technology. Use of the system requires participants to go through a shared learning experience to use the technology correctly, and this alone can facilitate cooperation in a manner that affects the substance of the subsequent discussions. The transference of some of the protocol of decision making onto technological devices appears to reduce the amount of intragroup tension in difficult decision situations. The technology is perceived, correctly or incorrectly, as "neutral" in respect to the issues being discussed.

Whether these affective benefits of GDSS technology truly contribute to the quality of resulting decisions is as yet unclear. On the one hand, it can be argued that improvement of the general atmosphere for decision making (e.g., making the process more structured or more "professional") results in improvements in individuals' contributions to the process. Under this assumption, the technology constitutes an effective "intervention" in the process of group decision making, with the intent of getting the decision makers to cooperate and arrive more quickly at decisions. The goal is not to provide more information, or even better information, but to use information technology to secure cooperation among participants by getting them to focus more quickly on the issues.

On the other hand, decisions that are reached more quickly or with greater group consensus are not necessarily better than decisions arrived at through less expeditious and enjoyable means. As we shall discuss below, the current research in GDSSs appears to ignore important prior research on the basic nature of group behavior in circumstances in which judgment and decision are required. But apart from that basic concern, research in the GDSS field itself suggests that techniques for facilitating group cooperation often result in poorer judgments than the "best" decision maker in the group would arrive at on his or her own [Rohrbaugh 1979, 1981; Rohrbaugh and Wehr 1978]. Although the improved speed and increased solidarity with which group decisions are made save time and make group participants feel better about the decision process, the larger goal of improving the quality of decisions has not been demonstrated. At the least, there should be additional care taken in defining the practical objectives of GDSS application to distinguish improvement of optimal performance as opposed to average performance.

#### 3.2.2 Facilitation of Protocols

GDSS technologies appear to facilitate execution of the protocols of group decision making. Group decision making typically rests on protocols for focusing decision attention on the key issues, iteratively eliciting the views of the issues from the participants, and attempting to reach some threshold of agreement among participants about what action to take. GDSS technologies seem to focus participants' attention more quickly and precisely on the major issues embodied in the decision problem. This happens through several means. In the simplest systems, such as computer-supported graphic display, it occurs through the replacement of text and tables with charts and graphs. For many people, text and tables are difficult to read for "significant differences" among the data elements, whereas charts and graphs quickly display the highlights of the data elements and the differences between them. The particular advantages of computer-generated graphics are that summary tabular data can be immediately translated into graphic displays, which saves time and allows more flexibility in choosing what to display and when, and that computer-generated graphics can be manipulated to highlight specific features of the data that might be of interest (e.g., changing the $x$- and $y$-axis scales).

Voting systems have similar but more pronounced effects. They allow for rapid identification of variance in participant attitudes on given issues. Anonymous voting helps reduce bias of dominant individuals in the group, and results are rapidly tabulated and displayed to a common screen in a summary format. Agreement and disagreement on issues is readily apparent. When confidence measurement is introduced to weight votes of individuals, greater interpretive information is available for assessing the meaning of the votes. Voting-based decision protocols are predicated on the assumption that pluralities (or, better, majorities) signify substantial collective confidence in a given choice. Sometimes voting constitutes the end of the decision process (one side wins; the other loses), but in most decision situations votes serve the intermediate role of helping to identify where consensus is lacking. Electronic voting systems are designed to facilitate the use of voting by identifying presence or lack of consensus, allowing issues to be discussed and debated again, and bringing new information to bear on the discussion.

Information retrieval and modeling/simulation systems facilitate identification of key issues by providing a means of probing the assumptions and facts underlying a particular problem. Information retrieval systems allow new data to be brought into the discussion. These data can be used to clarify the factual bases of the discussion and to reveal where participants' beliefs about the facts are in error. Models make it possible to relax or tighten constraints, change exogenous variable values, and bring in or throw out variables from consideration. Simulations reveal whether outcomes of given changes in assumptions substantially affect the final outcome, allowing sensitivity testing.

These aspects of GDSS technology build on established protocols of group decision making. Research has not definitively shown whether these protocols are always effective at yielding good decisions, but collective experience, as well as research, indicates that there is some wisdom in them. Yet, it is not clear that established protocols, or at least those identified in requirements analysis for GDSSs to date, have been sufficiently comprehensive. Most protocols for small group decision making rest on the assumption of rationality [Huber 1982b]. They do not deliberately facilitate alternative models of group interaction. Close adherence to the rational model automatically limits assessment of improvements in decision-making protocols through GDSS technologies by precluding the possibility that other protocols—for example, those that would stimulate conflict and confrontation—might yield important benefits for the decision process.

#### *3.2.3 Quality of Information Available for Decisions*

In some cases, GDSSs appear to improve the quality of information available to the decision maker. This is achieved in two ways: use of online databases to provide information from sources not otherwise accessible to participants in their decision-making meetings and the provision of modeling and simulation capability for reducing, assessing, and integrating information into the decision process.

The use of online databases in decision conferences is not very widespread at present. The most advanced systems do allow searches of large corporate or other databases for relevant information, but owing to the complexities of accessing, reducing, and displaying such information in a real-time manner, such systems are rare. More often, the information to be used in a decision conference will be brought into the meeting after being compiled in advance by staff support personnel. Computer-based systems provide important assistance, but such uses of information systems do not constitute the real-time use of databases envisioned in the more elaborate characterizations of GDSSs.

The most common uses of GDSSs to improve the quality of information are found in settings that use modeling and decision analysis capabilities to filter out and analyze data prepared in advance and brought into the meetings. Typically, decisions rest in part on factual data that need not be current to the minute (e.g., the costs of various proposals or financial data on the previous month's performance) and in part on perceptions of group participants about the feasibility and efficacy of various options for action. The systems seldom provide any new factual information but rather a means of using factual information to explore the sensibility of different assumptions. They also provide an opportunity to segregate factual information from biases and assumptions and systematically test the ways in which the facts coupled with various assumptions influence some objective function agreed on by the group. The objective function might be a "final" goal, or it might be an intermediate step toward a goal. In either case, GDSSs can contribute to the precision and care used to deal with the facts and assumptions participants bring to meetings.

Whether these capabilities improve the quality of decisions depends on the ability of the individual participants to filter through available information and make sense out of it given the challenge of the decision problem. It is widely acknowledged that improving decisions by simply providing more information is not possible. Too much information quickly results in overload of the participants' abilities to deal with the issues and in some cases can be disruptive to the decision process by providing a confusing array of details for participants to disagree over. The common observation in the literature is that the "right" information must be provided; but the question of what is the "right" information remains. As existing research on the use of models in complex decision processes suggests, providing more precise data on the ramifications of decisions can disrupt the process of decision making by sharpening participants' views of who might gain and who might lose from various options [King and Kraemer 1983]. Simply connecting the group decision meeting to online databases is not likely to improve the process or quality of the decision-making process dramatically. Nevertheless, there is a real possibility that the benefits of GDSSs for testing the assumptions of participants given available data will prove to be among the most important provided by this technology.

#### *3.2.4 The Benefits in Perspective*

Two observations about benefits must be made. First, it is not clear whether all of the benefits accrue through the use of GDSSs or under what conditions they do accrue. Obviously, some of the benefits depend on the presence of GDSS technologies that make them possible (e.g., voting systems are needed to facilitate voting protocols). But assuming that the systems are in place, we do not know what other variables are important to achieve the desired benefits. The fact that many of the commercial systems have been abandoned suggests that something was missing. At best, we are presently limited in our assessment of the benefits of these systems to claims of the developers and participants and our observations about which systems survive and which are abandoned. Our overall judgment is that there is promise in these systems, even though the specific claims of their promoters are often not realized as extensively or quickly as hoped for.

Second, it is not clear what effect these systems have on the quality of the decisions resulting from their use. Studies of teleconferencing and structured group decision processes suggest that these systems can expedite decision processes and increase participants' feelings of solidarity about group decisions and satisfaction with the process. But the linkage between these perceptions and the net consequences of decisions for the welfare of the group, organization, or society has not been established.

## 4. BARRIERS TO SUCCESSFUL USE OF GDSSs

We identify a number of barriers to successful use of GDSSs. For ease of presentation, we divide these into three categories: technical problems, problems with the GDSS "package," and incomplete understanding of the decision-making process.

### 4.1 Technical Problems

GDSSs depend on one or more of a number of technologies: computer processing and storage, graphics displays, database management systems, statistical processors, decision analysis and modeling programs, communications, and distributed input devices. At the current stage of technical development, there are several shortcomings in these technologies that affect GDSS use; we summarize them here.

*Accessibility and flexibility in using computing resources.* In a few cases it is possible to include all the computing resources necessary for a full-scale GDSS in the conference room. Many of the newer systems use microcomputers, which can be accommodated in the decision room, but these systems do not stand alone. Access to major processing power or online databases cannot easily be accomplished using PCs, so it becomes necessary to link the input/output technology (e.g., terminals, video displays, printers) in the conference room with the computing resources located elsewhere. This is technically feasible, but there are problems of cost, speed, and reliability of data communications for this purpose. Increased use of GDSSs and/or decreased costs for data communication are necessary to overcome this problem.

*Display technology.* Despite continuing performance and price improvements in computer and video technology, some lingering problems remain. One is the fact that most video projection equipment is not designed to operate for computer display, especially if high-resolution graphics are to be used. The good quality computer video display systems, although less costly than their predecessors, are still quite expensive. A good quality color projector system that can display a medium-resolution color image large enough for use by a group of 20 people costs a minimum of $10,000, while high-resolution projectors and those for large audiences cost much more; the use of such systems must be frequent enough or important enough to warrant this investment. This barrier will not be overcome until either the market for such displays increases to the point at which scale economies reduce costs or the production technology of such displays improves sufficiently to reduce production costs.

*Graphics capability.* A key component of many GDSSs is the ability to display the results of analyses quickly and effectively. There have been many major advancements in graphics in the past few years, but problems remain. A particularly pressing problem is the difficulty of rapidly, preferably automatically, turning computer-generated output data into good quality graphic displays. Another problem arises from the limitations of the display technology to present more than a portion of the relevant data at one time. The working matrix information relevant to a given decision can dramatically exceed the amount of data that can be displayed on the screen or the video projector, so the operator of the system must constantly move different parts of the display into the "window" provided by the screen. Even with a fast operator this can be disconcerting to the participants. This problem might be overcome through use of very-high-resolution display technologies that allow for compressing the full display onto a single screen. If the screen were large enough, all participants could see the entire display at once. We are not aware of systems that do this as yet.

*Modeling and analysis software.* Decision conference and collaboration systems depend on modeling and analysis software to permit the structuring of decision problems and modeling of various decision outcomes given agreed-on input data. Rapid strides have been made in recent years in the creation of systems such as spreadsheets, but more elaborate modeling capabilities for doing simulations and econometrics are required. These require more powerful computer support, and as noted above, this means linking the conference room to a remote computer facility. It also usually means that a highly skilled modeler who is familiar with the system must be present to run the analyses. There probably will be continued improvements in modeling and analysis software, and these are likely to prove useful to GDSSs. But when the needed improvements will appear is not clear.

*Integrated database/modeling capability.* Most decision conference and collaboration systems depend mainly on the data supplied by participants in the conference or in a previous conference for modeling. To achieve the kinds of integrated database/modeling uses of computing envisioned by Huber [1982b], it will be necessary to link together modeling capabilities with database management systems that can access large databases. As yet this has not been accomplished in the GDSSs.

### 4.2 Problems with the GDSS "Package"

As we noted in Section 2, it is useful to characterize the combination of GDSS technics, organizationware, and people as a "package." Successful application and routinization of GDSSs is impossible if the components of the package are missing. Without the enabling technologies provided by hardware and software, GDSSs are little more than dreams. Moreover, the pieces of the package must be integrated in a manner that is technically proficient, organizationally stable, financially sound, and demonstrably productive for its clients and customers. In this sense, GDSSs fit within the larger class of computing-based artifacts that must be understood within a context of production and application and not merely as tools for accomplishing a discrete task [Kling and Scacchi 1982].

Here we must step back for a moment to consider the evolution of GDSSs presented in earlier discussions. Much of the research on graphics display, decision modeling, and decision conferencing was, and in some cases still is, supported by the U.S. Department of Defense Advanced Research Projects Agency (DARPA). DARPA supports advanced research to discover whether emergent technologies have important military application. Over the past two decades DARPA has spent a great deal of money on research and development of computing and information technologies. Some of the developments that originated from such support have been classified; among those that have not, some have found commerical application and some have been tried in the marketplace and have failed. We place GDSSs in this latter category.

All of the DARPA-spawned systems have been developed with defense-related concepts of the decision-making processes in mind [cf. Buede 1979; CACI, Inc. 1978; Martin et al. 1981], and efforts were mainly aimed at creating the technical support for these processes. This concentration on technology has pushed the state of the art forward, but it has not built a base of institutional and market capability necessary for commercial success. Both the Decisions and Designs, Inc. (DDI) and Perceptronics systems were DARPA project spin-offs, and neither has been particularly successful in the marketplace. The SUNY Albany Decision Techtronics Group (DTG) was a spin-off of the DDI effort and presents a different but no more financially profitable case. DTG's institutional home, the Institute for Government and Policy Studies, is a public, nonprofit organization affiliated with a major university. Its state-funded budget helps defray costs, and its service mission ties it closely to New York state agencies that might use its services. DTG management would like to make the system "profitable" by running enough conferences to cover the operating costs of the enterprise and it is hoped, produce a surplus to support research. Perhaps it will be able to do so. The system at the University of Arizona has been used by outside agencies for decision meetings and is being transferred to both corporations and universities, but there has been no comprehensive assessment of the implications of such use for commercialization [Vogel and Nunamaker 1988]. The University of Minnesota system is basically a research system and is not intended for use by external clients. In general, the university-based GDSSs (which are about the only active research centers for GDSSs at this time) do not provide an adequate model for an efficient and competitive service enterprise such as Data Resources, Inc.'s economic data, modeling, and time-sharing service [King 1983].

### 4.3 Incomplete Understanding of the Decision-Making Process

The study of individual and group decision making is a relatively new field, replete with unanswered questions about decision behavior [Hammond et al. 1977; Kaplan and Schwartz 1977; Kunreuther and Shoemaker 1982; Quinn 1978; Ungson and Braunstein 1982]. This shortfall results in part from a general lack of understanding of cognitive processes and in part from the inherent ambiguities surrounding complex decision situations that make the study of decision making empirically difficult. This is the primary reason most efforts to develop supportive techniques and technologies for decision making have focused on the relatively narrow, rational view of the decision process. This view is comparatively simple and straightforward: Decision participants attempt to optimize their decision choices on the basis of careful specification of the facts and refinement of their understanding of the probable consequences of their available options. But as experience shows and the other models of decision behavior attempt to describe, this rational viewpoint is limited in its utility to "real-world" decision making because it specifically excludes the baffling nonrational or quasi-rational behaviors individuals often exhibit. The rational viewpoint has an important role to play and sometimes does describe the behavior of individuals in real decision processes. But in many cases it is an "ideal" description of behavior that bears little resemblance to reality.

The discrepancy between ideal and realistic accounts of decision behavior creates a peculiar paradox for the development and application of GDSS technologies. On one hand, creation of discrete decision tools requires a specific model of decision behavior, and the rational model of decision behavior is the best developed and most internally consistent model available. It provides a clear-cut specification around which the decision aids can be designed. Other models of decision behavior have the singular drawback of being "fuzzy" in their accounting of decision behavior. They leave room for inconsistency, ignorance, deliberate deviousness, and even irrationality on the part of individuals. They specifically incorporate the ambiguities that make system design difficult or even impossible. For this reason, most of the efforts to develop GDSS technology have avoided these other models.

On the other hand, the rational model is demonstrably weak as a descriptor of actual decision-making behavior. The very attributes of the decision process it excludes are often found in complex and important decision situations. To the extent that GDSSs are developed around the rational model, they seem doomed from the start to a limited set of decision situations. Yet, the ambiguities inherent in the other models of decision behavior work against the creation of tools that genuinely aid decision making. Huber [1982b] acknowledges that the rational model is useful owing to its simplicity but posits three other models of decision behavior taken from the literature on decision making as important alternatives and suggests how GDSS technology might be used for them.

One is the *political/competitive model*, in which organizational decisions are viewed as consequences of strategies and tactics of units and individuals trying to influence things in a manner beneficial to themselves. GDSSs could be used by the individuals or units in the competitive process to answer the following questions:

(1) Who are the other parties at interest in the decision?
(2) What influence do the other parties have?
(3) What alternatives favor or damage the other interests?
(4) How can other parties influence alternative selections?
(5) Which alternatives might other parties choose, and how likely is it that they will choose them?

GDSS technology might help answer these questions by listing the other parties involved in the decision, providing historical data on the positions taken by other parties in other decisions, providing data on the other parties' affiliations, and providing gaming capabilities such as coalition formation models.

Another model is the *garbage can model*, which holds that organizational decisions are consequences of intersections of problems looking for solutions, solutions looking for problems, and decision makers looking for opportunities to make decisions [Cohen et al. 1972]. This model highlights the role of chance and timing in decision situations. GDSS technology might help with the garbage can model of decision making by providing the following kinds of information:

(1) What problems and opportunities might be forthcoming, how likely is it that they will appear, and when will they appear if they do?
(2) What potential solutions might be forthcoming, how likely is it that they will appear, and when might they appear?
(3) What potential opportunities for decision making might be forthcoming, how likely is it that they will appear, and when might they appear?

GDSS technology might help by providing the opportunity for "environment scanning" to build decision makers' understanding of the larger context of the decision situation. Keyword searches of relevant data sources, names and addresses of relevant experts, data on stock market changes or other "news" (e.g., events, patents granted), and decision models would facilitate decision makers' environment scanning.

The final model is the *program model*, which holds that organizational decisions are consequences of programs and the programming of units involved in the decision situation. Programs are standards, group norms, budget limits, and so forth. Programming is the prior professional training, biases, reinforcements, and other cognitive backgrounds of the individuals involved. GDSS technology might aid in the program model of decision making by providing the following:

(1) data on past behavior of units and subunits in dealing with particular kinds of decisions,
(2) accuracy assessments of the behavior information provided to assess the kinds of biases units and subunits incorporate in their decisions and actions,
(3) data on the time and costs that units and subunits spend to implement decisions.

Capabilities such as CPM, Gantt charts, and PERT can facilitate such analyses.

Under these alternatives, GDSS technology could be put to work to identify problems and opportunities, refine understanding of the consequences of options, and clarify the role of the decision makers in the process of dealing with the issues. Within the political/competitive model, GDSS at the level of each competitive group might aid in identification of the competing parties and assessment of their strengths and weaknesses. In the garbage can model, GDSSs might help identify solutions that have been available "on the shelf" to fit the problems that have arisen. And in the program model, GDSSs might be used to identify the relevant behaviors of various units and subunits in contributing to problems or their solutions. These kinds of GDSS aids to decision making could be built and tried, although to date we have seen no systems that are designed to do such things.

Curiously, existing decision support systems (not GDSSs) have been applied to such uses, and these provide a model of what could happen with GDSS technology under the right circumstances. Research on the use of computerized modeling systems in conflictual problem domains [Dutton and Kraemer 1986; King 1983, 1984; Kraemer et al. 1987] suggests that these systems are used in highly political ways by various political factions in the decision arena. The systems become, in essence, an integrated part of the political decision-making process. It is unclear whether use of such systems in political decision making actually improves the quality of resulting decisions, but most of the participants believe they have become essential to the process. Perhaps the widespread deployment of GDSS technology among competing interests in politically sensitive decision situations might have the same results.

The ambiguities surrounding the nature of decision making are also found in work that questions how and why organizations acquire and manipulate information in the first place. The conventional wisdom is that information is collected to serve some operational or decision-making purpose, and no doubt much information is collected for such purposes. But information is collected for other reasons as well, including signal and symbolic purposes [Feldman and March 1981]. The role of the analysis of information is similarly poorly understood. The logical assumption is that analyses of data for decision making have a material effect on subsequent decisions, but this is often not the case. In fact, much formal analytical work for decision making is done, apparently, because the managers and analysts involved believe that such analyses ought to be done even if no one uses them [Feldman 1988]. This raises the fundamental question of whether GDSS technology will provide a major improvement in the actual making of decisions as opposed to simply improving the appearance of thoroughness, carefulness, and rationality in the decision-making process.

The GDSS vision is useful, but to date it has been too circumscribed. Perhaps the most intriguing manifestation of this narrowness is the apparent lack of awareness among GDSS researchers of the controversies over the basic qualities of group processes. As noted earlier, group activity has come to be seen as necessary, efficient, and reinforcing of democratic values. Yet, the substantial body of research done over the past 30 years suggests that the picture is not so clear as originally thought. For example, group performance on intellective tasks has been shown to be far below the expected baseline of optimal or correct performance [Crisswell et al. 1962; Lorge and Solomon 1955]. Groups also exhibit significant inefficiencies, including tendencies to develop egalitarian social interaction structures that inhibit the production of optimal solutions, and losses from group processes that have the same effect [Davis and Restle 1963; Steiner 1972]. Groups demonstrate more extreme behavior than individuals in decision making, and critical debate over differing points of view has been found to be of little effect in damping the use of biased heuristics, contrary to common belief [Stasson et al. 1988]. Groups often are overconfident of their judgments, as well. It is worth considering whether the real effect of the GDSS as commonly articulated might be to help groups do more expeditiously those things they do worst or, at least, reinforce the lowest common denominator of quality.

Continued research into the nature of decision processes is an essential requirement for the development of more effective GDSSs, especially in decision settings that do not closely conform to the rational model of decision behavior. Interestingly, however, this does not mean that research on decision processes must precede new GDSS development. On the contrary, we believe that the development and application of GDSS tools is an important component of doing research on decision processes. In the proper settings, and under the right controls, these tools can be powerful instruments for experimental study of decision processes. Recent conferences of scholars to discuss these issues show promise that such studies will become more common [Galegher et al. 1988].

### 4.4 Summary

The comparatively simple GDSSs of electronic boardroom and teleconferencing are established in use, although the full extent of such use is difficult to ascertain. The technologies are practical, and improvements are constantly being made. The price/performance ratios of the underlying technologies are falling. In most cases these GDSS tools are not specifically designed to facilitate group decision processes in the large sense. Rather, they facilitate discrete aspects of decision processes, such as display of data, recording and display of votes, and communications among members of the decision group.

The information center is growing in use and will probably see continued growth in the future. The technology is being developed by major computer hardware manufacturers who have a clear objective in supporting this technology—the expanded use of computer systems that require computer equipment. Again, however, these systems are not dependent on a detailed understanding of the processes of group decision making. Often, they are single-user systems applied to noncontroversial problems such as finding a way to generate a report the user wants. To the extent that information centers become more focused on functional areas such as marketing or organizations, they might come to play an important role in the real-time decision meeting by facilitating access to specialized information systems and computer capabilities tailored for the specific users that make up the decision meeting.

Group networks are springing up as networking technologies become more widespread and accessible. Like teleconferencing centers, network technologies are merely enabling features that could eventually be the backbone of major group work projects. But they also serve more routine purposes, such as the simple exchange of administrative information. This basic role for such systems is actually an asset to their chances for survival and eventual contribution to group decision processes, since these systems do not have to justify their existence on the basis of facilitating group decision making.

The decision conference and the collaboration laboratory are simultaneously the most problematic and promising application domains of GDSSs. The technical systems necessary to create effective GDSS tools for real-time decision making are difficult to build, and the potential uses of such systems are not well specified. The most coherent specifications of the decision process are built on the rational model of decision making, which at best accounts for only a part of true decision behavior that takes place in group decision making. Development of technical support for other models of decision behavior is a harder problem to tackle. Nevertheless, the development and use of the decision conference and collaboration laboratory types of GDSSs in controlled experimental settings could facilitate research into the nature of decision making where such understanding could be gained.

## 5. LIKELY NEAR-TERM FUTURE OF GDSSs

As noted above, it is difficult to tell for certain where GDSS development is headed. We can, however, make some observations that might be of use in determining the promise of GDSSs, both as an area of research and development and as a technological development useful for decision makers.

### 5.1 Likely Growth Rates in GDSSs

For the next few years, we believe there will be relatively little growth in GDSS application at the "high" end of decision conferences and collaboration laboratories. The user base of these systems is still small, and the genuine utility of the systems is still insufficiently proved to provide evidence that the systems will be widely adopted in the short run. Still, there appears to be evidence of continued interest in the form of governmental and corporate funding, so development will probably continue. If reductions are made in the cost of the systems and improvements are made in both the technology and other components of the GDSS package, there might be a significant acceleration in the growth rate within three to five years. We would characterize this area as experimental, but with potential to become commercially viable. Those who enter this field will be taking on the risks normally associated with experimental systems and uncertain markets.

### 5.2 The Technology

There is little doubt that many of the problems now found with GDSS technology will be declining in the next few years. We anticipate that there will be continued improvements in the price/performance ratios of computer processor technology, which will put the technology more within reach of many organizations. Display technology is likely to improve in performance as well as price. Software that facilitates data access, data analysis, decision analysis, and modeling will continue to be developed. These software improvements will probably be spurred in part by the extensive development efforts now underway to capitalize on the growing microcomputer market. More user-friendly interfaces will be built to facilitate end-user access to and use of databases. The one area of technology in which we are uncertain of the future is in the creation and maintenance of the necessary databases to support advanced GDSS uses, especially those requiring data that cut across organizational lines. For example, we are doubtful that rapid progress will be made in the area of assembling for online use extensive corporate databases, let alone those dealing with the kinds of political information Huber [1982b] suggests would be necessary to support decision making under the political model.

### 5.3 Knowledge of Decision Processes

There is likely to be less spectacular progress in efforts to improve understanding of decision processes. Progress in this area depends on progress in other fields such as cognitive science and management science. There could be important breakthroughs in this area, but rapid progress cannot be counted on. Rather, we see a slightly accelerating but still slow growth in knowledge of decision processes. We believe experimental use of GDSSs might help provide new knowledge about decision-making processes, in much the same way that artificial intelligence technologies are being used to help with research on the functioning of human cognition. This will require the establishment of ongoing research effort, however, and it is not likely to result simply by the deployment and use of GDSSs in organizations.

## 6. CONCLUSIONS

The field of GDSSs is as yet not well developed, even as a concept. There are divergent and conflicting definitions of what the term means; as we have shown, it can refer to simple systems for voting and display of data or to highly integrated systems that incorporate voting, modeling, data analysis, decision analysis, and data display. Moreover, even the simple technologies of GDSSs have had only limited adoption and use in organizations. Most organizations' conference rooms look like they did 15 years ago—no computer terminals, no video displays, no modeling systems. The technology has been adopted by some organizations only to be subsequently abandoned. In such cases we can only conclude that the technology was ineffective and/or uneconomical to use.

Still, there is considerable promise in the field. The benefits from GDSS use described in Section 3 suggest that further development and experimentation is warranted.

We believe that nonprofit institutions would be promising research environments for GDSS development at this time. In particular, universities and nonprofit research laboratories are likely to be the hosts of productive efforts that move these systems forward; this is because the systems are still sufficiently experimental in nature to warrant investment as research endeavors. Although some for-profit companies have built GDSSs, they are not yet making much money. Perhaps the technology is still underdeveloped, and once it is more fully developed the markets will respond. On the other hand, experience to date suggests that we still do not know whether there is anything inherent in the GDSS concept to make the markets respond, even after technological improvements.

We suggest three lines of further research into GDSSs that would be fruitful. First, we believe that a more rigorous and detailed examination of the experiences with existing GDSSs would produce valuable information about the promises, problems, and challenges involved in this technology. It would be worthwhile to examine carefully a number of significant successes in use of GDSSs, as well as some notable failures. Some of these successes have available extensive data on the experiences with the systems that could be studied. In any case, such a study would make it possible to assess the factors affecting GDSS use much more fully than has been possible in this review.

Second, we suggest that more detailed experimental use of GDSS technologies be undertaken to investigate their effects on decision processes. A useful means of conducting such research would be to assemble operating examples of all the major available systems and scientifically test them in laboratory situations using controlled groups of participants and structured decision problems. Universities would be likely sites for such research, since similar psychological studies are often done at universities using students as subjects. Beyond this assessment of GDSSs as "black boxes," there should be careful evaluation of the effects of the component parts of GDSS packages on group decision making.

Third, there is a need for in vivo studies of group decision making, with and without the benefit of GDSS technology, in routine organizational settings. The in vitro experiments common in the research to date are valuable and, as we note, should be continued and elaborated. But current knowledge is biased in the direction of ad hoc rather than continuing users. Moreover, it is unlikely that experiments can provide a comprehensive picture of the dynamics of decision making in the context of real organizational opportunities and constraints. True experimental research in living organizations is extremely difficult to organize and carry out, but quasi-experimental research methods, which have not as yet been applied to the study of group decision making or GDSS use, offer considerable promise.

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