EFFECTS OF TECHNOLOGICAL SUPPORT ON DECISION MAKING PERFORMANCE OF DISTRIBUTED GROUPS

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Effects of Technological Support on Decision Making Performance of Distributed Groups

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Abstract

This research was concerned with the collection of empirical data necessary to estimate the effects of decision support tools on the performance of distributed groups. Data was collected in a controlled experimental environment that simulated a geographically-dispersed meeting through the use of videoconferencing and group communication support (GCSS) technology. Results of the use of a Group Decision Support System (GDSS) on group process and outcome variables were mixed. As predicted by the literature the use of a GDSS by distributed groups improved overall group consensus, decision accuracy, and decision effectiveness. The use of a GDSS also increased perceived process structure. Contrary to previous studies, the use of a GDSS increased decision time, and decreased overall satisfaction with the group process. No significant effects were found for perceived consensus, cooperation, amount of information exchange, or confidence in the decision.

A strong correlation was found between decision quality and decision time. An even stronger correlation was found between perceived structure of the process and satisfaction with the process. The lack of feedback about the process and its outcomes could explain the lack of a GDSS effect on perceptions of consensus, cooperation, and confidence in the decision. Perception of subjective measures of the process may depend on the presence of the appropriate types of feedback. The results suggest that an increase in structure without a perceived improvement in decision quality (confidence in the decision) tends to reduce group satisfaction.

A richer taxonomy for Computer Supported Cooperative Work (CSCW) systems is proposed whereby three orthogonal dimensions of group support are defined. These three dimensions of group support are: Communication support, decision support, and presence support. This new taxonomy suggests a number of research directions aimed at the empirical identification of contextual and design factors relevant to distributed group performance and decision making performance in general.

Dedication

To Mom and Dad

Acknowledgments

I wish to thank my family for all their trust and support. I also wish to thank my advisor Dr. Brian M. Kleiner, and the rest of committee, Dr. Woodrow Barfield and Dr. Robert C. Williges, for all their help in the execution of this study. Many thanks to the Industrial and Systems Engineering Department and the Computer Science Department at Virginia Tech for the use of facilities, equipment, and other resources without which this study would have never been completed. Last but not least, I want to thank all my friends in Blacksburg for their company and good times.

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Chapter 1. Introduction and Research Problem

Background

The current organizational environment

The external environment in which many organizations operate is characterized by being turbulent and of a highly dynamic causal nature. In these dynamic environments task requirements and organizational goals are constantly changing (Rouse, Cannon and Salas, 1992). Due mostly to these highly dynamic organizational environments, the economics of doing business are shifting.

The current business direction is towards a more customer-oriented framework. In this framework the traditional methods of mass production are being replaced. The new framework prescribes service-oriented products which emphasize market segmentation and a knowledge-based approach customized to each customer's requirements. Goldman, Nagel and Preiss (1995) have used the term *Agile Competition* to label this new type of economic framework. Among its many characteristics, agile competition involves the integration of information and communication technologies to coordinate geographically distributed resources regardless of location to achieve powerful competitive advantages. Agile competition has led to very broad product ranges, short product life cycles, arbitrary lot sizes, and highly individualized and customized products (Goldman et. al., 1995).

Organizational responses

There are two responses to these new competitive forces from an organizational design perspective that are relevant to this research. First, organizations are shifting away from traditional hierarchical models. Instead, current developments in organizational design and management emphasize a movement towards flatter types of organizational designs. These designs are moving in a direction where work is organized around autonomous teams and other forms of self-managing group processes (Hubber, 1984).

The second, more recent response to these environmental forces is a move towards what is known as the virtual organization. This type of organization takes advantage of current developments in information and communication technology to effectively coordinate resources regardless of -- and sometimes taking advantage of -- geographical location (Goldman, Nagel, and Preiss, 1995). Thus, a virtual organization can leverage great competitive advantage by tightly integrating all types of resources (e.g., information, expertise, production capacity, etc.) across great physical distances without sacrificing flexibility or responsiveness.

Implications

Appearance of distributed groups

The new virtual organizations will depend highly on a new form of organizational unit known as the distributed group. Distributed groups are defined as groups in which the members are not collocated. These groups combine the self-organizing and self-managing characteristics of traditional high-performance work groups with high levels of geographical dispersion. Due to their nature, distributed groups must rely on technological support to bridge the geographical gap between its members and effectively communicate and coordinate organizational activities. At the heart of this endeavor is the ability of the group members to effectively combine the available information and expertise into effective decision making, albeit the constraints imposed by their geographical separation.

Organizations lose valuable time arranging for and traveling to meetings. Managers spend between 25% and 80% of their time in meetings, with 50% of that time wasted as a result of information loss, information distortion, and sub-optimal decision making (Dufner, Roxanne and Turoff, 1994). Any technology which can reduce wasted time due to traveling or inefficient decision making could be valuable from an organizational design perspective. This is specially true in the case of distributed groups since their geographical separation increases the communication and decision-making barriers encountered by their members.

Need for technological support

Computer Supported Cooperative Work (CSCW) concentrates on applying communication and information technologies to the problem of supporting and enhancing group interaction and decision making activities (Baecker, 1993). Baecker (1993) first grouped all systems designed for this purpose under the general category of electronic meeting systems. Current trends in the field of CSCW are towards greater differentiation in objectives and design. Technology plays an important role in enhancing group performance by supporting the group member's interactions. It does this by helping overcome the constraints imposed by communication barriers and the limited human ability to process information (Saaty, 1990).

In the case of distributed groups, the technological support for group activities is absolutely essential. Since the members of a distributed group are not collocated, they need technological augmentation of the communication process to bridge the geographical distance that separates them. It is noteworthy that most studies on CSCW systems used groups without any kind of technological support as a control group (Kraemer and Pinsonneault, 1989). Since this situation is often not feasible in real-life distributed groups, the results of some of these research studies were difficult to generalize to distributed groups. Although there is a considerable amount of research in the area of electronic group support, a theory of distributed group performance that incorporates technological support has not emerged. Comparisons between studies showed discrepancies as to the effect of different contextual and group process factors of the CSCW system on the final outcomes of the group (Kraemer et. al., 1989).

For example, some researchers found the use of CSCW systems increased the degree of consensus of the participants (George et. al., 1988; Steep and Johnson, 1981; Vogel and Nunamaker, 1988) and decreased the time needed to arrive at a decision (Bui et. al., 1987; George et. al., 1988; Nunamaker, 1987). On the other hand, similar studies found the use of CSCW systems decreased group member cooperation (Gallupe et. al., 1988; Siegel et. al., 1986; Turoff and Hiltz, 1982; Hiltz et. al., 1986) and increased the time needed to reach a decision (Easton et. al., 1989; Gallupe et. al. , 1988; Siegel et. al., 1986; Turoff and Hiltz, 1982).

The discrepancies mentioned above are only a small sample of a number of discrepancies that Chapter 2 will discuss in more detail. They are used here to illustrate the need for a better understanding of CSCW design variables.

Different types of CSCW

A review of the CSCW literature by Kraemer and Pinsonneault (1989) found that part of the reason for the discrepancies mentioned above lies in a failure to differentiate between two fundamentally different types of technological support. Kraemer and Pinsonneault categorized Computer Supported Cooperative Work (CSCW) systems according to the different levels at which technology supports the group process. Using this criteria they define and differentiate between two types of CSCW systems: Group Communication Support Systems (GCSS), and Group Decision Support Systems (GDSS). Their review concluded most of the previous research becomes consistent -- or at least less inconsistent -- by grouping studies according to the type of support the technology provides for the group process.

Group Communication Support Systems (GCSS)

Group Communication Support Systems serve primarily as information aids. Pinsonneault and Kraemer (1990) identified the purpose of these systems as reducing communication barriers and supporting the communication process of the group. General examples of these systems are collaborative laboratories, electronic conference rooms, and electronic chalkboard systems (Zachary, 1986). These systems provide information exchange and control, and representational capabilities, as described by Zachary (1986) in his taxonomy of decision support techniques.

Group Decision Support Systems (GDSS)

Group Decision Support Systems perform the specific role of decision-making support. GDSS supports the decision making process by structuring it in some way. By doing this, GDSS reduces the effect of human's limited ability to process information (Saaty, 1990). Using a GDSS groups are capable of integrating the knowledge of all members into better decision making. Zachary (1986) describes some of the support techniques corresponding to GDSS. These techniques include choice models, analysis and reasoning methods, judgment refinement techniques, and process models.

Other taxonomies

Other researchers had also identified the importance of distinguishing between different levels of group support. An extensive review of the study of decision support systems by DeSanctis and Gallupe (1985) classified CSCW systems into three levels according to their support for the group process. Level 1 is aimed at the removal of communication barriers. Level 2 is aimed at reducing uncertainty or noise in decision making. Level 3 were defined as systems where technology would actually intervene in the way group members interact by what they called "machine-induced group communication patterns." Level 3 systems were hypothetical in nature at the time of their writing. To date little research exists in the area of level 3 systems. The three levels identified by DeSanctis and Gallupe are shown in Table 1.1.

Related to Kraemer and Pinsonneault, Level 1 systems are equivalent to GCSS, and Level 2 systems equivalent to GDSS. Although Pinsonneault and Kraemer (1990) combine Level 1 and Level 3 systems into the GCSS category, a more appropriate taxonomy could classify them separately, perhaps in a new category called Computer Mediated Communication Systems (CMCS) as suggested by Hiltz and Turoff (1985).

Table 1.1: Taxonomy of CSCW systems adapted from DeSanctis and Gallupe (1985).

Level	Objective
1	Removal of common communication barriers and facilitation of information exchange
2	Decision modeling and group decision techniques aimed at reducing uncertainty or 'noise'
3	Machine-induced group communication patterns and active filtration and structuring of information exchange

Research problem

The evidence mentioned above indicates that the type of technological support for the group process may have a significant effect on various group variables. In other words, GCSS and GDSS systems affect groups similarly in some ways, but fundamentally different in others. Unfortunately, most previous studies concentrate on only one particular type of system.

Although some inferences can be made about the differences between GCSS and GDSS from the existing literature, there is no way to fully understand their differences without some experimental research in a controlled environment. This is particularly important in the case of distributed groups since these groups will need at least some kind of technological support for the communication process.

Distributed groups will need at least the type of communication support provided by GCSS in order to bridge the geographical distance that by definition separates their members. Because of this, some of the findings for regular groups regarding GCSS and GDSS systems were difficult to interpret. The relevant question in the case of distributed group research relates to what can be gained -- or lost -- by augmenting group processes beyond the level of GCSS (Level 1 system) to a GDSS (Level 2 system).

Problem statement

This research focuses on the structural support and interfaces provided by technology for the decision making process, in particular for distributed groups. Below is the main research question of this study.

> *How do different levels of technological support for the decision making process affect the decision making effectiveness of nominal groups when they are constrained by geographical dispersion?*

Distributed groups in the field can be cross functional or self-managed, and their members often share a common history, goals, and objectives that are impossible to simulate in a laboratory experiment. Due to the constraints of experimental data collection this research simulated distributed groups by using ad-hoc nominal groups formed randomly with members that shared little or no previous experience. By performing a controlled experiment the researcher clarified how the level of support for the decision making process affected variables related to the group process, the task-related outcomes, and the group-related outcomes.

Subproblems

The main problem stated above can be subdivided as follows:

Subproblem 1

What is the effect of different levels of technological support for decision making on the internal group processes of distributed groups?

Subproblem 2

What is the effect of different levels of technological support for decision making on the task-related outcomes of distributed groups?

Subproblem 3

What is the effect of different levels of technological support for decision making on the group-related outcomes of distributed groups?

Purpose and objectives

The purpose of this research was to collect experimental evidence necessary to perform an empirical estimation of the statistical significance and relative size of the potential cause and effect relationships mentioned above.

This research focused on one particular independent variable: The level of technological support for the decision making process of the group. There were three main categories of dependent variables of interest in this research: Group process variables, task-related outcome variables, and group-related outcome variables.

The remainder of this chapter lists the individual dependent variables in each category mentioned above. It also states the individual research hypotheses corresponding to each dependent variable.

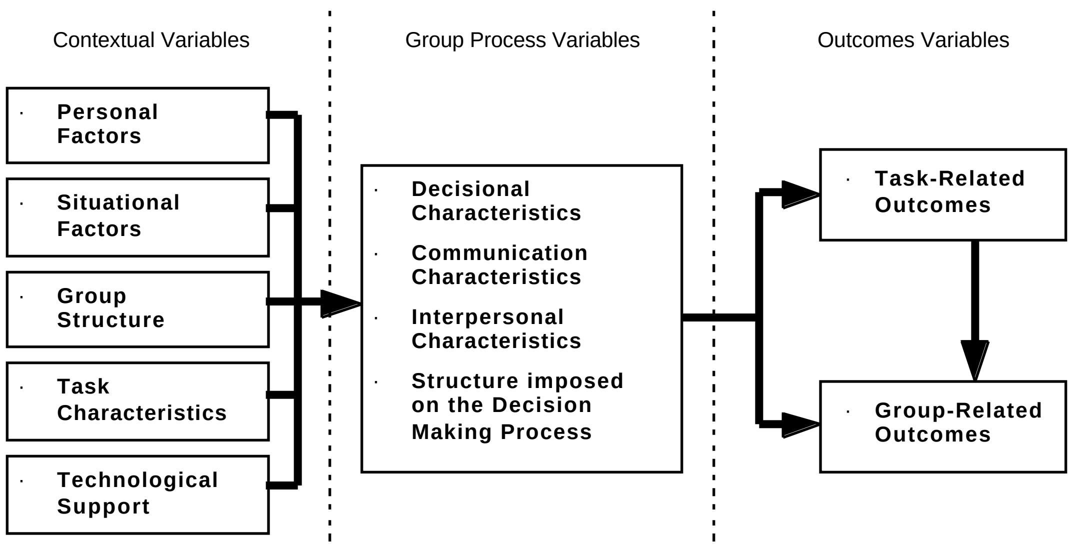


Figure 1.1: Conceptual model for the study of distributed groups (Adapted from Pinsonneault and Kraemer, 1990).

Chapter 2 provides a review of previous literature relevant to this research, and establishes the importance of the independent and dependent variables in the context of understanding distributed group performance. In that chapter a more detailed theoretical framework is developed for the study of distributed group performance.

Chapter 3 details the experimental design and procedures used to assure a controlled situation, eliminate undesired bias, and collect and analyze the data. It also describes in detail the facilities, equipment, and software used to collect the experimental data.

Conceptual model

A conceptual model for this research is shown in Figure 1.1. This model is an adaptation of the framework for analyzing GDSS and GCSS presented by Kraemer and Pinsonneault (1989). The model in Figure 1.1 only shows general categories of contextual variables, group process variables, and outcome variables. Figure 1.2 shows the same conceptual model, but this time listing the specific variables relevant to this research.

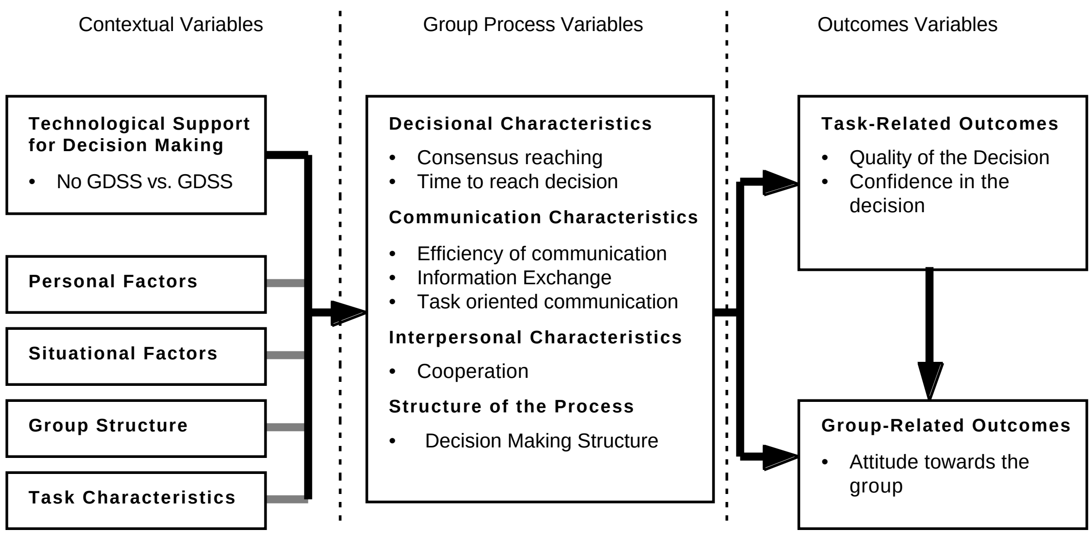


Figure 1.2: A more detailed research model showing variables of interest.

Research hypothesis

Previous literature on CSCW and distributed groups was inconclusive. However, certain predictions could be made regarding the effect that different levels of technological support for the decision making process (No GDSS vs. GDSS) will have on the different process and outcome variables of a distributed group during decision making. Following is a list of process, task, and group variables which are relevant to this research with their respective research hypothesis. Refer to Chapter 2 for a more in-depth explanation of how these hypotheses are justified by the existing literature.

Group process variables

The existing literature on CSCW indicated that different levels of technological support for decision making have an effect on group process variables. There were four main categories of group process variables: Decisional characteristics, communicational characteristics, interpersonal characteristics, and structural characteristics.

Decisional characteristics

There were four specific variables from the decisional characteristics category which were relevant to this research. These were: Depth of analysis, participation, degree of group consensus, and time to reach the decision. The existing literature only supported predictions regarding the last two: Degree of consensus and time to reach a decision. The first two research hypotheses were based on these two variables:

Consensus

Distributed groups with more technological support for decision making will exhibit a higher degree of consensus than distributed groups with lower technological support for decision making (George, Easton, Nunamaker, and Northcraft, 1988; Steeb and Johnson, 1981; Vogel and Nunamaker, 1988).

Decision making time

Distributed groups with more technological support for decision making will exhibit decreased time needed to reach a decision than distributed groups with lower technological support for decision making (Easton et. al., 1989; Gallupe et. al., 1988; Siegel et. al., 1986; Turoff and Hiltz, 1982; Bui et. al., 1988, George et. al., 1988; Nunamaker, 1987; Nunamaker et. al., 1988; Vogel and Nunamaker, 1988).

Communication characteristics

Previous studies suggested there could be differences in communication characteristics between distributed groups with different levels of technological support for the decision making process. The existing literature on CSCW identified five variables under the category of communicational characteristics. These variables were: clarification efforts, efficiency of communication, amount of information exchanged, amount of non-verbal information, and amount of task oriented communication. The existing literature supported predictions for two out of these five variables: Communication efficiency and amount of information exchange.

Communication efficiency

Although the only evidence for the effects of decision making support on group performance was related to co-located groups, these findings were generalized to distributed groups. Distributed groups with more technological support for decision making will exhibit more efficiency of communication than distributed groups with lower technological support for decision making (Hiltz et. al., 1986; Siegel et. al., 1986).

Information exchange

Distributed groups with more technological support for decision making will exhibit more information exchanged between its members than distributed groups with lower technological support for decision making (Jarvenpaa et. al., 1988; Siegel et. al., 1986; Smith and Vanecek, 1989; Turoff and Hiltz, 1982).

Interpersonal characteristics

The existing literature on CSCW identified two variables under the category of interpersonal characteristics. These variables were: Degree of cooperation, and degree of domination by a few members. Previous studies supported a prediction regarding the first variable: Degree of perceived cooperation.

Cooperation

Distributed groups with higher technological support for decision making will exhibit more cooperation between its members than distributed groups with lower technological support for decision making (Gallupe et. al., 1988; Siegel et. al., 1986; Turoff and Hiltz, 1982; Hiltz et. al., 1986).

Structure of the process

The last category of group process variables only had one relevant dependent variable identified by the existing literature. This variable was the perceived structure of the group process. The existing literature supported a clear prediction regarding this variable.

Perceived structure of the process

Distributed groups with higher technological support for decision making will exhibit more perceived process structure than distributed groups with lower technological support for decision making.

The use of decision support technology should result in an increase in the perceived structure of the decision making process. This hypothesis is important in confirming that the manipulation of the CSCW system is successful at increasing the perceived level of support (Pinsonneault and Kraemer, 1990).

Task related outcomes

There were a number of outcome variables related to the task being performed by the group which were relevant to this research. Variables in this category included quality of the decision, variability of the quality over time, breadth of the decision, and commitment of the group members to the decision.

There was no clear indication from previous literature as to the effect of technological support for decision making on some of these variables. The problem lied once again in the fact that most existing studies used one of the two types of CSCW systems – GCSS or GDSS. Previous studies found that groups supported by either type of system outperformed unsupported groups, but there was no indication from the literature as to which type of system, GDSS or GCSS, would provide the greatest advantages.

There were two variables for which previous studies predicted a difference. These two variables were decision making quality and confidence in the decision.

Decision making quality

Distributed groups with higher technological support for decision making will exhibit higher decision quality than distributed groups with lower technological support for decision making. This hypothesis is based on the consistency of the evidence in favor of increased decision quality for groups using a GDSS versus groups using a GCSS. Although previous studies reported an increase in decision quality for both types of supported groups, the increase was more consistent and had a stronger effect in groups with high support for the decision making process (Bui and Sivasankaran, 1987; Bui et. al., 1988; Easton, et. al., 1989; Ellis et. al., 1989; Gallupe et. al., 1988; George et. al., 1988; Jarvenpaa et. al., 1988; Leblank and Kozar, 1987; Steeb and Johnson, 1981; Turoff and Hiltz, 1982).

Confidence in the decision

Distributed groups with higher technological support for decision making will exhibit higher confidence in the decision than distributed groups with lower technological support for decision making. According to previous studies, groups supported by GDSS showed more confidence on the decision than unsupported distributed groups. Groups that were supported by GCSS exhibited a decrease in group member confidence towards the decision when compared to unsupported groups (Gallupe et. al., 1988; Nunamaker et. al., 1987; Steeb and Johnson, 1981; Vogel and Nunamaker, 1988 ; Watson et. al., 1988; Zirgus et. al., 1987).

Group related outcomes

The final category of dependent variables was concerned with the perceptions of the group's members regarding each other and the group as a whole. Previous studies found GDSS increased the satisfaction of the group members with the group processes when compared with unsupported groups. The literature regarding the effect of GCSS on this variable was inconclusive, but no strong evidence was found to indicate that GCSS increased satisfaction with the group processes over unsupported groups.

Satisfaction with the group processes

Distributed groups with higher technological support for decision making will exhibit higher satisfaction towards group processes than distributed groups with lower technological support for decision making (George et. al., 1988; Jessup et. al., 1988; Nunamaker, 1987
Nunamaker et. al., 1987, 1988, 1989; Steeb and Johnson, 1981; Vogel and Nunamaker, 1988).

Table 1.2: Summary of research hypotheses

Variable Name	**Effect of higher technological support for the decision making process**
Group Process Variables	
Consensus	Increased (+)
Decision Time	Decreased (-)
Communication Efficiency	Increased (+)
Information Exchange	Increased (+)
Cooperation	Increased (+)
Perceived Process Structure	Increased (+)
Task Related Outcome Variables	
Decision Quality	Increased (+)
Confidence in the Decision	Increased (+)
Group Related Outcome Variables	
Satisfaction with Group Processes	Increased (+)

Table 1.2 provides a summary of all ten research hypotheses.

Research Model

Figure 1.3 shows a complete research model. The research model was extended from Figure 1.2 by indicating the predicted relationship between independent and dependent variables as they were stated in each of the research hypotheses. Refer to Chapter 2 for a theoretical framework for this experimental model.

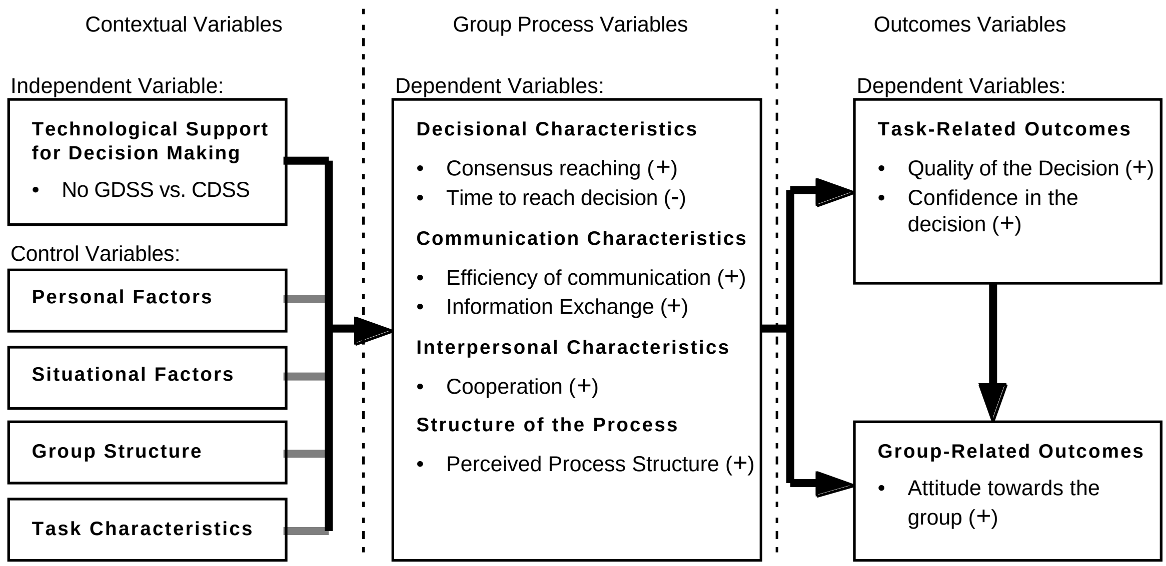


Figure 1.3: Research model showing the independent variable and its effect on the relevant dependent variables. (Adapted from by Pinsonneault and Kraemer, 1990).

Chapter 2. Review of Related Literature

Macroergonomics and distributed groups

Distributed groups and macroergonomic design

According to the Macroergonomics Technical Group of the Human Factors and Ergonomics Society, "Macroergonomics is concerned with the optimization of organizational and work system design through consideration of relevant personnel, technological, and environmental variables and their interactions" (Kleiner, 1997). The central focus of macroergonomics is the optimization of work system design. The effects of GDSS on distributed-group performance is relevant to the design of the distributed-group work system. Because of this, Macroergonomics is an appropriate approach to study the effects that sociotechnical variables such as the effect that the use of a GDSS has on distributed group performance.

Macroergonomics achieves work system optimization through a systematic consideration of the relevant sociotechnical system variables in the ergonomics analysis, design, implementation, evaluation, and control process. These variables fall within three empirically-identified sociotechnical subsystems (Hendrick, 1984). These three subsystems are: The technical or technological subsystem, the social or personnel subsystem, and the external environment. A fourth sociotechnical system element, job and task design, falls within the cognizance of microergonomics, but is influenced by the design of the work system. In fact, macroergonomic design of the work system helps determine many of the characteristics which should be designed into individual jobs for harmonization of the total system. Work system design, thus, includes both the structure and related processes of the entire work system (Kleiner, 1997). Figure 2.1 shows a sociotechnical model of a work system.

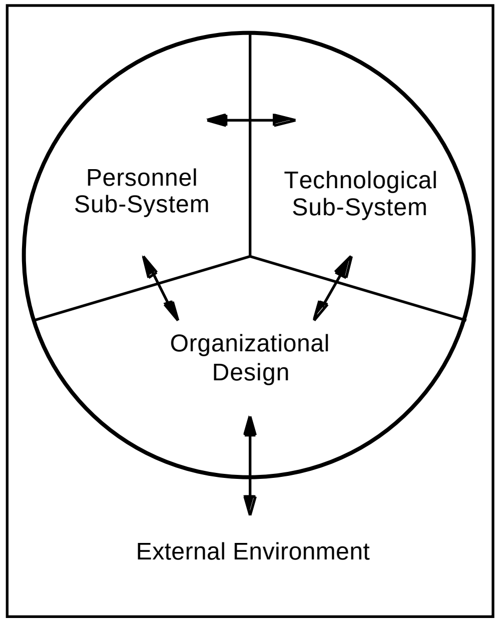


Figure 2.1: Macroergonomic view of a work system (Adapted from Hendrick, 1996).

Macroergonomics is a top-down sociotechnical system approach to the design of organizations, work systems, jobs and related human-machine, user-system, and human-environment interfaces (Hendrick, 1995). It begins with a systematic analysis of variables in the personnel subsystem, technological subsystem, and external environment (Hendrick, 1995). Once defined, these variables help prescribe the organizational design, the allocation of functions, and the micro-ergonomic design.

The goal of macroergonomics is whole system improvement through a top-down, joint design of all involved subsystems. This principle of joint design and optimization applies to the personnel and technological subsystems, and also to the role of groups, and distributed groups in particular, in organizations.

Distributed groups, and groups in general, are components within a larger organizational system. Although the purpose of optimizing distributed group performance is important from an ergonomic and job design standpoint, from a macroergonomic perspective distributed group performance is secondary to the joint design of all subsystems for the optimization of overall organizational performance. Very little empirical evidence exists about the performance of novel work units such as distributed groups and its relationship with overall organizational performance.

One particular research study seems to support the importance of the integration of the group and the rest of the organization. Troyer (1995) found empirical support for the hypothesis that differences between group and organizational normative structures correspond to lower group performance as perceived by external evaluators. Although this can be interpreted in a number of ways, it seems to provide insight into the importance of the interaction between the distributed group and the larger organization. It may, for example, provide insight into the paradox of implanting highly egalitarian workgroups in otherwise bureaucratic organizations (Troyer, 1995). Organizational performance may be influenced as much by group embededness into the organization as by the actual group performance level. Although this is an important observation, an understanding of performance factors at the group level must still prelude a broader understanding of the relationship between group and organizational design.

A macroergonomic view of distributed organizations

The term ‘distributed’ is used here in the context of organizational design. A distributed component is an organizational unit for which the traditional physical infrastructure, including geographical collocation and means for physical interactions, is replaced by information and communication technology. The term ‘virtual group’ has been used in the past to identify distributed groups and other types of distributed organizational components (Cano and Kleiner, 1996). In this study, the term distributed group has been used instead of virtual group to clarify the distinction between distributed organizational components and true virtual-reality technologies. It is important to note that virtual-reality technologies can be used to support and enhance distributed group performance by supporting the sense of presence of the group. This issue will be discussed further in Chapter 5.

Modern organizational theory has as one of its basic assumptions the need to group people and units together for coordination and supervision purposes. Lucas and Baroudi (1994) noted current directions in information technology are increasingly invalidating this assumption. Research in this area is scarce, and the results pointed to conflicting interpretations. At the groups level, there was at least some evidence that distributed groups could outperform groups meeting face-to-face in problem solving tasks (Valacich, 1991). Other studies indicated that face-to-face groups produce more critical ideas (Er and Ng, 1995), were more cohesive, and generally outperformed distributed groups (Inzana, Willis, and Kass, 1994). Some of the discrepancies found in the literature could be attributed to secondary factors such as the type group decision support systems used (GDSS), the use of verbal communication channels, the use of anonymity, and specific task characteristics.

Is important to note that distributed groups will most likely emerge where environmental constraints limit the use of face-to-face groups. Under these conditions, such as large geographical distances or the impossibility to coordinate conflicting schedules, distributed groups may be the only alternative for pooling the best resources available. In these situations, empirical comparisons between distributed and collocated groups are practically insignificant.

Understanding distributed group performance

Organizations operate under environmental conditions characterized by turbulent decision-making. In these dynamic, high-consequence environments, task requirements and goals are constantly changing (Rouse, Cannon and Salas, 1992). Distributed groups operating under such conditions require system designs which jointly optimize both group and organizational level performance (Caldwell, 1994).

In order to optimize technological and organizational design variables of distributed groups, we must develop an understanding of the underlying group process dimensions that translate into successful group outcomes. To understand and objectively measure distributed group performance, we must operationalize and when possible, quantify these underlying processes. This quantification requires the development of a valid set of measures, and these measures must include design, process, and outcome dimensions in order to reveal the relationship among group characteristics, processes and outcomes, and to provide a framework for further research on distributed group design (Prince et. al., 1992).

Sociotechnical system theory and distributed groups

Justification for a sociotechnical framework for distributed group performance

Caldwell (1994) identified two important approaches for effective group analysis and research: the cybernetic and sociotechnical approaches. The cybernetic approach, which found its roots in mathematical tools for improving electrical and mechanical information systems, had some positive aspects, including the use of advanced quantitative tools. On the other hand, the cybernetic approach failed to consider the contextual and dynamic relationship between information and other system dimensions and the external environment. This fact made the cybernetic approach a less than ideal for the understanding of complex human-machine systems.

Caldwell (1994) proposed a sociotechnical measurement framework for identifying dimensions which were important in understanding distributed group performance and processes. Caldwell (1994) recognized that “the explicit integration of social and organizational contexts and group dynamics with technological components of complex systems places sociotechnical systems approaches in a central position for improved understanding of those systems."

Overview of sociotechnical system theory

The term "sociotechnical system" was first coined by Emery and Trist (1960) to better convey the nature of complex human-machine systems. Sociotechnical systems theory proposed a top-down view of a system as a transformation process permeable to the external environment. Two major components interact in this transformation process: the personnel subsystem, and the technological subsystem. The personnel subsystem comprises the human element of the distributed group. The technological subsystem includes not only machines, but also conceptual tools not represented by any physical equipment (Hendrick, 1991).

Sociotechnical systems theory emphasized the concept of joint causation which dictates that all parts of a system react together to causal events in the environment. This idea of joint causation serves as the foundation for a joint design and joint optimization approach to distributed group research and design. In this sense, since both subsystems react jointly to changes in the external environment the only way to avoid sub-optimization of the distributed group as a whole is to avoid optimizing one subsystem and then fitting the other (Hendrick, 1991).

Coexisting with these two subsystems is the organizational design. The organizational design of a distributed group determines how the external environment affects each of its two main subsystems. Also, the organizational design affects the way the two subsystems interact at every human-machine interface by defining task and function allocations as well as lines of communication, authority, and responsibility. The goal of organizational design should be to optimize the interaction of all subsystems to better match the whole system to the requirements of the external environment (Weisbord, 1987). Figure 2.2, adapted from Hendrick's (1986) sociotechnical system framework shows a conceptual model of a distributed group as a sociotechnical system.

Organizational design dimensions

Sociotechnical system theory prescribed a number of dimensions of organizational design important in system analysis and design. These dimensions were: Complexity, formalization, and centralization (Hendrick, 1984). These dimensions of organizational design could be operationalized as dimensions of distributed group design.

Complexity

Complexity refers to the degree of integration and differentiation that exists within a distributed group (Hendrick, 1986). There are three sub-dimensions of organizational complexity: Horizontal differentiation, vertical differentiation, and size.

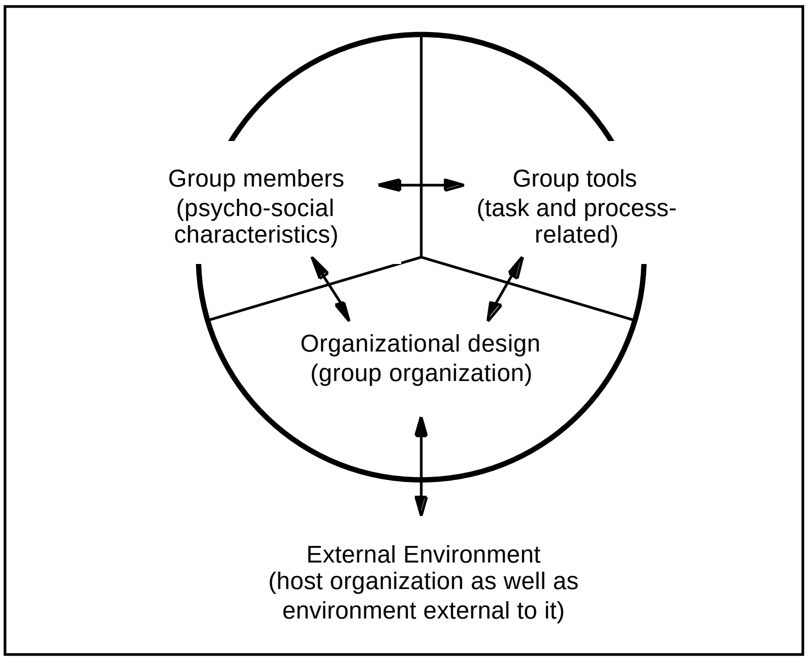


Figure 2.2: A group or team as a sociotechnical system (Adapted from Hendrick, 1996).

In distributed groups, horizontal differentiation refers to the degree of division of labor in the group. Groups with high horizontal differentiation have specific tasks and processes allocated to each group member. Groups with low horizontal differentiation are essentially collaborative groups where all members perform duties as needed without a clear division of labor.

Vertical differentiation refers to the number of authority levels existing in the group. It can range from essentially flat groups to highly stratified groups with many levels of authority. This dimension of distributed group organizational design is highly dependent on group size and the constraints placed by span of control and group member capabilities.

Both vertical and horizontal differentiation affect group complexity. As group complexity increases, the group depends more on integrating mechanisms to coordinate group member activities.

Existing empirical evidence suggested lower levels of complexity may improve performance at least at the group level. Weaver, Urban, Maniam, and Bowers (1994) found a significant interaction between feedback and hierarchical structure at the group level. Their study showed that non-hierarchical groups receiving group-level feedback outperformed groups with product structures regardless of type of feedback (individual or group level).

Size has also been found to have a significant effect on group performance, especially under the conditions imposed by distributed groups which rely on technological augmentation for communication and coordination between members. Valacich (1991) found significant effects for group size on group output quality and quantity for groups interacting through a Group Decision Support System (GDSS). Larger groups (larger than 10 people) appeared to outperform smaller ones when using a GDSS.

Formalization

Hendrick (1991) defined formalization as the degree to which jobs and functions are standardized and structured. In a group with high degree of formalization functions and processes are defined, either by rules or by constraints imposed by the group process itself. Formalization is also related to horizontal differentiation since higher degrees of division of labor may require higher degrees of formalization to coordinate tasks.

The degree of technological support for group processes can also have an impact on formalization by constraining the way in which group members accomplish their task. This relates to perceived group structure, which is one relevant dependent variable in this study. If while increasing the level of technological support for a process the process is also formalized, then the group will perceive a higher level of structure. So, process structure can be related to formalization and technological support unless mechanisms are implemented to guarantee flexibility and adaptability in the support technologies.

Centralization

This refers to the degree to which individual group members must obtain group level consensus in order to make a decision. Distributed groups with low centralization are characterized by empowered group members who make decisions without obtaining approval from the rest of the group. Distributed groups with a high degree of centralization are characterized by decisions in which the whole group participates.

Centralization can be achieved in a number of ways. Groups can arrive at centralized decisions by democratic processes, in which all members have equal participation. Centralization can also be achieved using hierarchical decision making, in which the group leader or leaders consider the opinion and information provided by other group members, but reserve the right to make the final decision. There is very little empirical evidence about the effects of formalization or centralization on distributed group performance.

Dimensions of the personnel subsystem

The personnel subsystem of a distributed group comprises the people in the work group and their relationships with each other and others within the broader organization (Hacker and Kleiner, 1996). Sociotechnical theory places special emphasis on the understanding of personnel subsystem variables, since characteristics of the group members will affect the design of other dimensions of the distributed group. Hendrick (1991) recognized two important dimensions of an organization’s personnel subsystem: the degree of professionalism and the psycho-social characteristics of the members.

There is extensive research on the effects of individual characteristics on individual performance. Some of the research has found that certain characteristics are particularly important in determining group level performance. Cognitive complexity, for example, was found to have a significant effect on group problem solving performance (Hendrick, 1979). Groups with a heterogeneous composition regarding cognitive style were also found to be significantly better than homogeneous groups performing decision making tasks (Kandel, 1991).

Further research in this area will allow the identification of optimal designs for the psycho-social characteristics of the individual members and the overall group composition.

Dimensions of the technological subsystem

The technological subsystem includes the rules, procedures, policies, and devices used by the group to accomplish their task (Hacker and Kleiner, 1996). Researchers have tried to identify important underlying dimensions of technology in many different ways. Perrow (1967), defined technology as the necessary knowledge base for task performance. This approach is compatible with the sociotechnical definition of the technological subsystem since it includes machine-technology as well as conceptual tools, guides, and procedures. This approach allows for the generic classification of technologies used by distributed groups across two main dimensions: task variability and task analyzability (Hendrick, 1986).

Technology support for distributed groups

The role of communication and integration technology in distributed groups

Distributed groups need specialized technological subsystem components dedicated to the integration and communication functions indispensable in distributed cooperative environments. Jin, Levitt, Christiansen, and Kunz (1995) identified five major functions the technological subsystem needs to support in distributed groups. These five functions are: work communication, information exchange, failure exception, decision making, and noise processing.

Work communication is the technology needed to generate communication between members and send it to the respective group members for execution. Information exchange is the technology used to help in coordinating work. Failure exception is the technology used to identify and quickly communicate a task failure. Decision making technology provides mechanisms to incorporate all available information and generate a stochastic decision regarding which alternative actions should be taken.

Some communication exchanged by distributed group members may be irrelevant to accomplishing the group tasks. This is known as non-task-related communication. Nevertheless, this noise presents additional requirements on distributed group members and noise processing technologies need to be implemented to make the process of sorting and processing this information more efficient and effective (Jin et. al., 1995).

Figure 2.3 illustrates the central role of information and communication technology in a distributed group. Unfortunately, the studies that analyze the effects of communication and integration technology on group performance rarely describe the capabilities of the systems used based on a taxonomy such as the one proposed by Jin et. al. (1995). This makes the comparison between studies performed under different systems difficult at best.

For example, Petrovic and Krickl (1994) reported that users of an Electronic Meeting Room (EMR) performing a brainstorming task outperformed traditional groups. The study found significant effects for number of contributions, number of different contributions, and number of “good” contributions. Johnson (1994) found no significant difference between computer supported and non-computer supported groups, but this research used a problem solving task and a different type of CSCW system. Finally, Ferris (1995) found a significant regression effect between type of communication (oral, written, and computer mediated communication), but none of the individual predictor variables had beta weights significant above the p=0.05 level.

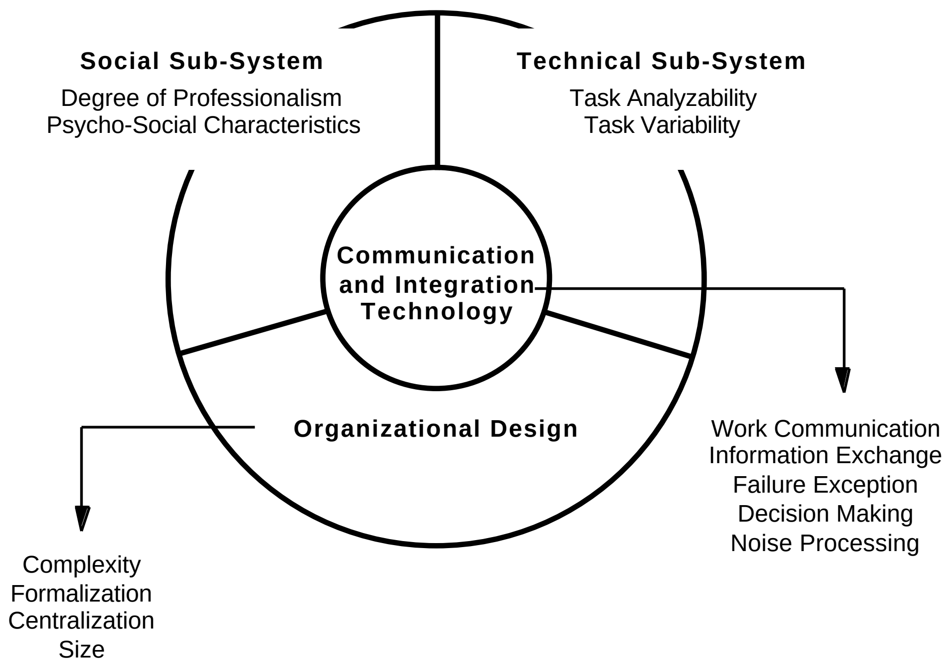


Figure 2.3: Macroergonomic view of a distributed group as a Sociotechnical System, showing subsystems and important design and contextual variables.

Technological support for decision making in distributed groups

Research on the effect of technological support for group processes has typically concentrated on testing for the effects of technology when compared to unsupported groups. Most studies concentrate on one particular type of technological support (GCSS or GDSS). Pinsonneault and Kraemer (1990) provide a complete review of the literature where they found that by grouping studies according to the type of CSCW used the findings which appear inconsistent become consistent within each type.

Table 2.1 summarizes previous research in the area of GCSS which is relevant to this study. This Table includes the authors of the research and the effect on the process and outcome variables of the GCSS supported groups as compared to unsupported groups. Table 2.2 summarizes previous research in the area of GDSS which is relevant to this study. This Table also includes the authors of the research and the effect on the process and outcome variables of the GDSS supported groups as compared to unsupported groups.

By comparing Tables 2.1 and 2.2, the relevant research hypotheses proposed in this study can be seen in the light of previous research and studies. Most of these studies were only concerned with one type of CSCW system (GCSS or GDSS) and compared groups using these systems with unsupported groups. Although this limits the interpretability of the findings with regards to this research, it can be seen that for many process and outcome variables, the effect observed is opposite for GCSS and GDSS.

The Analytic Hierarchy Process

In order to truly implement a GDSS, the technology must go beyond simply supporting the communication process. Many techniques have been proposed for this purpose, but the most well known and studied of all is probably the Analytic Hierarchy Process, or AHP (Dyer and Forman, 1992).

The AHP is a process designed to tackle decision making problems characterized by choice and prioritization. The process was developed by Dr. Thomas Saaty in the 1970's. After the development of its software implementation – called Team ExpertChoice™ - the process has been applied to a variety of decision-making problems (Dyer and Forman, 1992).

According to its developer, the Analytic Hierarchy Process contributes to the solution of complex problems by guiding users though the structuring of the problem into a hierarchy of criteria, stakeholders, outcomes, and alternatives (Saaty, 1980). Figure 2.4 shows an example of a hierarchy as modeled by the software package Team ExpertChoice™. The process then uses judgment from the users to develop a set of priorities. These priorities are used to predict the most preferred outcomes according to the judgments (Saaty, 1990).

Table 2.1: Summary of GCSS research that supports the predicted effects on dependent variables.

Variable name	**Predicted effect**	**Studies that support this effect**
Group process variables		
Member participation	Increased (+)	Hiltz, et. al., 1988 Siegel et. al., 1986 Turoff and Hiltz, 1982 Zirgus et. al. ,1987
Depth of analysis	Increased (+)	Gallupe et. al., 1988 Siegel et. al., 1986 Turoff and Hiltz, 1982
Consensus	Mixed Results	
Decision time	Increased (+)	Easton et. al., 1989 Gallupe et. al., 1988 Siegel et. al., 1986 Turoff and Hiltz, 1982
Communication efficiency	Decreased (-)	Hiltz et. al., 1986 Siegel et. al., 1986
Information exchange	Decreased (-)	Jarvenpaa et. al., 1988 Siegel et. al., 1986 Smith and Vanecek, 1989 Turoff and Hiltz, 1982
Cooperation	Decreased (+)	Gallupe et. al., 1988 Siegel et. al., 1986 Turoff and Hiltz, 1982 Hiltz et. al., 1986
Task related outcome variables		
Decision quality	Increase (+)	Bui and Sivasankaran, 1987 Easton, et. al., 1989 Ellis et. al., 1989 Gallupe et. al., 1988 Jarvenpaa et. al., 1988 Leblank and Kozar, 1987 Turoff and Hiltz, 1982
Confidence in the decision	Decreased (+)	Gallupe et. al., 1988 Watson et. al., 1988 Zirgus et. al. ,1987
Group related outcome variables		
Satisfaction with group processes	Mixed results	

Table 2.2: Summary of GDSS research that supports the predicted effects on dependent variables

Variable name	**Predicted effect**	**Studies that support this effect**
Group Process Variables		
Member participation	Increased (+)	George et. al., 1987 Nunamaker et. al., 1987 Nunamaker et. al., 1988 Vogel and Nunamaker, 1988
Depth of analysis	Increased (+)	Gray, 1983 Nunamaker et. al., 1988 Steeb and Johnson, 1981 Vogel and Nunamaker, 1988
Consensus	Increased (+)	George et. al., 1988 Steeb and Johnson, 1981 Vogel and Nunamaker, 1988
Decision time	Decreased (-)	Bui et. al., 1988 George et. al., 1988 Nunamaker, 1987 Nunamaker et. al., 1988, 1988 Vogel and Nunamaker, 1988
Task related outcome variables		
Decision quality	Increase (+)	Bui et. al., 1988 George et. al., 1988 Steeb and Johnson, 1981
Confidence in the decision	Increase (+)	Nunamaker et. al., 1987 Steeb and Johnson, 1981 Vogel and Nunamaker, 1988
Group related outcome variables		
Satisfaction with group processes	Increase (+)	George et. al., 1988 Jessup et. al., 1988 Nunamaker, 1987 Nunamaker et. al., 1987, 1988, 1989 Steeb and Johnson, 1981 Vogel and Nunamaker, 1988

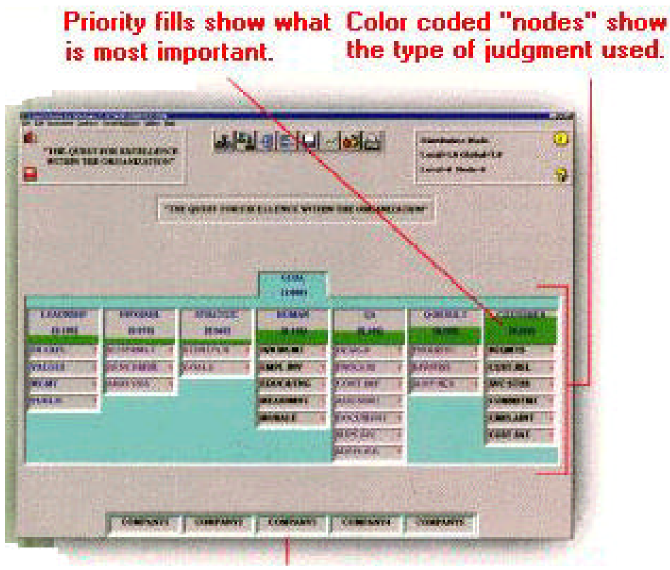


Figure 2.4: A view of the Team ExpertChoice™ software implementation of an AHP hierarchy (Expert Choice Inc., http://www.ahp.net/).

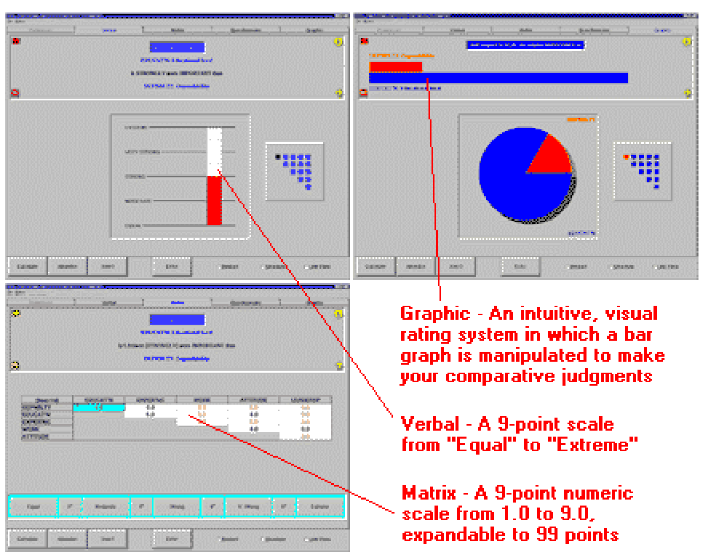


Figure 2.5: The three modes of pairwise comparison styles allowed by Team ExpertChoice™: Graphical, verbal, and numerical (Expert Choice Inc., http://www.ahp.net/).

By knowing the sensibility of a decision to certain assumptions or judgments the amount of inherent risk embedded in the decision can be estimated. Sensitivity refers to the degree in which the predicted outcome changes given a change in some of the judgments used as input. This can vary considerably since the importance of judgments is affected by previous judgments higher in the hierarchy. Figure 2.5 shows a graphical representation of an AHP judgment comparisons rendered by the software package Team ExpertChoice™.

Another quality of the AHP is its ability to generate accurate ratio scales from imprecise verbal comparisons. Priority ratios are calculated from the eigenvectors and eigenvalues of reciprocal matrices representing pairwise comparisons. Since each matrix contains more values than the minimum needed to calculate a value arithmetically the system has a certain redundancy within it. This redundancy is used within the process to 'average out' errors of judgment, in a way that has been shown to produce impressive accuracy in real life implementations (Dyer and Forman, 1992).

Distributed group performance

Investigating human processes and performance at the group level is important for several reasons. First, researchers have identified the need for further research in the area of groups in general (Goodman, Ravlin, and Schminke, 1987; McGrath, 1986) and distributed groups in particular (Cano and Kleiner, 1996). Second, different group types may represent different design and management requirements (Mohrman, 1993; Parker, 1994). This implies the need to understand and define the determinants of effectiveness for distributed groups (Goodman, 1986), which may or may not be different than those for other types of group structures. Types of groups include functional teams which are homogeneous with respect to technical orientation of its members; Cross-functional teams which combine members with different technical competencies; and self-managed teams which have autonomous control over such decisions as member selection, work design, and scheduling. Most taxonomies assume self-managed teams to be formal or permanent structural components and the others to be informal or parallel organizational structures.

This research is particularly interested with distributed groups, which are characterized by a high degree of geographical dispersion. Distributed groups can be cross-functional and self-managed in nature. Distributed groups can also share long-term goals and extensive group history, which is a prerequisite for the often misused label of 'team'. Because of the limitations imposed by experimental research, this study was limited in scope to ad-hoc groups with very low levels of complexity (flat teams with little formalization and centralization) and no previous group history.

A model of group decision making

A general model of group decision making is important in understanding the effects of technological support on distributed group performance. Most research models of group performance are variations of McGrath's (1964) group performance model. In this model, contextual and design factors of the group determine the characteristics of the group process. The group process in turn determines the level of group performance. Figure 2.6 shows an adaptation of the McGrath model.

Most scholars agree group performance has two dimensions: task-related outcomes and group-related outcomes (McGrath, 1964; Hackman, and Morris, 1975; Kolodny, and Kiggundu, 1980; Gladstein, 1984; Tannenbaum, Beard and Salas, 1992). Task-related outcomes refer to metrics directly related to the task being performed. As such, task-related outcomes are to a certain degree task-specific, although certain task-related outcomes such as decision accuracy and satisfaction with the decision can be generalized to a large number of tasks. Group-related outcomes refer to how group members feel about working with one another, the extent to which they feel the time devoted to group activities is worthwhile, and whether they are satisfied with the group process (Pinto, Pinto and Prescott, 1993).

It is important to note that in McGrath's model task-related outcomes are influenced by the characteristics of the group process, but group-related outcomes are influenced by both the group process and the task related outcomes. In other words, group member perceptions of task performance can have an effect on group-related outcomes.

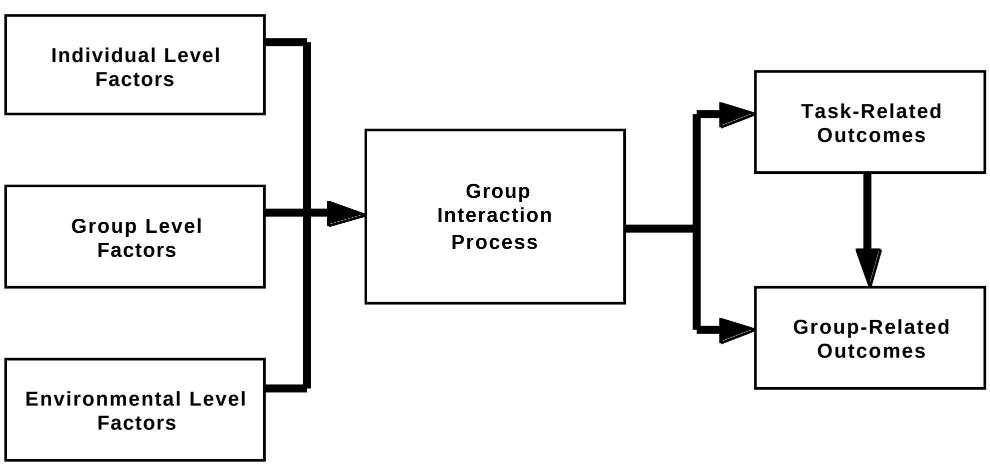


Figure 2.6: Group Performance Model (Adapted from McGrath, 1964).

Most models of group performance consider group interaction processes as important factors influencing group performance. Group interaction characteristics which are directly observable may be more reliable than subjective measures of performance and satisfaction since the later are self-reported constructs which are vulnerable to bias (Muckler, and Seven, 1992). Group interaction processes include metrics such as amount of communication, adaptability, cooperation, acceptance of suggestions or criticisms, giving of suggestions or criticisms, group spirit, and coordination (McIntyre, and Salas, 1995).

Distributed group communication channels

Kies, Williges, and Rosson (1997) describe text, audio, and video as the three major channels of communication used in computer-augmented communication. Each one of these communication channels has unique advantages and disadvantages. Below is a brief discussion of each type of communication channel.

Text

Of the three communication channels, text represents the lowest bandwidth requirements (Kies et. al., 1997). Text is better used for tasks in which the visual cues are not as critical. According to Kies et. al. (1997), such tasks included the exchange of information, exchanging opinions, and generating ideas (Hiltz, Johnson, and Turoff, 1987; Adrainson and Hjelmquist, 1991). It was demonstrated that tasks which relied on the transmission of gestures and facial expressions, such as persuasion, problem resolution, and getting acquainted with the other participants were better accomplished in a face-to-face session.

In addition to low bandwidth, text-based communication has the advantages of easy storage and preservation of communication history, ease of use, increased participation among group members, the availability of both synchronous and asynchronous formats, less conformity of opinions, and less influence from dominant participant (Kiesler, Siegel, and McGuire ,1984). On the other hand, text-based communication has the following disadvantages: Higher time requirements to reach consensus, (Kiesler, Siegel, and McGuire, 1984; Hiltz, Johnson, and Turoff, 1987; Adrainson and Hjelmquist, 1991; and Sproull and Kiesler, 1991), difficulty in interpreting nuances of messages without verbal or visual cues (Garter and Wellman, 1993), and difficulty in coordinating communication among group members (Ellis, Gibbs, and Rein, 1991 and Kiesler, Siegel, and McGuire, 1984).

Audio

The auditory channel has been found to be the most critical factor to effective communication under certain task and contextual conditions (Kies et. al., 1996; Chapanis, 1975). Voice communication seems to greatly increase the sense of presence, or being located in the same place when used in distributed communication (Short, Williams, and Christie, 1976; Böcker and Mühlbach, 1993). Also, Sproull and Kiesler (1991) found that voice communication is more personal because it is often easily recognizable, and does not offer the de-personalizing effects of text. Auditory communication, however, has the potential disadvantages of being transient, and not easily stored for recall and manipulation. Also, there is the potential for sensory overloading, and poor localization (Gaver, 1992).

Video

Visual communication represents the richest of the communication channels, and current technology has reached the point at which video communication is possible without measurable degradation of performance (Kies et. al., 1997). Research has shown that conversation is mediated to a large extent with visual cues such as eye contact, facial expressions, gesture, and posture (Argyle, 1975). Information such as participant interest, personality, and emotion is easily conveyed through the visual channel. Video-based communication is becoming more feasible over computer networks due to faster computer processors, better compression algorithms, and faster networks.

Given the important role the visual channel plays in communication, it is curious that many studies show no task performance improvement when adding video to a communication system (Ochsman and Chapanis, 1974; Weeks and Chapanis, 1976, Williams, 1977; Gale, 1990; Masoodian, Apperley, and Fredrickson, 1995). Some researchers (Tang and Isaacs, 1993; Isaacs and Tang, 1994) noted these studies have used subjects who are unfamiliar with each other, measured performance on a contrived task, and do not account for long-term usage. While their findings suggest that users prefer video to other communication modes, there remains no solid understanding of how video is used for real tasks over an extended period of time (Kies et. al., 1997).

Group performance theories

Research on the utility of alternative communication media is complex. Some studies have compared video to other media such as text and audio while others have focused on the differences between video and face-to-face communication. Studies generally reflect the objectives and backgrounds of the researchers, resulting in large differences between methodology, rigor, and interpretation. These differences make extracting commonalties from this large body of research difficult. Some researchers propose that the utility of the video channel is task-dependent (Short, Williams, and Christie, 1976; Williams, 1977; Angiolillo, Blanchard, and Israelski, 1993). Interpersonal tasks, such as negotiation and persuasion can be assisted by the inclusion of a video channel, whereas information exchange tasks such as lectures and brainstorming are relatively immune to the effects of video (Angiolillo, Blanchard, and Israelski, 1993). Williams (1977) partitions tasks into cooperative and conflictive classes and argues that the former is, for the most part, insensitive to video while the latter benefits from a video channel.

Communication media theories

Several theories exist to explain the role of various communication media. The Social Presence Theory was postulated by Short, Williams, and Christie (1976). The theory suggests that the degree of presence or feeling of being collocated is enhanced by the characteristics of the medium. High bandwidth media such as video tend to benefit interpersonal tasks, while low bandwidth media are adequate for information exchange tasks.

Daft and Lengel (1986) postulated an extension to that theory, the Media Richness Theory . This theory attempts to explains how the richness of the medium affects the allowances for feedback, personalization, number of channels used, and variety of language. Video, which allows facial cues and body gestures to be transmitted, is considered a rich medium while text is not so rich. It is theorized that the richness of the medium greatly impacts the ability of the group to resolve uncertainty or equivocality.

Social information processing theory

Communication media theories focus on the characteristics of the media to explain the characteristics of the group interactions. The Social Information Processing Theory (Fulk, Steinfeld, Schmitz, and Power, 1987) proposes that the dynamics and past experiences of the group play a large role in the acceptance of various communication media; thus, a shared view of socially-constructed meaning is established from the use of a particular medium. A similar theory, Symbolic Interactionism (Trevino, Lengel, and Daft, 1987) suggests that symbolic messages inherent in the use of a medium combine with its richness to explain the choice of different media use in organizations.

Multi-level theory

The Multi-Level Theory (MLT) of group decision making performance was proposed by Hollenbach, Illgen, Segro, Hedlund, Major, and Phillips (1995). This theory is one of the most elaborate theories of group decision making, and although is geared towards hierarchical groups some of its postulates apply to group decision making in general.

MLT predicts that group decision-making accuracy is determined by constructs that occur at one of four levels: group level, dyadic level, individual level, and decision level. Three core constructs are predicted as the most important determinants of decision making accuracy. These three core constructs are: Informity, or the degree to which individuals and groups are well informed about the decision; hierarchical sensitivity, or leader sensitivity to subordinate accuracy; and staff validity, or the decision accuracy of group members.

Below the three core level constructs MLT defines three other secondary constructs which occur at the lower levels. At the decision level the theory defines decision informity, which is the amount of information the group had on any individual decision sub-unit. At the individual level the theory defined individual validity, which is the predictive validity of any individual group member. Finally, at the dyad level the theory defines dyadic sensitivity, which is the weight assigned by the centralized decision maker.

Unfortunately, this theory specifically addresses decision-making in hierarchical groups, which are not included in the scope of this research. In hierarchical groups information is process in a hierarchical fashion, with the final decision made by the highest level of the hierarchy. Although this type of group is common in situations such as flight crews and military units, this research is more concerned with the decision making performance of self-managed, cross functional distributed groups which exhibit a more democratic, consensus based decision making model.

Decision making framework

Kleiner's (1997) decision making framework considers the decision making system as four interrelated input/output subsystems. This framework defines a decision making subsystem (DMS), a decision tool subsystem (DTS), and a work process subsystem (WPS). The decision making subsystem is concerned primarily with decision makers converting information from decision tools into prescriptions for action. In a group structure, the process of converting information to a decision requires effective communication. The decision tool subsystem transforms data from the work process into information for decision making. Again, in a group environment, data may be derived from several sources, necessitating an effective communication process.

The focus of the WPS is the data-information-decision-action process, and therefore, criteria for the WPS are operationally defined in information flow terms. The DMS is a human-dominant subsystem, the DTS is predominantly a technological subsystem, and the mission or WPS is viewed as sociotechnical subsystem. However, each can be described through analogous performance criteria which relate to critical components and interfaces of each subsystem. Subsystem-specific measures have been defined for each general performance criterion. The model uniquely considers the decision makers, their decision tools and the mission in which their decisions are focused.

Kleiner's decision making framework (Kleiner, 1997) has the advantage of explicitly defining the role of decision tools and decision support technology in the group's decision-making process. By explicitly defining technological, social, and organizational constructs of organizational decision making this framework is helpful in understanding distributed group performance from a sociotechnical system perspective.

Procedures for measuring group performance

Complex computer-augmented communication systems, such as GCSS and GDSS, are best studied with a variety of complimentary measures (Watts, Monk, and Daly-Jones, 1996). For example, Anderson, Newlands, Mullin, Fleming, Doherty-Sneddon, and Van der Velden, (1996) studied video-mediated communication with task performance measures, subjective assessment, and direct conversation measures. Kies, Williges, and Rosson (1997) describe ethnographic procedures that are needed to investigate communications in conferencing environments. Ethnographic techniques include both contextual analyses and interaction analyses. Although the majority of the research on electronically-mediated video, audio, and text communication has been examined in highly controlled situations, observational methods are also useful in evaluating communications of distributed groups. Interviews, questionnaires, ethnomethodological observations, and conversation analysis measures provided a holistic understanding of computer-mediated communication.

Observational procedures

Verbal protocol analysis

The use of verbal reports as data can augment traditional data collection methods because they can describe strategy; engage operators; involve operators; distinguish between levels of operation; identify and promote learning; and explain individual differences (Kleiner and Drury, 1998). A "protocol" is a verbatim transcript of a decision-making or problem-solving process (Glass, Holyoak and Santa, 1979). There are three types of verbalization: (1) reports of stimuli that remain constant and are available to the senses; (2) information retained in memory; and (3) information retained in long-term memory (Ericsson and Simon, 1984). Many studies rely on concurrent data which comprise verbal reports created while a subject performs a task. Retrospective protocols, which are generated after a task is performed and are believed to require long-term memory (LTM) retrieval, are needed to both validate concurrent protocols and to gain deeper insight.

Ericsson and Simon (1984) have defended the use of verbal protocols as "hard" data. In addition to producing hard data, the use of protocols produces interesting data not otherwise obtained (Bainbridge, 1974). Since there is much evidence for cognitive processes in judgment and discrimination (Ericsson and Simon, 1984), it follows that cognitive modeling of these processes can be realized through the use of protocols.

Protocol and content analysis are applicable to decision making and problem solving tasks. In a classic work, Newell and Simon (1972) described a protocol analysis technique to study the way in which people solve cryptarithmetic problems. Other applications of verbal protocols include their use to study the mental procedures used by skilled electronics repairmen (Rasmussen and Jensen, 1974); to study the strategies of gas grid control operators (Umbers, 1979); to develop computer programs to simulate human problem solving (Glass et. al., 1979); to investigate manual vs. automated versions of visual monitoring (Fuld and Wickens, 1986); to develop insight into the problems associated with text editing systems (Mack, Lewis and Carroll, 1983); to help predict fault diagnosis performance (Sanderson and Murtagh, 1988); to model specific cognitive processes (Sanderson, James and Sieder, 1989) and in human-system function allocation (Kleiner and Drury, 1998).

An alternative to protocol analysis is to use content analysis, whereby behavior is categorized, coded, and analyzed. For example, Sanquist and Fujita (1989) were interested in design and evaluation issues. They predicted categories of protocols and subsequently evaluated the percentage of protocols falling into these categories. The authors indicated that such a categorization scheme could eliminate the use of costly prototypes. In another example of content-based approaches, the impact of active participation and communication of humans in automated systems was studied (Idaszak, 1989). In this study, seventeen categories of inter-operator communications were effectively analyzed.

Interaction analysis

Audio-video tapes of group communications can be studied by an interaction analysis. Originally, the content of the group communications were classified into different types of communications such as declarative statements, questions, etc. by experts analyzing the audio communication recordings (Bales, 1950; Williges, Johnston, and Briggs, 1966). Recently, more sophisticated approaches such as SYMLOG (Polley, Hare, and Stone, 1988) have been used with fairly good reliability, but such techniques are tedious and require the presence of a trained expert (Hacker, 1997; Meredith, 1997). SYMLOG stands for ‘A System of Multiple-Level Observation of Groups’ and it provides quantitative measures of group interactions

A more detailed content analysis consists primarily of recording the frequency of communication breakdown and communication turn-taking among group members. For example, Kies (1997) used an interaction analysis to isolate six classes of operationally-defined communication breakdown metrics: verbal turn-taking breakdown, reference breakdown, visual breakdowns, audio breakdowns, and shared conversation breakdowns. Based upon the type of task involved, the specific metrics required for interaction analysis may vary.

Ethnomethodology

Hughes, Sharrock, Rodden, Kristoffersen, O'Brien, Rouncefield, and Calvey (1995) discuss ethnomethodological data collected by reviewing the videotapes and looking for behavioral patterns, such as work flow organization, interaction with and use of artifacts, plans, and procedures, and mechanisms by which work activities were made aware to all group members. Metrics can be developed to isolate various communication themes central to distributed group performance. For example, Kies (1997) used interviews, questionnaires, ethnomethodological observations, and conversation analysis measures to provide a holistic understanding of video-mediated communication. Six themes or behavioral patterns related to conversation fluidity, support tools, effects of time, work organization, group configuration, and visual issues emerged from these four analysis methods.

A number of examples of these non-augmented observational procedures is summarized in Table 2.3. The examples are selected from cases were the groups themselves were performing under augmented conditions. Observational procedures aimed at measuring outcome or perceived variables are the most simple to implement. In many cases these variables can be measured by real-time observation, such as timing, counting, etc., or by post-experimental questionnaires. These techniques require little or no post-experimental processing or coding of the data before analysis can begin. The AT:ST ratio is defined as the ratio between analysis time and sequence time (Sanderson and Fisher, 1994). Techniques based on real-time observation - such as the ones mentioned above - have AT:ST ratios close to 1:1.

As the variables of interest become more complex, the techniques used to measure them require increasing amounts of post-experimental processing and coding before the data is suitable for analysis. This results in increasing AT:ST ratios. For example, ratios between 3:1 and 10:1 have been reported for techniques aimed at analyzing video-based usability data (Nielsen, 1993). For the most complex types of analysis, such as the modeling of cognitive processes of users , ratios of 500:1 and even 5000:1 have been reported (Ritter and Larkin, 1994). Clearly, large AT:ST ratios impose a practical limitation on the ability to implement rich but complex communication measurement techniques (Sanderson and Fisher, 1994). All these types of analysis are aimed at studying the rich interpersonal interactions that occur during a group activity. Although analysis at this level is beyond the scope of this research the findings of many of these studies complement this research.

Table 2.3a: Non-augmented group communication metrics.

Author	Year	Task	Variable	Method
Steeb and Johnston	1981	Complex political crisis	Depth of Analysis	N/A
			Consensus	N/A
			Time to Decision	N/A
			Cooperation	N/A
			Quality of Decision	N/A
			Breath of Decision	N/A
			Satisfaction w/Decision	N/A
			Confidence of Members	N/A
			Satisfaction w/Group	N/A
Turoff and Hiltz	1982	Rank order a list of items	Decision Quality	Compare with known solution
			Consensus	Kendall's coefficient of consensus
			Communication Process (exploratory)	Interactive Process Analysis (Bales, 1950)
Cray	1983	N/A	Task oriented communication	N/A
			Depth of Analysis	N/A

Table 2.3b: Non-augmented group communication metrics (Continued).

Author	Year	Task	Variable	Method
Gallupe	1985	N/A	Decision Time	N/A
			Decision Quality	N/A
			Satisfaction w/process	N/A
			Participation	N/A
			Number of alternatives	N/A
Nunamaker et. al	1987	Varied planning sessions for multiple organizations	Dynamics of communication (exploratory)	Structured observation (time study)
			Participation	Questionnaire
			Satisfaction of Members	Questionnaire
George et. al	1987	Sales territory assignment	Participation	N/A
			Consensus	N/A
			Information Exchange	N/A
Zigurs et. al	1987	Develop admittance criteria	Participation	N/A
			Quality of Decision	N/A
Watson et. al	1988	Allocate grant funds for a hypothetical research foundation	Consensus	Fuzzy Analysis of Consensus (Spillman et. al., 1980)
Jessup et. al	1988	University parking problem	Clarification of efforts	N/A
			Exchange of information	N/A
Nunamaker et. al	1988	Varied decision tasks (field study)	Depth of Analysis	N/A
			Participation	N/A
			Time to Decision	N/A
			Clarification Efforts	N/A
Gallupe et. al	1988	Marketing Case	Depth of Analysis	N/A
			Participation	N/A
			Consensus	N/A
			Time to Decision	N/A
			Quality of Decision	N/A
Poole et. al	1988	Resource Allocation problem	Participation	N/A
			Consensus	N/A
			Clarification Efforts	N/A
Dickson et. al	1988	Resource Allocation problem	Consensus	N/A
Easton et. al	1989	Impact of a policy statement	Quantity of alternatives	Direct observation
			Dist. of Participation	Direct observation
			Process Satisfaction	Questionnaire
			Decision Quality	Deviation from known solution
			Decision Time	Direct Observation
			Satisfaction w/decision	Questionnaire

Table 2.3c: Non-augmented group communication metrics (Continued).

Author	Year	Task	Variable	Method
Smith and Vanecek	1989	Solve a murder mystery	Amount of information exchanged	Direct observation of number of clues exchanged
			Comprehensiveness	Direct observation
			Progress towards goal	Semantic differential scales
			Freedom to participate	Semantic differential scales
			Deviation from correct answer	Deviation from known solution
Dufner et. al	1994	Allocate grant funds for a hypothetical research foundation	Perceived Decision Quality	Survey
			Perceived Media Richness	Questionnaire
			Satisfaction w/system	Questionnaire
			Satisfaction w/decision process	Questionnaire
			Perceived Equality of Influence	Questionnaire
Dufner et. al	1994		Perceived Consensus	Questionnaire
Franz and Jin	1995	Implementation of an integrated payroll system for a large public service organization	Dynamics of group conflict (exploratory)	Coding of speech utterances (Donohue et. al., 1984)
Swigger and Brazile	1995	Retrieving relevant documents from an on-line database	Precision (ratio of relevant documents to total documents	Direct observation
			Recall (ratio of relevant documents found to total relevant documents)	Direct observation and comparison to an 'expert search'
Brannick et. al	1995	Flight simulation scenario for pilot/copilot team	Assertiveness	behavior anchored rating scale, and Multi-Trait Multi-Method (MTMM) analysis
			Decision Making/Mission Analysis	BARS and MTMM
			Adaptability	BARS and MTMM
			Situational awareness	BARS and MTMM
			Leadership	BARS and MTMM
			Communication	BARS and MTMM

Table 2.3d: Non-augmented group communication metrics (Continued).

Author	Year	Task	Variable	Method
Poole and Holmes	1995	Allocate grant funds for a hypothetical research foundation	Organization of the decision process	Decision Function Coding System (Poole and Roth, 1989), number of decision phases
			Procedural Insight	DFCS, proportion of acts indicating understanding
			Task-communication fit	DFCS, difference from group decision profile and 'correct' decision profile
			Number of ideas generated	Direct observation
			Critical examination of ideas	Proportion of criteria definition, solution elaboration, and negative solution evaluation statements
			Ideational connection	Proportion of statements linking criteria and solutions
			Task focus	Proportion of task-oriented statements
			Start-up friction	DFCS, proportion of orientation statements aimed at clarifying procedures
			Mechanical friction	Direct observation of number of problems with system use
			Equality of participation	DFCS, deviation from equal proportions of statements
			Leadership emergence	DFCS, deviation from equal proportion of orientation and solution confirmation statements
			Amount of communication	Direct observation of number of statements
Urban et. al	1996	Resource management military simulation	Communication Effectiveness	Number of targets successfully engaged
			Communication process	Coding of speech utterances

Computer -augmented procedures

Due to the complexities of using verbal reports as data, and the current trend to employ this techniques for studying cognitively complex tasks, interest in semi-automated and automated knowledge acquisition tools and expert systems has increased. One area where advances in technology are clearly assisting in the measurement process of group communication is in the automated transcription of human speech. Once only possible through tedious and time consuming manual work, Automated Speech

Recognition technology (ASR) has finally become powerful enough for continuous speech, speaker independent voice recognition, and commercial applications of this technology are on their way (Baber and Noyes, 1996; Rudnicky, Hauptmann, and Lee, 1994). Some examples of commercially available packages which offer these capabilities are IBM® Continuous Speech System™ (ICSS), Dragon Systems® Naturally Speaking™, and Voice Recognition Systems® VRS™ package. All these systems implement ASR technology while only requiring off-the-shelf PC computer hardware platforms.

The next step in augmenting the measurement of group communications is the coding of speech utterances into a format suitable for analysis. Interest on these technologies has also been on the rise. For example, Kleiner and Drury (1998) described the use of the Ethnograph (Seidel and Clark, 1984) for content analysis of skill-based tasks. Boose (1986) reviewed the Expertise Transfer System, a computer program that interviews experts and helps them build expert systems. Sanderson, James and Sieder (1989) reviewed SHAPA, an interactive verbal protocol tool. The MacSHAPA system (Sanderson et. al., 1994), an extension of the original SHAPA software, incorporates text, audio, and video-based content analysis.

The advantage of these and other similar systems is that they provide a systematic means for exploring cognitive processes. Also, by automating or increasing the processing time and coding of raw textual, verbal, and visual data, these techniques help reduce the AT:ST ratio for the most complex measurement techniques, making them more feasible to implement. It is important to note that although these systems greatly assist in the data collection process, they are by no means automated at their current stage and expert input is always required to complement the computer analysis.

One notable exception is the JABBER system (Kazman, Al-Halimi, Hunt and Mantei, 1996). This system integrates speech recognition, lexicographic analysis, agenda management, temporal idiom recognition, and automatic annotation to analyze the interactions occurring in a meeting in real time and with almost no human intervention. Although the system is still in prototype stages, and is intended purpose is indexing meeting recordings for latter retrieval, its capabilities indicate the current directions in automated communication metrics.

As noted by Sanderson et. al. (1994), there is a potentially vast number of computer-based approaches that can be taken, and investigators will often tailor the approach on the basis of the goals and constraints associated with a particular study. Table 2.4 provides a brief summary of significant systems which automate or in any other way augment the process of measuring the communication process of groups. The Table describes the different techniques according to the type of task being analyzed, the variables or constructs of interest, and the methods for operationalizing and measuring these constructs. The implementation and use of computer-augmented procedures for measuring group communication and decision making performance is beyond the scope of this research, but findings from these studies show research moving in a direction of richer direct measurement of group processes.

Table 2.4a: Computer-augmented techniques to measure communication-related data.

Author	**Year**	**System**	**Task**	**Variable**	**Method**
Waterman and Newel	1971	PAS-I	Teams observed during varied problem solving episodes, limited to cryptarithmetic problems	Sequence of mental activities	Limited language parser and Computer verbal protocol analysis
Waterman and Newel	1973	PAS-II	Teams observed during varied problem solving episodes, regardless of context	Sequence of mental activities	Natural language parser and Computer verbal protocol analysis
Potel et. al	1976	GALATEA	Any video data - from human behavior to molecular biology	Event sequence analysis	Computer Video Exploratory Sequential Data Analysis (VESDA)
Bahskar and Simon	1977	SAPA - Semi Automatic Protocol Analysis	Teams solving thermodynamic problems	Predictions about subjects next statements	Computer verbal protocol analysis
Ericsson and Simon	1984	MPAS	N/A	Sequence of mental and communication activities	Computer verbal protocol analysis
Seidel and Clark	1984	Ethnographer	N/A	N/A	Computer Exploratory Sequential Data Analysis (ESDA)
Boose	1986	Expertise Transfer System	Expert system implementation	Expert knowledge elicitation	N/A

Table 2.4b: Computer-augmented techniques to measure communication-related data (Continued).

Author	Year	System	Task	Variable	Method
Lueke et. al	1987	VPA - Verbal Protocol Analysis	Groups performing system usability testing	N/A	Computer verbal protocol analysis
Fisher	1988	PAW - Protocol Analysis Workshop	Computer programming skills	N/A	Computer verbal protocol analysis
Sanderson et. al	1989	SHAPA - Hemi Semi-Automatic Protocol Analysis	N/A	Sequence of mental and communication activities	Computer verbal and non-verbal protocol analysis
Mackay	1989	EVA - Experimental Video Analyzer	N/A	Interaction analysis	Computer Video Exploratory Sequential Data Analysis (VESDA)
Losada and Markovitch	1990	Group Analyzer	Teams observed during varied problem solving episodes	Behavioral patterns over time	Computer Video Exploratory Sequential Data Analysis (VESDA) and Bales SYMLOG
Roschelle et. al	1990	Video Noter	Any video sequence	Indexing of sequential activities	Computer Video Exploratory Sequential Data Analysis (VESDA)
Heise	1991	Ethno	N/A	Event structure analysis	Computer Exploratory Sequential Data Analysis (ESDA)
Olson and Olson	1991	Meeting Plots	Group design meetings	Sequence of activities	Computer Video Exploratory Sequential Data Analysis (VESDA)
Harrison	1991	VANNA - Video Annotation and Analysis	Software usability testing and behavioral studies	Annotations and verbal transcriptions	Computer Video Exploratory Sequential Data Analysis (VESDA)
Ritter	1992	SMT - Sequential Modeling Tool	N/A	Cognitive Model development and testing	Computer Exploratory Sequential Data Analysis (ESDA)
Sanderson et. al	1994	MacSHAPA	Teams performing varied problem solving tasks	Sequence of relevant cognitive and communication events	Computer Video Exploratory Sequential Data Analysis (VESDA)

Table 2.4c: Computer-augmented techniques to measure communication-related data (Continued).

Author	Year	System	Task	Variable	Method
Swigger and Brazile	1995	CSCT - Computer Supported Cooperative Training	Teams retrieving relevant documents from an on-line database	Group Process (exploratory)	Correlation between features used and effectiveness
Kazman et. al	1996	Jabber	Any distributed group meeting	Annotation of temporal events	Fully automated, real time transcription and lexicographic and semantic analysis
Kleiner and Drury	1997	Ethnograph	Printed circuit board inspection	Analysis of skill-based tasks	Computer Exploratory Sequential Data Analysis (ESDA)

In summary, most of the automated metrics require expert observers who have been trained to use these procedures. In addition, these techniques usually require a great deal of time in collecting and summarizing the results thereby increasing the overall cost and reliability of these metrics. Since no fully automated approaches have been identified, there remains a need automate these methods and metrics. The development of automated methods for measuring group performance is beyond the scope of this research.

Summary of group performance measures

The previous two sections described a number of observational and computer-augmented procedures used in previous studies to measure group performance. Not all these procedures were appropriate for the objectives and scope of this study. In general, this research was concerned with the initial estimation of the effect that the use of a GDSS had on the performance of distributed groups. Although certain group process variables were of interest, the main focus of this study was determining if the use of a GDSS could be held responsible for fundamental differences in the overall performance and group processes of a distributed group.

Many of the procedures discussed in the previous sections are aimed at a very detailed understanding of the group's communication processes. This methods usually involved the detailed collection, indexing, and analysis of the group communication sequence, creating very high AT:ST ratios (analysis time vs. sequence time). Since the goal of this study was an initial estimation of the effect of GDSS on distributed groups, only techniques with low AT:ST ratios were employed. These techniques included direct observation for variables such as decision time and quantity of information exchanged, deviation from a known solution for estimation of decision quality and accuracy, and post-experimental questionnaires for estimation of subjective variables such as perceived cooperation, structure of the process, confidence in the decision, and satisfaction with the group process.

As an example of some of the observational procedures used in this study, Turoff and Hiltz (1982) used direct comparison with known results to estimate decision quality. They also used the Kendall's coefficient of consensus (Spillman et. al., 1980) to estimate group consensus from individual member's choices. Nunamaker, Applegate and Konsynsky (1987) used post-experimental questionnaires to measure satisfaction with the group process. Similarly, Easton, Vogel and Nunamaker (1989) used deviation from a known solution to determine decision quality, direct observation to determine decision time, and post-experimental questionnaires to estimate satisfaction with the decision. Another study that used deviation from a know solution to determine decision quality was Smith and Vanecek (1989), which also used direct observation of number of clues exchanged to measure amount of information exchanged.

Most computer-augmented procedures mentioned above were aimed at reducing the high AT:ST ratios inherent to some of the more advanced observational procedures. Since these advanced observational procedures were not used in this study, the use of elaborate computer-augmentation techniques was not required. Nevertheless, technology and computer augmentation played an important role in data collection. The use of videoconferencing and GCSS as the main communication channels allowed for a permanent record of the communication process. Chapter 3 will discuss data collection procedures in more detail, including the experimental methodology and for facilities and equipment set-up used for data collection.

Chapter 3. Methodology.

Experimental design

This study adopted a one-way experimental design aimed at determining if in fact the single independent variable – technological support for the decision making process – can be held responsible for the hypothesized effects on the ten dependent variables. To test this, groups were asked to solve two short decision making tasks under two conditions: with and without technological support for the decision making process. These conditions were labeled ‘No GDSS’ and ‘GDSS’, and this terminology will be used throughout the remainder of this study.

A within-subject design was chosen to optimize the use of experimental subjects and to increase the statistical power of the analysis. Due to this within-subject design, two versions of the decision making task had to be developed, labeled Task A and Task B. Equally important was the balancing of the order in which the two experimental conditions and the two tasks were administered. The combination of all these factors provides four minimum combinations needed for a fully balanced design. The four minimum combinations of treatments, tasks, and ordering are shown in Table 3.1.

Table 3.1: Minimum combinations needed for a balanced design

First Condition	Second Condition
No GDSS / Task A	GDSS / Task B
GDSS / Task A	No GDSS / Task B
No GDSS / Task B	GDSS / Task A
GDSS / Task B	No GDSS / Task A

The number of replications used had to balance the statistical power of the tests of significance with the cost, time, and added complexity that a large number of replications add to the execution of the experiment. With this aim in mind, two complete replications of the four minimum treatment combinations listed above were used for data collection.

Table 3.2 shows the complete experimental design; a one-way within-subjects design balanced for the order of administration of the conditions and the order of the experimental tasks. Eight groups were used in the experiment, with the second four being a replication of the first four treatment combinations.

Table 3.2: The complete experimental design.

	Treatment 1	Treatment 2
Group 1	No GDSS / Task A	GDSS / Task B
Group 2	GDSS / Task A	No GDSS / Task B
Group 3	No GDSS / Task B	GDSS / Task A
Group 4	GDSS / Task B	No GDSS / Task A
Group 5	No GDSS / Task A	GDSS / Task B
Group 6	GDSS / Task A	No GDSS / Task B
Group 7	No GDSS / Task B	GDSS / Task A
Group 8	GDSS / Task B	No GDSS / Task A

Justification for experimental methodology

As shown in the previous chapter, the existing literature and previous research seem to indicate that technological support for decision making is a major moderating variable in the field of CSCW system design. In other words, GCSS and GDSS seem to affect group processes and group performance in similar ways for some variables and in opposite ways for others. This finding is an encouraging one, since it could provide a foundation for the development of a theoretical framework that better explains the role that technological support plays in the performance of distributed groups.

Unfortunately, these findings are based on comparisons made between studies. Although the existing evidence is consistent across a number of studies, there is a strong need for formal empirical research in controlled environments that directly compares different levels of technological support for the decision making process, and estimates the effect direction and magnitude on the relevant group process and outcome variables. Table 3.3 provides a summary of the research hypotheses and the expected effect directions.

Level of analysis and group size

The level of analysis in this research is at the group level. The performance of each group in the ‘No GDSS’ and ‘GDSS’ conditions was measured and analyzed by recording group-level measures only. Analysis of the effects of technological support for the decision making process on individual attitudes and performance were beyond the scope of this research. Participants were not required to provide authorization for individual level analysis in the informed consent.

Table 3.3: Summary of research hypothesis.

Dependent Variable	Predicted Effects
Group Process Variables	
Consensus	Increased (+)
Decision Time	Decreased (-)
Communication Efficiency	Increased (+)
Information Exchange	Increased (+)
Cooperation	Increased (+)
Decision Making Structure	Increased (+)
Task Related Outcome Variables	
Decision Quality	Increased (+)
Confidence in the Decision	Increased (+)
Group Related Outcome Variables	
Satisfaction with Group Processes	Increased (+)

As mentioned before, there was evidence indicating that group size could have an important effect on group performance. Since this research was not primarily concerned with the effects of group size this factor was held constant. This research used 3 person ad-hoc nominal groups. This size was found by Wolfe and Chacko (1983) to be the optimal size for medium-complexity business game tasks which involve decision making. Also, Wolfe and Chacko (1983) found that as group size increases there is an interaction effect between group process gains and losses which could introduce undesired effects into the current experiment if large group sizes are used.

Group structure

Sociotechnical system theory emphasizes the important role that organizational design plays in work system performance. Although the effect of organizational design on distributed group performance was beyond the scope of this study, the actual group structure used for data collection is important in interpreting and generalizing the results. Following is a description of the group structure used in terms of complexity, formalization and centralization.

Complexity

This study used groups of low organizational complexity. Complexity includes three sub-dimensions, which are horizontal differentiation, vertical differentiation, and size. The teams used had no vertical differentiation, in the sense that they were flat teams with no hierarchical component. Moderate horizontal differentiation was implemented in the form of slightly different roles. Although the roles implied different information available for each group member, the function that the members performed within the group were essentially the same. Finally, group size, which was discussed further above, was fixed at 3-person groups, which is considered a small group (Valacich, 1989).

Formalization

This study did not attempt to explicitly manipulate formalization. Formalization was dictated in great part by the structure imposed by the communication and decision support technologies used. In the 'No GDSS' condition formalization was low, with very little procedural structure imposed by the software. Group members were free to exchange information in any order they wanted, discuss the pros and cons of the alternatives, and vote on a final decision at their own pace. The introduction of a decision support package in the 'GDSS' condition imposed additional procedural structure on the group members due to the fact that the GDSS software elicited pairwise comparisons from members in a fixed order. Formalization under the 'GDSS' condition could be characterized as moderate.

Centralization

This study employed groups with high centralization in the sense that all decisions had to be arrived to by the whole group. The process by which centralization was achieved was democratic in nature, with all group's members having equal participation in the decision. Since there was no vertical differentiation there was no need to establish hierarchical decision-making schemes were the group's leader has a higher weight in the decision making process.

Data collection

Data needed

Two kinds if data were necessary for performing this study: primary and secondary data.

Primary data

The primary data needed for this research corresponds to each of the ten dependent variables. This data was obtained for each one of the two conditions each group was tested under.

Secondary data

Secondary data includes all the data necessary to control the experimental procedures. This included demographic information about the subjects, contact information, subject assignments to groups, times and dates for scheduled experimental sessions, and special codes to identify groups and subjects while guaranteeing confidentiality.

Admissibility of data

The criteria for admissibility of the data was designed to assure that no unintended bias was introduced in the experiment either by excessive variation in the control variables or improper manipulation of the independent variable.

Data was only considered admissible if the technology used for the experiment worked as described in this chapter. Problems with hardware or software that stopped the execution of the session or otherwise interrupted it for more than 5 minutes made the data inadmissible. In a similar fashion, experimental sessions which could not be completed due to the schedule of the participants or problems with forms, equipment, etc. were not included in the final data analysis. Only data which satisfied all the requirements stated in this section was admitted in the final analysis.

Although problems with data collection and equipment were encountered during the initial pilot testing, all but one of the experimental sessions were used in the final analysis. The experimental session in question was stopped and could not be completed due to a problem with the GCSS hardware. After these problems were corrected all the remaining data was collected successfully.

Methods of data collection

In order to collect empirical data, each research hypothesis had to be operationalized in the form of an experimental variable. With the exception of two, all hypotheses were operationalized into a single experimental variable. The two hypotheses with more than one experimental variable were consensus and decision quality.

Consensus was measured both subjectively (by averaging responses to a post experimental questionnaire addressing consensus, which is a common method for measuring this construct) and objectively (by calculating the degree of unanimity between group members). The two experimental variables for consensus were called perceived consensus (PC) and measured consensus (MC) respectively.

The quality of the decision making outcome was also measured in two ways. Decision accuracy (DQ) was measured by calculating a score according to the percent of correct answers of each group in each decision making task. Since time is usually a constraining variable in real world decision making, an overall efficiency of the decision making process was calculated by combining accuracy and time (DE). Following are more detailed descriptions of how experimental data was collected for each variable.

Group process variables

Perceived consensus (PC)

Perceived consensus was measured to determine the participants' perceptions as to what degree of unanimity existed in their decisions. This was addressed by a question in the post-treatment questionnaire (See Appendix B). Answers to the question by each participant were averaged to obtain an average perceived consensus for the group.

Measured consensus (MC)

Measured consensus was determined by examining the judgments made by each member of the group and calculating the Kendall's coefficient of consensus for each decision (Spillman et. al., 1980). The Kendall coefficient of consensus assigns a number from 0 to 1 to a group decision based on the unanimity of the group choices. A value of 1 indicates perfect unanimity, while a value of 0 indicates no unanimity at all. Since each task consisted of a number of smaller decisions, measured accuracy was operationalized as the average of the Kendall coefficient of consensus for each one of the discrete group decisions.

Decision making time (DT)

Decision time was logged by the experimenter during each experimental session in the Data Collection Form (See Appendix A8). Decision time was really a measure of process time, since there was no way to discern between time used for information exchange, for decision making, and for non-task-related communication.

Information exchange (IE)

The type of task used in this experiment had a fixed amount of discrete pieces of information that had to be exchanged by group members in order to solve each decision making problem correctly. Due to this design, amount of information exchange could be measured by simply counting how many of these discrete pieces of information were exchanged by the participants. Information was counted as exchanged once it was posted in its correct category in the Group Systems™ Software Categorizer tool. Verbally exchanged information was not counted since it did not have permanence and could not be used by group members during decision making.

Communication efficiency (CE)

Communication efficiency was not measured directly. Instead, this dependent variable was calculated by dividing the amount of communication exchange by the total amount taken to complete the decision making problem. So,

$$CE = \frac{CX}{DT}$$

Perceived cooperation (CO)

Degree of perceived cooperation was addressed by a question in the post-treatment questionnaire. Answers to the question by each participant were averaged to obtain an average perceived cooperation for the group.

Decision making structure (DS)

Degree of perceived process structure was addressed by a question in the post-treatment questionnaire. Answers to the question by each participant were averaged to obtain an average perceived degree of decision making structure for the group.

Task related outcome variables

Decision making accuracy (DA)

The task used for this experiment consisted of seven discrete multi-criteria decisions, each one of which had a predetermined correct answer. This type of design allowed for the degree of decision quality to be determined by looking at each group decision and comparing it with the correct result, and then calculating a percent of correct answers for the group.

So, decision quality was calculated as:

$$DQ = \frac{\sum_{i=1}^{7} Q_i}{7}$$

Were Q_i is a boolean variable representing whether or not the group obtained the right answer in question i.

Decision making efficiency (DE)

A measure of overall decision making efficiency was calculated based on the time constraints imposed on the participants. Participants were instructed to complete the decision making task as quickly as possible. Participants were also told that after the first 30 minutes there would be a 1/2-point penalty for every five minutes taken to solve the problem. There were two reasons for this calculation of decision efficiency. First, time is an important aspect of decision making, so a measure that combined decision quality and decision time was desired. Second, it was necessary for practical reasons to impose a time constraint on the participants and in some way control the duration of each data collection session.

Based on this constraint a decision efficiency score was calculated as:

$$DE = \frac{\sum_{i=1}^{7} Q_i}{7} - 0.5 \left(\frac{DT - 30}{5} \right)$$

Were Q_i is a boolean variable representing whether or not the group obtained the right answer in question i, and DT is the decision time

Confidence in the decision (CD)

Degree of confidence in the decision was addressed by a question in the post-treatment questionnaire. Answers to the question by each participant were averaged to obtain an average degree of confidence in the decision for the group.

Group-related outcome variables

Satisfaction with the group processes (SP)

Degree of satisfaction with the group processes was addressed by a question in the post-treatment questionnaire. Answers to the question by each participant were averaged to obtain an average degree of satisfaction with the group processes for the group.

The task

Overview of the global investment task

Groups were required to complete two short decision making tasks involving multiple criteria while interacting remotely through a CSCW system. The task was developed specifically for this research, and was designed to measure one specific aspect of group decision making: Multi-criteria decision making with distributed information.

The task was based on a global investment scenario. Group members had to rate three countries in a scale from 1 to 10 regarding the desirability to invest in a manufacturing operation in that country. Before being able to rate the countries, the group had to decide which was the best investment alternative in each country, from 3 alternatives (partner with a local company, buy an existing facility, or build a new manufacturing facility). Also, the group had to decide which was the best management alternative in each country, from two possible alternatives (local management or American management). So, each group was faced with seven decisions to complete the task.

Variations of the experimental task

Since a within-subject design was chosen, two variations of the task were needed. These two variations needed to be different enough to avoid learning effects, but similar enough to provide the same level of challenge and for their performance measures to be directly comparable. This was accomplished by using two different sets of countries, and completely different information for each set, while leaving the background and objectives of the task fixed. Table 3.4 shows the countries used for each variation of the experimental task.

Table 3.4: Countries used in each version of the global investment task.

Task 1	Task 2
Italy	Indonesia
United Kingdom	Mexico
Brazil	Germany

Both tasks were made equivalent in difficulty by using the same relative trade-off for countries in each task, but assigning the values to different types of information. Table 3.5 summarizes the seven decisions in version A of the experimental task. Table 3.6 shows the same information for Task B.

Table 3.5: The seven decisions that each group had to make to complete version A of the Global Investment Task.

Decision	Alternatives
1. Select best investment alternative in Italy	Partner Buy Build
2. Select best management alternative Italy	Local Management American Management
3. Select best investment alternative in the United Kingdom	Partner Buy Build
4. Select best management alternative in the United Kingdom	Local Management American Management
5. Select best investment alternative in Brazil	Partner Buy Build
6. Select best management alternative in Brazil	Local Management American Management
7. Rate the countries in a scale from 1 to 10	Italy United Kingdom Brazil

Table 3.6: The seven decisions that each group had to make to complete version B of the Global Investment Task.

Decision		Alternatives
1.	Select best investment alternative in Indonesia	Partner Buy Build
2.	Select best management alternative Indonesia	Local Management American Management
3.	Select best investment alternative in the Mexico	Partner Buy Build
4.	Select best management alternative in the Mexico	Local Management American Management
5.	Select best investment alternative in Germany	Partner Buy Build
6.	Select best management alternative in Germany	Local Management American Management
7.	Rate the countries in a scale from 1 to 10	Indonesia Mexico Germany

Participant roles

Each group member was randomly assigned a role. The role determined what type of information the participants would have regarding each of the decisions to be made by the group. The roles and the information that was available to each role are listed in Table 3.7.

Since each role had access to a particular type of information, only by sharing all information with group members could each decision be made correctly. In order to make the decision making challenging, each piece of information was assigned a level of importance. Participants had to weight the importance of the information provided by their group members in order to make a decision.

Table 3.7: Roles for the Global Investment Task, and the information that was available to each role.

Task Force	Information Available
Financial Task Force:	Financial information about each alternative and the financial climate in each country.
Industrial Task Force:	Industrial risks and benefits of each alternative and the industrial climate for each country.
Political Task Force:	Political risks and benefits for each alternative and the political climate in each country.

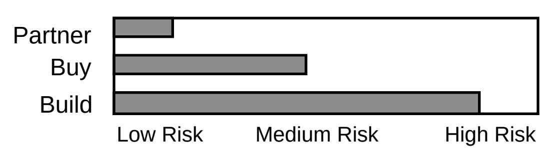
Data sheets

For each variation of the task each participant was given a data sheet. Participants had to share the information in their data sheets with the other group members before attempting to make a decision. Information was portrayed in the data sheets both textually and graphically. An example of the format used to portray information in the data sheets can be seen in Figure 3.1. For a complete copy of the experimental data sheets see Appendix A.

Italy

1. Select Investment alternative:

- The **Industrial Risk** associated with each investment alternative is given in the table on the right.
- The industrial risk of each investment alternative has a **low importance**.



Industrial Risk of Investment Alternatives

Figure 3.1: An example of the format used to portray information in the data sheets for the experimental task.

Subjects

Subjects for this experiment were recruited from undergraduate and graduate classes in the Industrial and Systems Engineering Department. A total of 33 subjects were used, with nine subjects used during pilot testing and 24 used for the main experiment. Participation was fully voluntary, but students in the undergraduate class could use their participation in the experiment in place of two class assignments. A total of 18 undergraduate students and 15 graduated students were used.

Subject selection criteria were minimal. Subjects needed a basic understanding of computer use, in particular the Microsoft Windows 95 operating system, in order to properly use the software required for the experiment. All students contacted fulfilled the criteria without a problem, probably due to the high use of computers in the College of Engineering at Virginia Tech. Subject criteria was enforced informally by observing subjects during the practice task to guarantee they had the required skills. None of the potential subjects contacted had to be dismissed due to failure to meet the subject selection criteria. Table 3.8 summarizes the subject selection criteria.

Table 3.8: Subject selection criteria

Criteria	Requirements
Age	No Restrictions
Gender	No restrictions
Education	Undergraduate and Graduate students from the Industrial and Systems Engineering Department
Computer Literacy	Subjects were required to have a basic understanding of the use of personal computers. Familiarity with the Windows™ operating system was also desired.

Facilities and equipment

Facilities

Data collection facilities

This experiment required the simulation of a distributed group, in which group members are geographically dispersed. This environment was simulated in the Usability Methods Research Laboratory (UMRL) located in McBryde 104 and operated jointly by the Computer Science and the Industrial and Systems Engineering Departments. Subjects were placed in three adjacent but acoustically insulated rooms (104a, 104b, and 104c). Each room was equipped, as will be described below, with the necessary equipment and software to interact via audio, video, text, and to use the GCSS and GDSS packages. Room 104c was also used for pre-experimental instructions and for providing instructional material.

Support facilities

In addition to the three experimental rooms used by the subjects, a fourth room (actually the hallway connecting all three rooms mentioned above) was used for the researcher to observe the participants and moderate the meeting. Room 102, also part of the UMRL Lab, was used to house the file and video-conferencing servers needed for the experimental set-up.

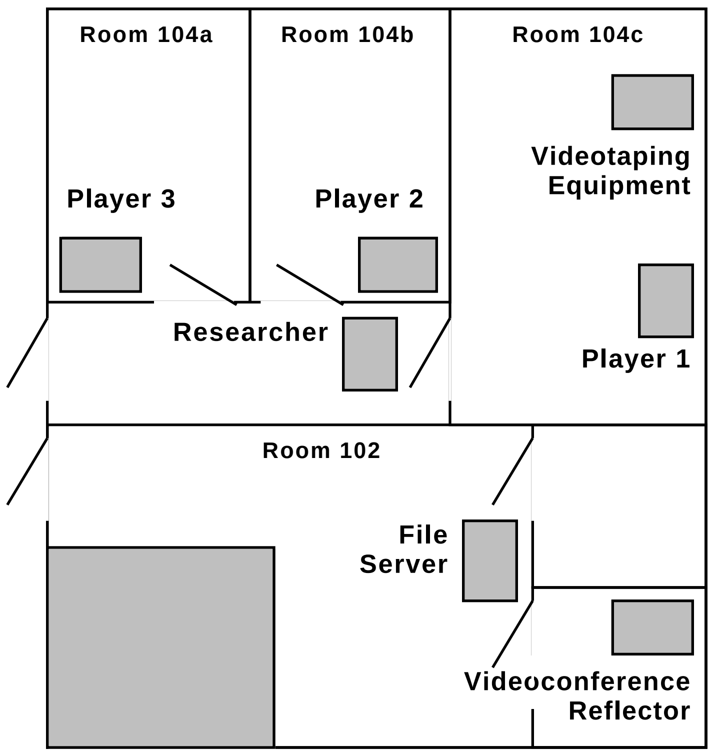


Figure 3.2: Facility layout used for data collection showing the location of workstations and other equipment.

Figure 3.2 shows the layout used for the experiment. Figure 3.3 shows an overall view of the main data collection facility (UMRL 104c).

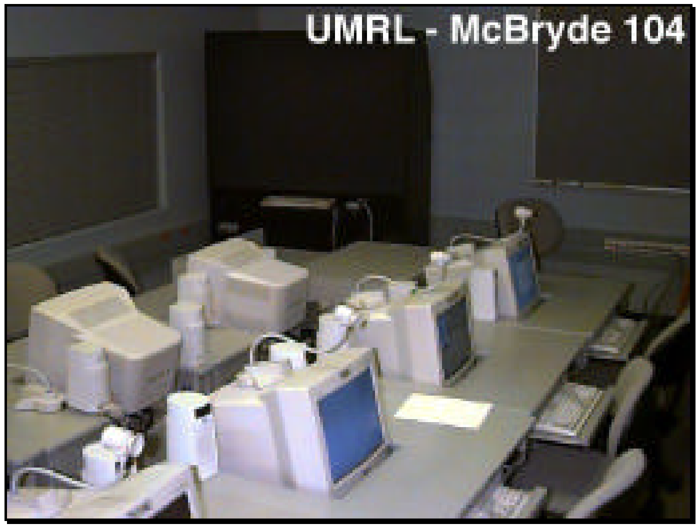


Figure 3.3: Overall view of the Usability Methods Research Laboratory (McBryde 104c)

Equipment

Computer workstations

The experimental design and the degree of technological support for group processes dictated a number of computer equipment requirements. These requirements could be further classified into equipment directly related to group member support, and additional equipment needed for file and videoconference servers.

Participant workstations

In order to provide each participant with the necessary communication channels (audio, video, and text) and with the prescribed GCSS and GDSS systems, each participant was randomly assigned a Gateway® G5-200™ Personal Computer running the Microsoft® Windows '95™ operating system. Table 3.9 shows the general configuration of these participant workstations.

The moderator used a computer configured in the same manner as the participant workstations to be able to monitor the tasks and moderate the group activities. Video-tapping of the experimental data collection was performed using a fifth workstation, also configured in the same manner. So, a total of five computers configured as shown in the first column of Table 3.9 were used.

Table 3.9: Configuration of the two types of computers used during data collection

	Participant and Moderator Workstations (5)	Reflector and File Server Workstations (2)
Manufacturer	Gateway	Gateway
Model	G5-200	G6-200
Processor	Pentium MMX	Pentium Pro
Speed	200 MHz	200 MHz
Memory	32 Mb	64 Mb
Hard Disk	2 Gb	4 Gb
Network	10 Mb/sec 10baseT Ethernet (PCI)	100 Mb/sec 10baseT Ethernet (PCI)
Operating System	Windows '95 Release 2	Windows NT 4.0

Server workstations

For the video-conferencing reflector a much more powerful computer workstation was needed. A Gateway® G6-200 Personal Computer running the Microsoft Windows NT operating system was used to run the video-conferencing reflector. The video-conferencing reflector was needed to allow more than one person to communicate through videoconferencing simultaneously. The more powerful workstation was necessary in order to provide the extra computational power required to receive and transmit video signals to and from each participant. A similarly equipped computer was used as a File Server to provide the participants' computer workstations with shared disk space. All information needed by the group support and decision support software was stored in this shared drive. The second column of Table 3.9 shows the configuration of the Reflector and the File Server workstations.

Network set-up

Computers were connected to the Virginia Tech Network via Twisted-Pair 10base-T ethernet media. Each computer was connected to an individual ethernet outlet capable of up to 100 Mb / sec. data transfer rates. Gateways and routers maintained by the Virginia Tech Computing Center were used to limit foreign traffic, thereby reducing congestion in the network lines used for the experiment.

Individual participant and moderator workstations were limited to a 10 Mb / sec. communication bandwidth due to the design of their PCI ethernet adapters. On the other hand, both the File Server and Videoconferencing Reflector workstations were equipped with 100 Mb / sec. ethernet adapter cards, avoiding communication bottlenecks and increasing overall performance when more than one participant workstation was accessing either one of these servers.

Figure 3.4 shows the file server workstation and the videoconferencing reflector. Figure 3.5 shows the three participant workstations and the moderator station.

Figure 3.4: File server (left) and Videoconferencing Reflector (right)

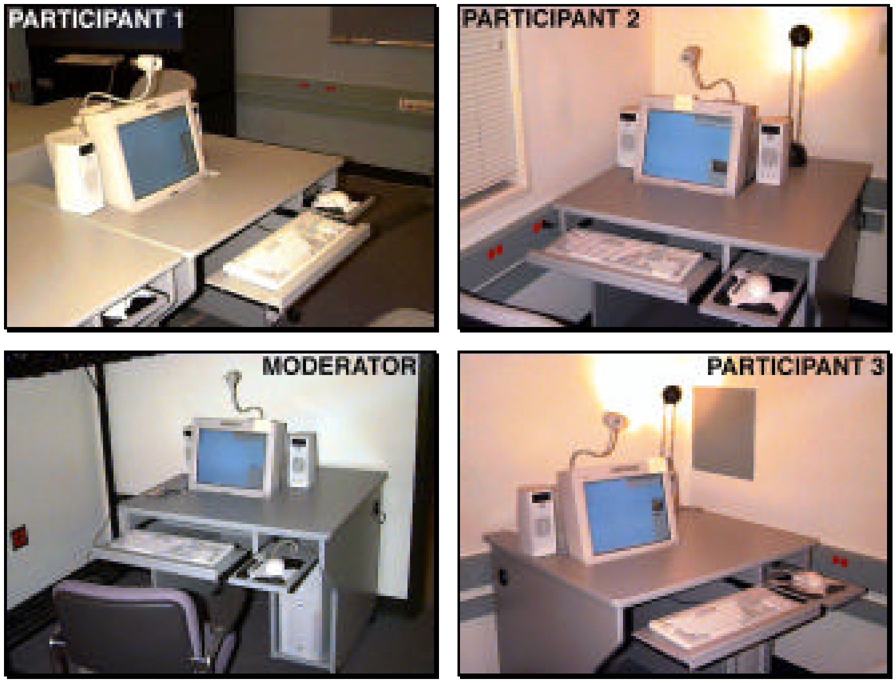


Figure 3.5: Workstations used in this research. Clockwise from the upper left: Participant 1, Participant 2, Participant 3, and Moderator

Figure 3.6: The video recording workstation (in the foreground) and the Xerox LiveBoard™ (background).

Other equipment

Another computer workstation was used to videotape the experimental data collection sessions. This computer workstation was connected to the reflector and set up to display the video images from the three participants. The video signal from the computer was fed to a VHS Video Cassette Recorder via a digital-to-analog converter. A Xerox LiveBoard™ was used as a projection screen to show training material to the participants. Figure 3.6 shows the Xerox LiveBoard™ and the video-recording station.

Software

Distributed groups require by definition a certain degree of technological support to bridge the geographical distances that separate group members. So, both experimental conditions (‘No GDSS’ and ‘GDSS’) required some baseline level of technological support in order to establish sufficient information channels for information to be exchanged and analyzed. This information ‘pipeline’ was established in two ways. First, group members had at their disposal audio and video communication through the use of a video-conferencing software. Also, the groups had access to text based communication through the use of a Group Communication Support System (GDSS) software package.

Besides the software packages necessary to establish a communication ‘pipeline’, a third software package was used to implement the experimental treatments. When under the ‘GDSS’ condition groups had access to the Team ExpertChoice™ software package in addition to the GCSS and videoconferencing software. Each software package is described in more detail below.

Videoconferencing

In order to fulfill basic interaction and communication needs, group members needed the capability to communicate with one another. Group members had access to videoconferencing to provide audio and video communication capabilities. With the software and hardware used the videoconferencing system was capable of a nominal refresh rate of 10 frames per second, displaying an image at a resolution of 160 x 120 pixels at 16 bits per pixel (thousands of color levels). Audio was recorded at 44 MHz and digitized to monophonic CD quality (16 bits, single channel).

Videoconferencing was implemented using the CUSeeMe™ software package, developed by Cornell University as a freeware software, and then licensed to WhitePine© Software who developed the commercial version used in this experiment. The latest commercial version available that was compatible with the hardware and software used in this experiment was version 2.1.1. This version allowed a number of participants to communicate through audio and video using a computer network.

In order to allow more than two group members to communicate simultaneously, a WhitePine© Reflector™ was used. The WhitePine© Reflector™ complements the CUSeeMe™ package by creating a distributed conference into which a two or more people can communicate in real time. The latest version of the CUSeeMe™ package was 2.1 for Windows NT™. Figure 3.7 shows a sample CUSeeMe™ screen (from the training video).

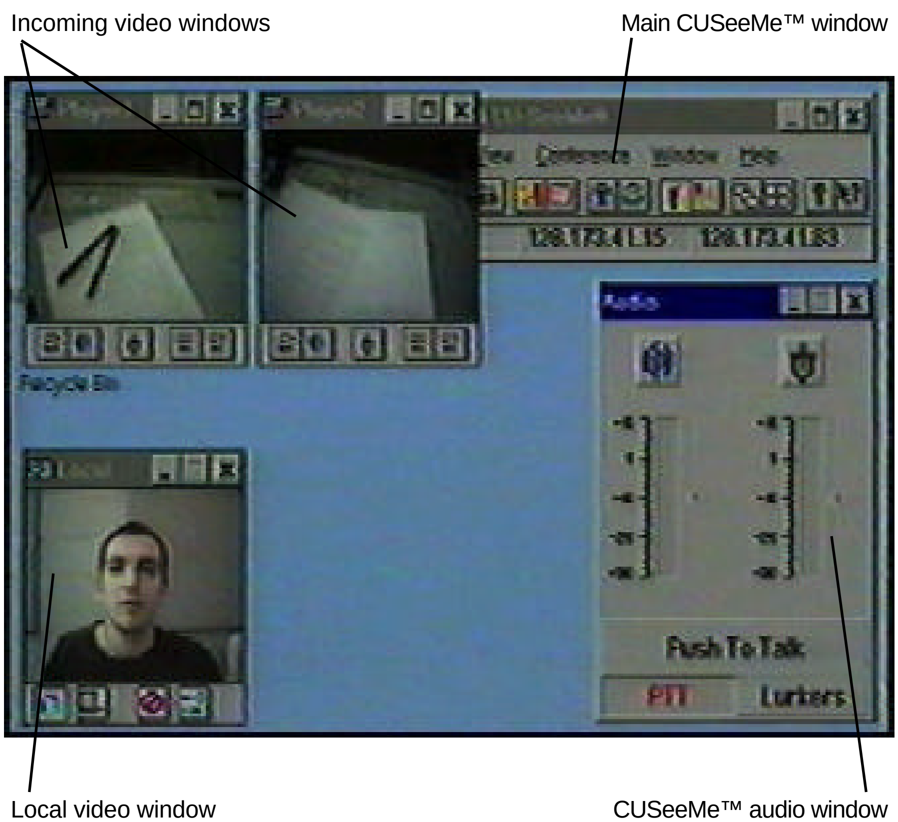


Figure 3.7: Sample screen of the CUSeeMe™ videoconferencing package showing the audio window and two incoming video signals.

Group Communication Support System

Group communication support was provided by using a Group Communication Support Package by Ventana Corporation: Ventana© Group Systems™. The Group Systems™ software was provided by Ventana© Software to the MGDSL lab under a special 50-user research license. The Group Systems™

package provides support for the communication process of a group with a number of communication tools.

First, Group Systems™ provides the group with an electronic agenda. An electronic agenda is a series of ordered activities the group will execute together. By providing the group with an organized list of activities, the group can stay organized and synchronized through the execution of these activities.

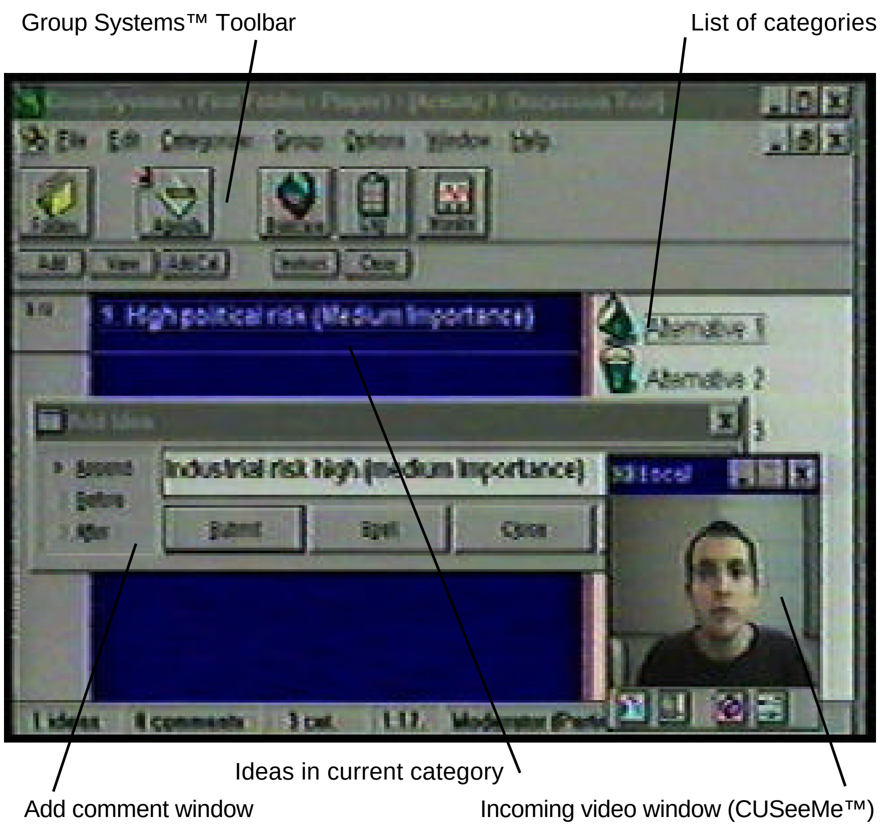


Figure 3.8: Sample screen of a discussion using the Categorizer tool from Ventana© Group Systems™.

Another tool provided by the Group Systems™ package was the discussion tool. Also called the Categorizer Tool in the Group Systems™ documentation, this tool allows group members to share information about a number of topics by posting the information in the form of text in pre-defined categories that every member of the group can examine at will. Besides providing a text-based communication channel, this tool provides communication support by organizing the information-exchange process. Figure 3.8 shows a sample screen from a discussion using the Categorizer tool from Group Systems™.

Finally, when operating under the ‘No GDSS’ condition group members took advantage of the Group Systems Voting Tool. Although not a decision support tool, the voting tool allows group members to express their opinion regarding a number of alternatives in an organized manner. The program automates the logging of ideas, collection of votes, and aggregation and reporting of results. Under the GDSS conditions the Team ExpertChoice™ package described above replaced the Group Systems Voting Tool as the way in which group members expressed their judgments. Figure 3.9 shows the voting screen from Group Systems™.

Although voting appears to support the decision making process, it only assists in the communication and aggregation of opinions. Each individual group member still needed to arrive at a decision on its own. For this reason simple voting tools were not considered decision support tool. Figure 3.10 shows the Results window were results from a group vote are displayed numerically and graphically.

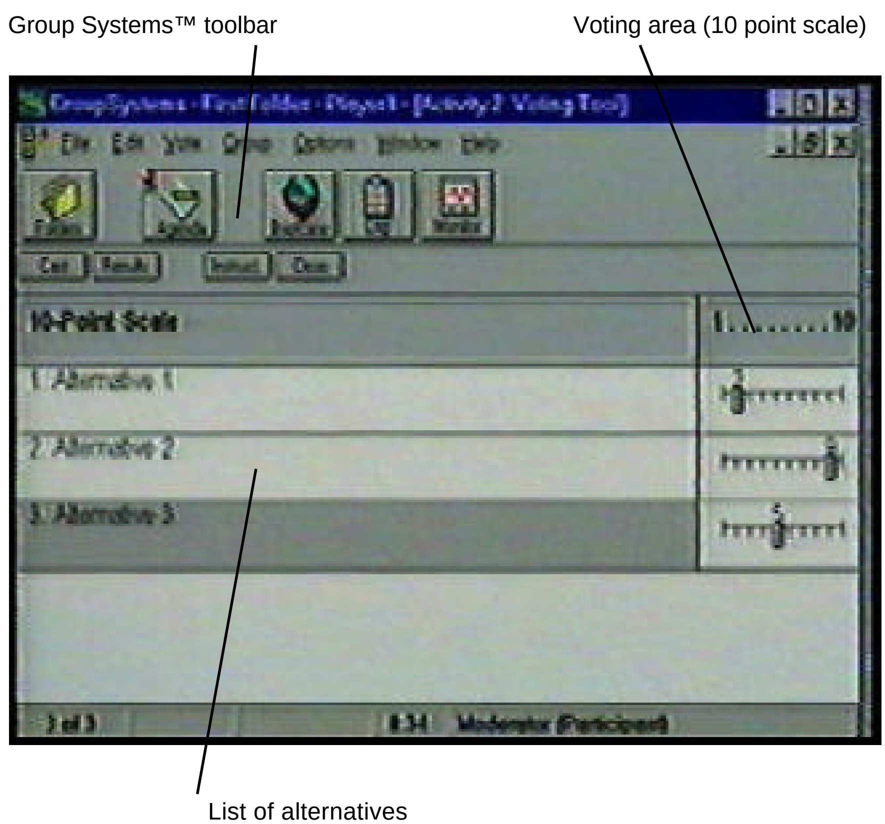


Figure 3.9: Group Systems™ voting window as used during this experiment.

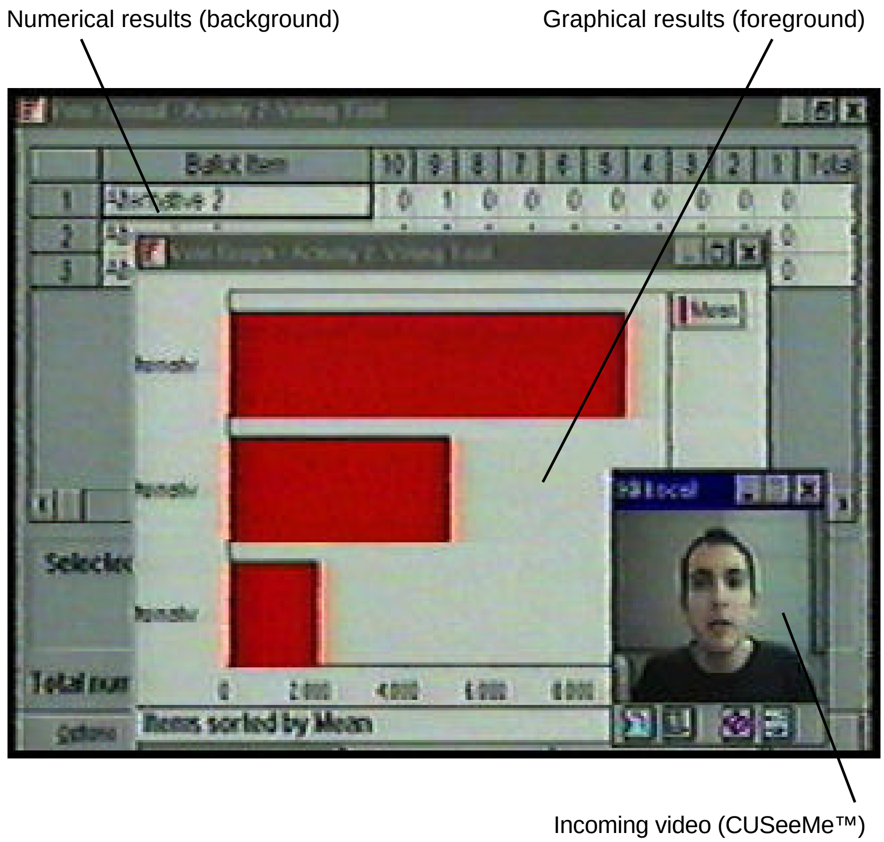


Figure 3.10: Group Systems™ Result window, graphically showing the results of a voting session.

Group Decision Support System

The main independent variable in this research experiment was the level of technological support for the decision making process. To operationalize the level of decision support a Group Decision Support System (GDSS) software package was used during the 'GDSS' condition. The software package employed was Team ExpertChoice™. The Team ExpertChoice™ software package was provided by ExpertChoice© Inc., under a special research license.

The Team ExpertChoice™ package is a software implementation of Analytical Hierarchy Process (AHP) as described in Chapter 2, with a user-friendly, menu-driven interface. The most recent version of the software, Team ExpertChoice™ version 9.0, was designed to run under Microsoft Windows 3.11 or Microsoft Windows 95 operating system. Team ExpertChoice™ provides the means for individuals or groups to apply the AHP without having to deal with the underlying mathematical computations involved, or needing extensive training on the Analytic Hierarchy Process itself.

The ExpertChoice™ software package supports the decision making process of a group by modeling the decision in the form of a logical tree. In its simplest form, a logical tree consists of a number of alternatives, and a number of criteria by which the alternatives will be judged. Figure 3.11 shows an example of a Team ExpertChoice™ model as it was used during this experiment.

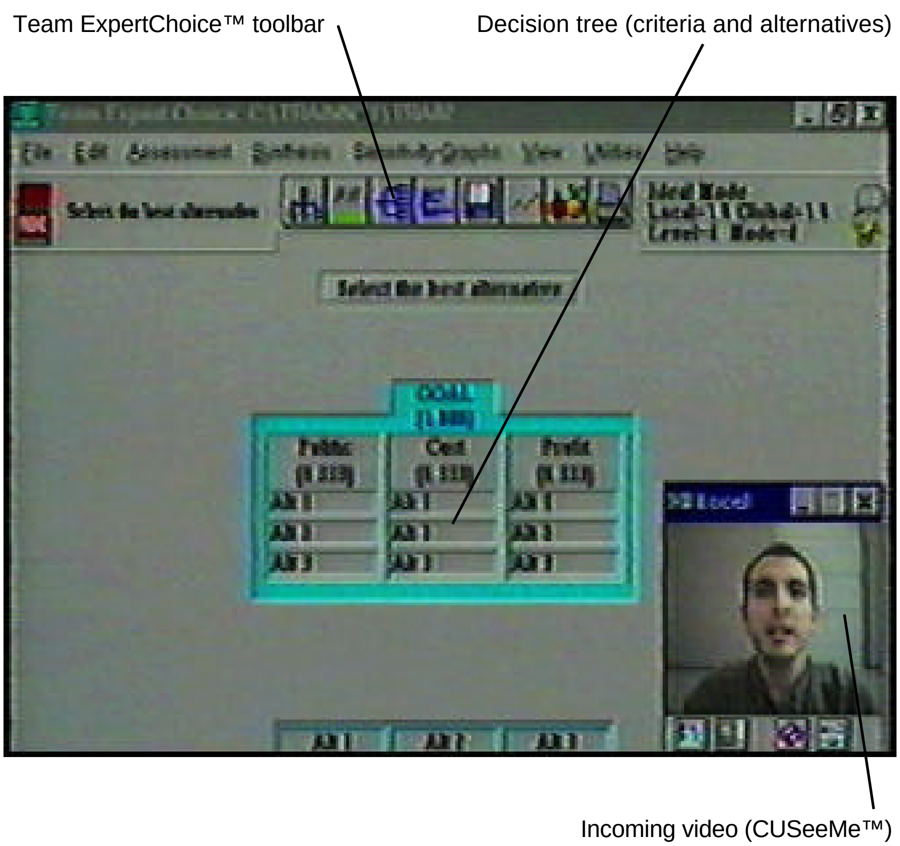


Figure 3.11: A view of a multi-criteria decision represented in Team ExpertChoice™ as a logical tree.

Once a decision model is available for a particular decision, Team ExpertChoice™ further supports the decision making process by identifying an optimal decision based upon a set of information provided by the users. Team ExpertChoice™ gathers information by eliciting judgments from the group's members regarding pairs of criteria or alternatives. This process, pairwise comparisons, supports the decision making process by simplifying each decision that group members need to make. By simplifying the decision process participants are less prone to error and to the limitations of human information processing capabilities.

ExpertChoice™ provides a number of interface enhancements that further facilitate the use of the AHP. For example, pairwise comparisons can be made either verbally, numerically, or graphically. Figure 3.12 shows the way Expert Choice implements the graphical comparison mode, which was the type of comparison used in this experiment.

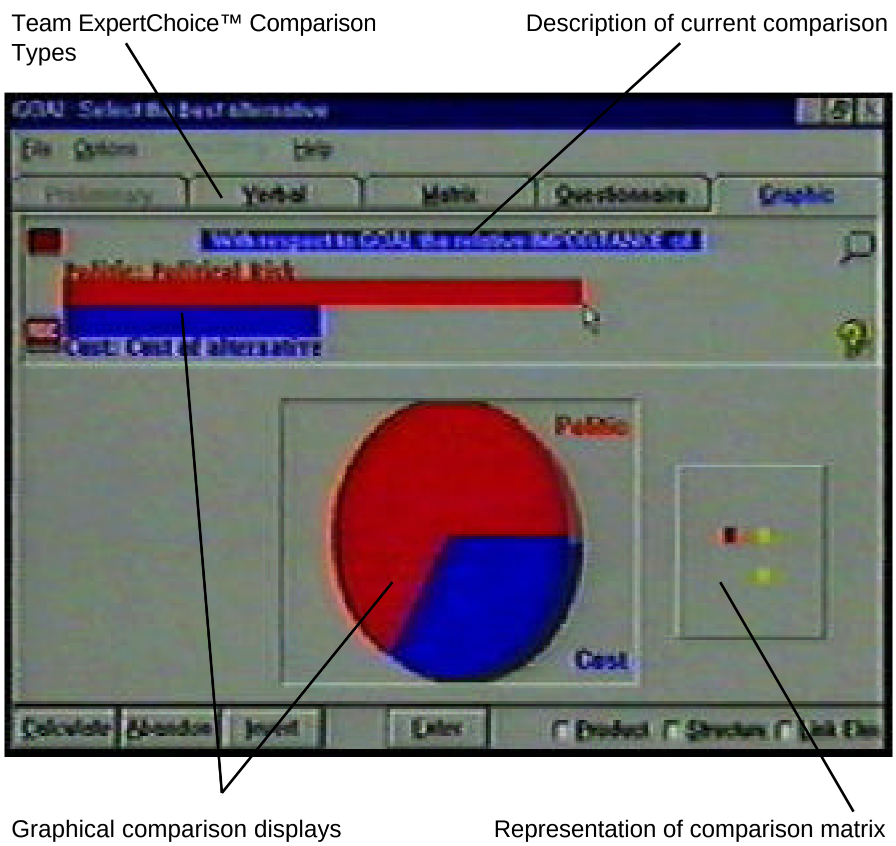


Figure 3.12: Team ExpertChoice™ graphical comparison method to collect participant judgments about criteria and alternatives.

Finally, Team ExpertChoice™ automates the decision making process by aggregating the judgments entered by all group members into a final group decision. Figure 3.13 shows the Team ExpertChoice™ Alternative selection window, where the judgments of all group members for all alternatives are combined.

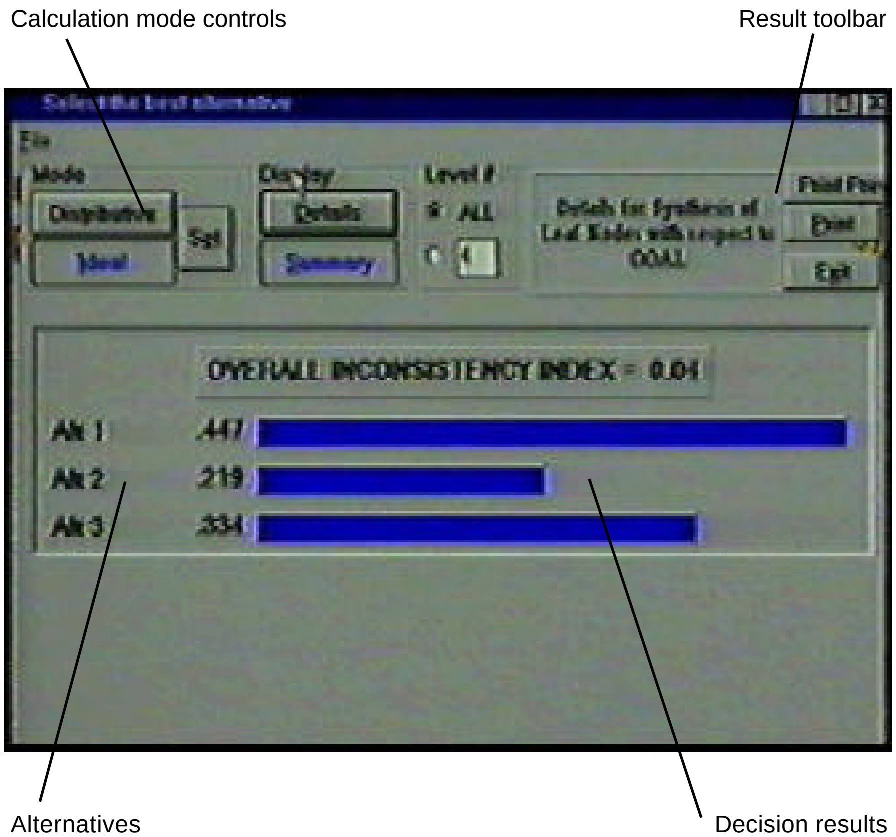


Figure 3.13: Alternative selection window in Team ExpertChoice™ showing the result of a group decision-making session.

The level of decision making support was operationalized using the Team ExpertChoice™ software package. In the 'No GDSS' condition group members had to solve a multi-criteria decision-making problem without the help of the Team ExpertChoice™ software. In the 'GDSS' condition groups had to solve a similar problem, this time with the help of the Team ExpertChoice™ software.

Software tool summary

To summarize, these were the software tools available in each of the experimental conditions:

No GDSS

This condition corresponds to distributed nominal groups performing a decision making task without technological support for the decision-making process. A communication 'pipeline' was established by providing audio, video, and text communication channels. Audio and video support was provided in the form of desktop video-conferencing software (WhitePine© CUSeeMe™). Text-based communication and communication support was provided by Group Communication Support Software, or GCSS (Ventana© Group Systems™).

GDSS

This condition corresponds to distributed nominal groups performing a decision making task with technological support for the decision making process. As with the 'No GDSS' condition, A communication 'pipeline' was established by providing audio, video, and text communication channels. Audio and video support was provided in the form of desktop video-conferencing software (WhitePine© CUSeeMe™). Text-based communication and communication support was provided by Group Communication Support Software, or GCSS (Ventana© Group Systems™). In addition, support for the decision making process was provided in the form of group decision support software , or GDSS (ExpertChoice© TeamEC™).

Procedures

Training

The level of technological support for different group processes required the use of a number of software packages, as mentioned above. In order to provide participants with at least a working knowledge of the different programs and the way they would be used in the experiment, a comprehensive training component was included as part of the experiment. This training component consisted of a 15 minute training video and two short practice sessions before each experimental condition.

Software training video

A training video was developed to train the participants in the use of the software packages. Video was used for training in order to show the participants exactly what they would see when performing the experimental task. The video also allowed to standardize the training procedures between data collection sessions. Although the video did not cover every available feature, it provided the subjects with a general understanding of the use of the software.

The training video, which lasted approximately 15 minutes, made extensive use of multi-media technology to enhance the learning experience of the subjects. The participants were able to see each actions being executed while receiving visual and audio cues from an on-screen video image of the investigator.

The training video covered the basic operation of the CUSeeMe™ videoconferencing package, the Group Systems™ GCSS package, and the Team ExpertChoice™ GDSS package. As mentioned above, the video presented the exact same screen configuration that the participants used during the experimental task. The training video was shown on a Xerox LiveBoard™ unit, which had a 36 inch projection screen. Figure 3.14 is a multi-media movie object of the training video (requires QuickTime™ 2.5 or higher from Apple Computer Inc.© to view).

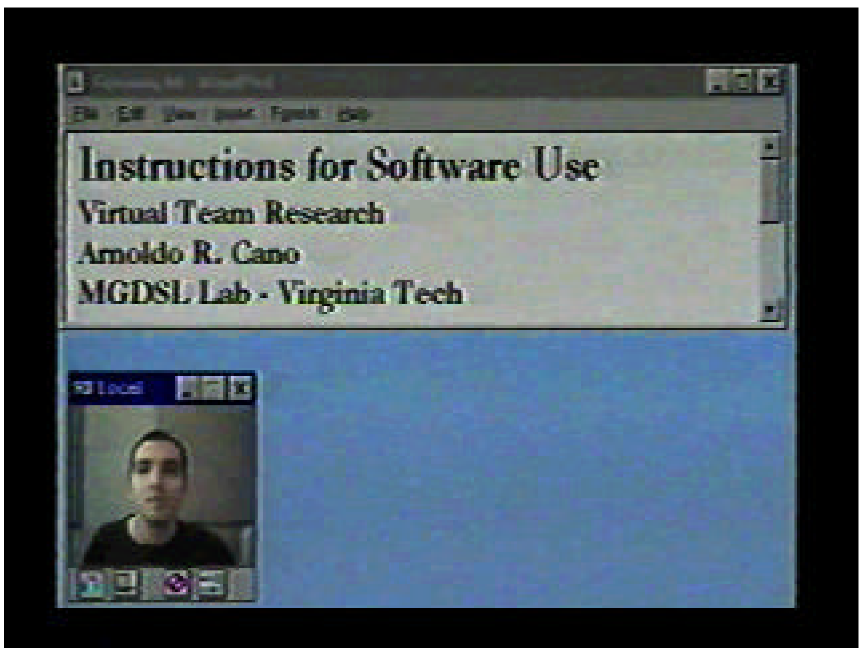


Figure 3.14: Quicktime movie clip of the first section of the training video for the experimental task (double-click to play movie. Requires QuickTime™ 2.5 or higher from Apple Computer Inc.© to view).

Practice tasks

Each group also completed two short practice tasks, one before each experimental condition. The practice task was modeled after the experimental task, and further familiarized the subjects with the software and the experimental procedures.

Before each treatment condition participants completed the short training exercise. These training exercises used a decision making task and software configuration analogous to the ones used in the data collection sessions. The practice task allowed subjects to familiarize themselves with the decision scenario and the software tools prior to the beginning of the data collection. It also gave subjects an opportunity to clarify any issues related to the task or the software. The investigator was available to answer questions during the training exercise.

Experimental procedure

Eight data collection sessions were needed to collect the necessary data for this experiment. Groups of three volunteer students were randomly assigned to each data collection session. The students were asked to meet in room 104c in the McBryde Building of the Virginia Tech's Blacksburg Campus. After greeting the students, the data collection session started. Each data collection session was organized in the following manner:

First, each participant was administered an informed consent form (see Appendix B1). The informed consent form explained the purpose and objectives of the study, and explained the rights of the participants. Each subjects was allowed to withdraw from the experiment before signing the informed consent, or at any time afterwards, without penalty. Once the subjects read and signed the informed consent form these were collected by the researcher.

After completing the informed consent, each participant was administered the pre-experimental questionnaire (see Appendix B2). The pre-experimental questionnaire was used to measure a number important demographic statistics relevant to this study. The variables measured in the pre-experimental questionnaire were: Academic status, computer experience, videoconferencing experience, GCSS experience, GDSS experience, and experience working with the other members of the group. Once the students completed the pre-experimental questionnaire these were collected by the researcher.

At this point the subjects were asked to arrange themselves in room 104c to watch the software training video, which had a duration of approximately 15 minutes. The software training video had three main sections, which described the use of the videoconferencing software, the GCSS software, and the GDSS software, respectively. The researcher stopped the video between each section to allow the subjects to ask questions. All questions about a particular software package were answered before moving on to the next section of the video.

Once the training video was completed the researcher proceeded to randomly assign each participant to one of the three roles and one of the three experimental workstations. Experimental background and definitions (Appendix A1 and A2) were given to each participant according to their assigned roles. These two handouts explained the nature of the experimental task and the format in which data was portrayed in the experimental data sheets. Once the subjects finished reading the background and definition handouts the researcher asked for any last questions or clarifications which may be needed.

At this point subjects began the practice for Treatment 1 (see Appendix A3). This practice run represented a decision equivalent to one of the seven decision the team would have to make in the actual experimental task. Also, the participants used the same software they would use in their first treatment. Subjects were at this point performing exactly as they would during the real data collection. Subjects were given all the time necessary to complete the practice run and ask any questions they may have.

After completing the practice for Treatment 1 the experimental data sheets were handed out (see Appendix A4 and A5) according each subject's role. Each participant was also given a participant log to keep track of the group's decisions and to use a scrap paper for any information the participants considered useful or important. The researcher logged the start time for treatment 1 in the experimental log, and data collection began. The group completed the first experimental task once all seven questions of the task were answered. Then, the researcher logged the finish time for the first treatment in the experimental log. All the data sheets and participant logs were then collected by the researcher.

Once the first treatment was completed the researcher administered the first post-treatment questionnaire (see Appendix B3). This questionnaire was used to measure a number of subjective dependent variables. These variables were: perceived consensus, perceived cooperation, perceived structure of the process, confidence in the decision, and satisfaction with the group process. Once the participants completed the post-treatment questionnaires these were collected by the researcher.

Treatment 2 was completed in the same manner as Treatment 1. It began with a practice run (see Appendix A3) which was completed using the same software the subjects would use during the actual data collection. Once the practice run for Treatment 2 was completed and all questions were answered the experimental data sheet and participant logs were handed out and the actual data collection began for Treatment 2. As with treatment 1, the researcher logged the start and finish time in the experimental log.

After completing Treatment 2, subjects were asked to complete a second post-treatment questionnaire, which measured the subjective dependent variables mentioned above. After completing the post-treatment questionnaire these were collected by the researcher and the subjects were dismissed.

Figures 3.15 shows a sample from the experimental tapes kept for each experimental session. The tapes captured the video signal for each participant, plus the complete audio signal for all three participants and the moderator. The moderator did not broadcast video to the participants, so his video signal was not recorded.

Figure 3.15: Sample of actual experimental session as recorded in the experimental tapes.

Chapter 4. Results

Demographics

A number of demographic variables were collected before the beginning of each experimental session in order to have a clear picture of the level of experience of the subjects with the technologies used in the experiment, and of the level of education and group experience. Information was collected from six important areas. The pre-experimental questionnaire used to collect this information is included in appendix B.

Academic status

The academic status of the participants was collected to estimate the educational level of the participants. The educational level of the participants is important to determine external validity. The results of this experiment are based on a well educated sample population. Figure 4.1 shows a histogram of academic status for the 24 subjects that participated in this experiment. The mean academic level was 3.417, with a standard deviation of 0.881. It is important to note that the 15 undergraduate subjects were randomly assigned to groups (5 groups), as were the nine graduate students (3 groups). The undergraduate groups were compensated with extra credit while the graduate groups volunteered for the experiment. Due to the within subject design there was no need to randomize treatments between undergraduate and graduate groups.

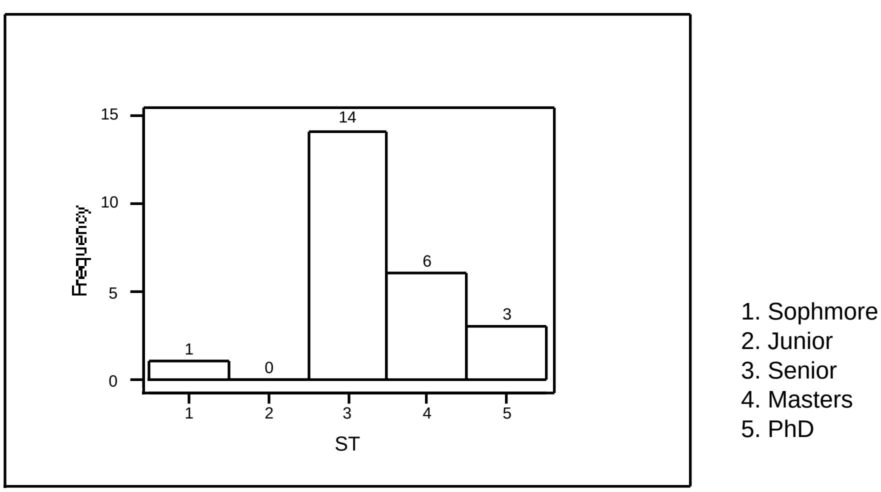


Figure 4.1: Histogram for the academic status of the experimental subjects.

Computer experience

The computer experience of the subjects was collected in order to understand how this variable may affect computer efficacy and performance. Figure 4.2 shows a histogram of computer experience for the 24 subjects that participated in this experiment. The mean academic level was 4.333, with a standard deviation of 0.637.

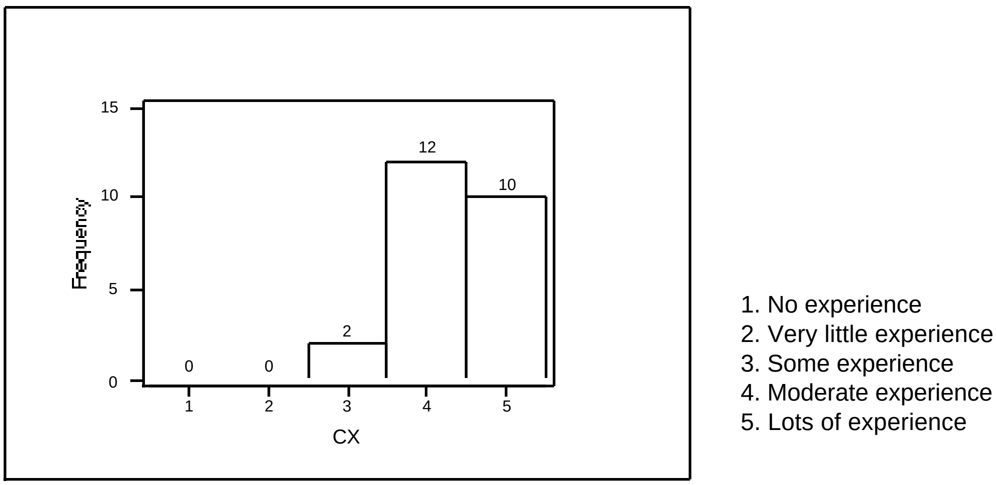


Figure 4.2: Histogram for the general computer experience of the experimental subjects.

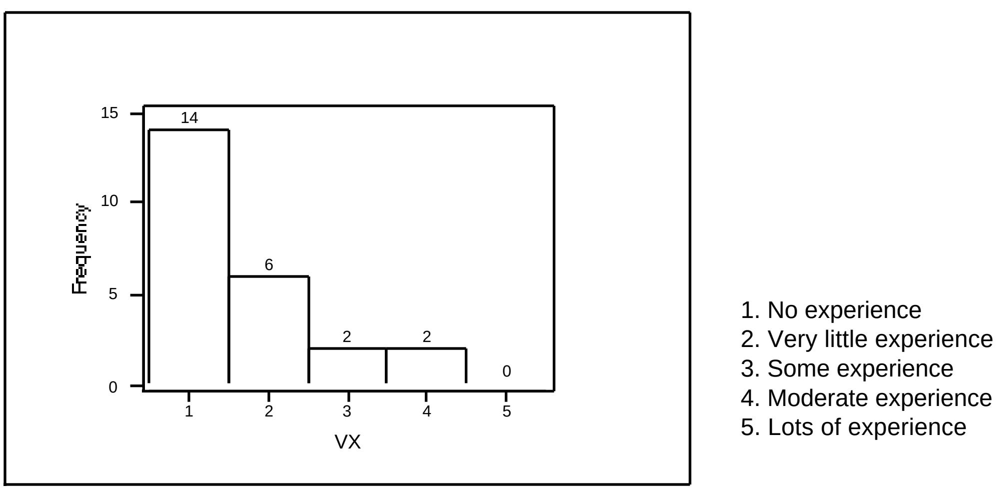


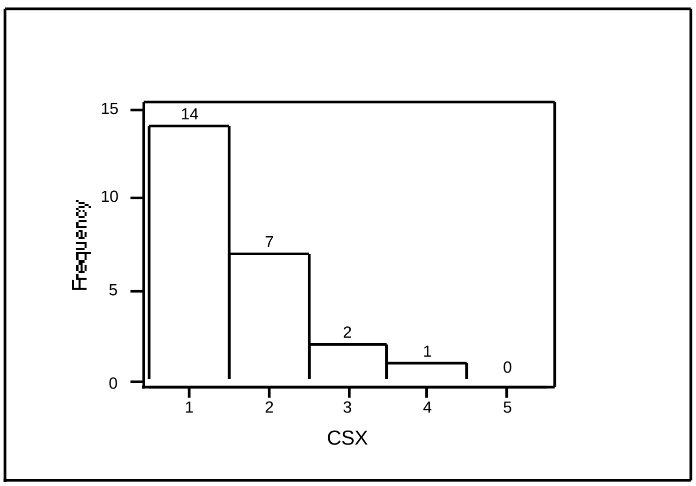
Figure 4.3: Histogram for the subjects' experience with videoconferencing hardware and software.

Videoconferencing experience

The experience of the subjects with videoconferencing software and hardware was collected in order to understand how this variable may affect video conferencing self-efficacy and performance. Figure 4.3 shows a histogram of videoconferencing experience for the 24 subjects that participated in this experiment. The mean videoconferencing experience was 1.667, with a standard deviation of 0.963.

GCSS experience

The experience of the subjects with Group Communication Support Software was collected in order to understand how this variable may affect attitudes and performance. Figure 4.4 shows a histogram of GCSS experience for the 24 subjects that participated in this experiment. The mean GCSS experience was 1.583, with a standard deviation of 0.830. GCSS experience was slightly higher than the experience with both videoconferencing and GDSS. This can be explained by the broad definition of GCSS systems, which include e-mail and chat software.

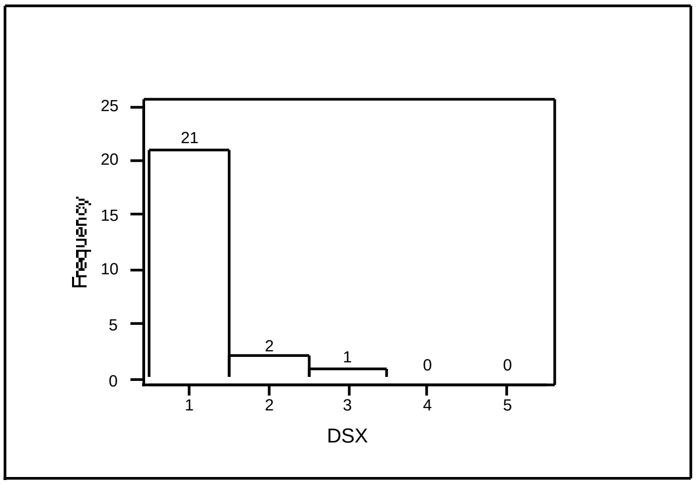


1. No experience
2. Very little experience
3. Some experience
4. Moderate experience
5. Lots of experience

Figure 4.4: Histogram for the subjects' experience with Group Communication Support Software.

GDSS experience

The experience of the subjects with Group Decision Support Software was collected in order to understand how this variable may affect attitudes and performance. Figure 4.5 shows a histogram of GDSS experience for the 24 subjects that participated in this experiment. The mean GDSS experience was 1.1667, with a standard deviation of 0.4815.



1. No experience
2. Very little experience
3. Some experience
4. Moderate experience
5. Lots of experience

Figure 4.5: Histogram for the subjects' experience with Group Decision Support Software.

Group experience

The experience of the subjects working together as a group was collected in order to understand how this variable may affect attitudes and performance. Figure 4.6 shows a histogram of group experience for the 24 subjects that participated in this experiment. Since the experience reported by the subjects was different for each subject even within the same group, group experience is reported here individually. The mean group experience was 2.917, with a standard deviation of 1.100.

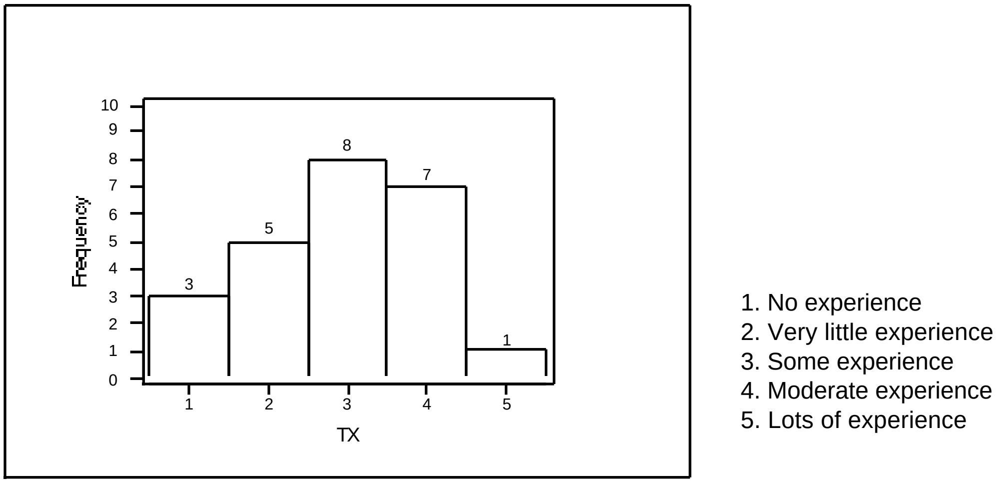


Figure 4.6: Histogram for the experience of the subjects working together as a group.

Tests for undesired effects

Task differences

Due to the within-subjects design of this experiment, two versions of the task had to be created. Although the two versions were balanced across treatment conditions, it was desired the two versions of the task shared equivalent levels of difficulty. In order to confirm the tasks were indeed equally difficult, a one way analysis of variance (ANOVA) was performed for each of the dependent variables. The results of this analysis confirmed the tasks were indeed equally difficult. Table 4.2 shows the F-value, p-value, and level of significance for the effect of task on each of the dependent variables (at the $\alpha=0.05$ confidence level).

Average decision time for Tasks A and B was 45.88 minutes ($\sigma=9.46$) and 46.63 minutes ($\sigma=14.27$) respectively. Average decision accuracy for Tasks A and B was 51.8% ($\sigma=24.1\%$) and 60.7% ($\sigma=21.3\%$) respectively.

Table 4.1: Summary of Analysis of Variance test of the effect of task on all dependent variables.

Variable	F-value	p-value	Significant (α=0.05)
Measured consensus	0.62	0.458	ns
Perceived consensus	0.31	0.597	ns
Decision making time	0.01	0.926	ns
Amount of information exchange	1.00	0.351	ns
Communication efficiency	0.02	0.885	ns
Perceived cooperation	3.95	0.087	ns
Perceived structure of group process	0.19	0.675	ns
Decision accuracy	0.38	0.558	ns
Decision making efficiency	0.65	0.445	ns
Confidence in the decision	0.47	0.516	ns
Satisfaction with group processes	0.04	0.846	ns

Ordering effects

Treatment levels for the independent variable had to be administered to groups in a particular order. Although the ordering of the treatments was balanced to account for any learning effect, it was desirable the order in which the treatments were administered be non-significant. In order to confirm there were no significant learning effect due to ordering of repeated measures, a one-way analysis of variance (ANOVA) was performed for each of the dependent variables. The results of this analysis confirmed that there was no significant ordering effect on any of the experimental variables. Table 4.2 shows the F-value, p-value, and level of significance for the effect of treatment order on each of the dependent variables.

Average decision time for the first and second treatments was 46.88 minutes (σ=11.70) and 45.63 minutes (σ=12.48) respectively. Average decision accuracy for the first and second treatments was 53.6% (σ=19.8%) and 0.5893% (σ=25.8%) respectively.

Table 4.2: Summary of Analysis of Variance test of the effect of order of treatment on all dependent variables.

Variable	F-value	p-value	Significant (α=0.05)
Measured consensus	2.00	0.200	ns
Perceived consensus	0.01	0.911	ns
Decision making time	0.03	0.877	ns
Amount of information exchange	0.10	0.763	ns
Communication efficiency	0.08	0.791	ns
Perceived cooperation	0.49	0.505	ns
Perceived structure of group process	0.19	0.675	ns
Decision accuracy	0.13	0.728	ns
Decision making efficiency	0.38	0.557	ns
Confidence in the decision	2.36	0.168	ns
Satisfaction with group processes	0.04	0.851	ns

Tests of experimental hypotheses

Task related outcomes

The effect of technological support for decision making on task related outcomes was analyzed using a multivariate analysis of variance. The result of the MANOVA was significant at the $p \leq 0.05$ level ($F=29.127$, $p=0.001$). This indicates that level of decision support had an overall effect on the group outcomes. Individual univariate Analysis of Variance tests were performed on each dependent variable related to task outcomes. Table 4.3shows a summary of the MANOVA test for task related outcomes, and the individual, univariate ANOVA tests. The complete MANOVA and individual ANOVA analysis for task-related outcome variables can be found in Appendix D.

Table 4.3: Summary of the Multivariate Analysis of Variance test of the effect of technological support for decision making on task related outcomes.

Dependent Variable	Multivariate-F (Hotellings)	p
Task-related outcomes	29.127	0.001*

Dependent Variable	F	p
Decision accuracy	19.34	0.003*
Decision making efficiency	6.05	0.044*
Confidence in the decision	0.11	0.747

* Significant at $p \leq 0.05$

Decision making accuracy (DA)

Level of technological support for the decision making process had a significant effect on decision making accuracy at the $p \leq 0.05$ level, thus rejecting the null hypothesis and confirming the experimental hypothesis that groups with higher decision support will show higher levels of decision accuracy.

Figure 4.7 shows the level of decision accuracy for each group under the ‘No GDSS’ and ‘GDSS’ conditions. Average decision accuracy for the ‘No GDSS’ condition was 39% ($\sigma=0.17$). Average decision accuracy for the ‘GDSS’ condition was 73% ($\sigma=0.12$).

Decision making efficiency (DE)

Level of technological support for the decision making process had a significant effect on decision making efficiency at the $p \leq 0.05$ level, rejecting the null hypothesis and confirming the experimental hypothesis that groups with higher decision support will show higher levels of decision efficiency. Average decision making efficiency for the ‘No GDSS’ condition was 35% ($\sigma=0.17$). Average decision making efficiency for the ‘GDSS’ condition was 53% ($\sigma=0.12$).

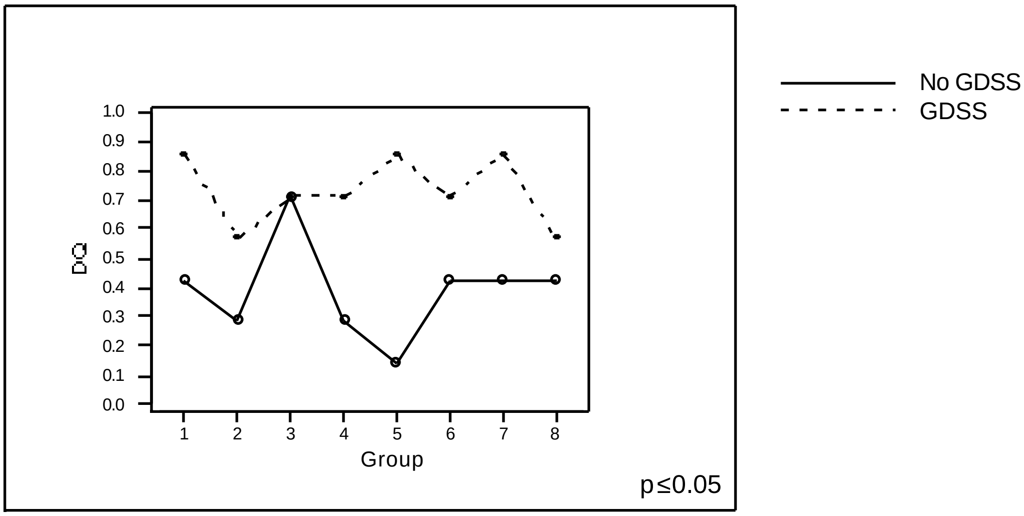


Figure 4.7: Plot of decision accuracy data for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

Confidence in the decision (CD)

Confidence in the decision was not significantly affected by the level of technological support for the decision making process. Average confidence in the decision for the ‘No GDSS’ condition was 3.46 in a scale from 1 to 5 (σ=0.59). Average confidence in the decision for the ‘No GDSS’ condition was 3.50 in a scale from 1 to 5 (σ=0.67).

Figure 4.8 shows the level of confidence on the decision for each group under the ‘No GDSS’ and ‘GDSS’ conditions. It is important to note that a large number of data points – 10 out of 16 or 62% – failed to be located outside the ‘undecided’ range. The implications of this lack of opinion regarding consensus will be discussed in Chapter 5.

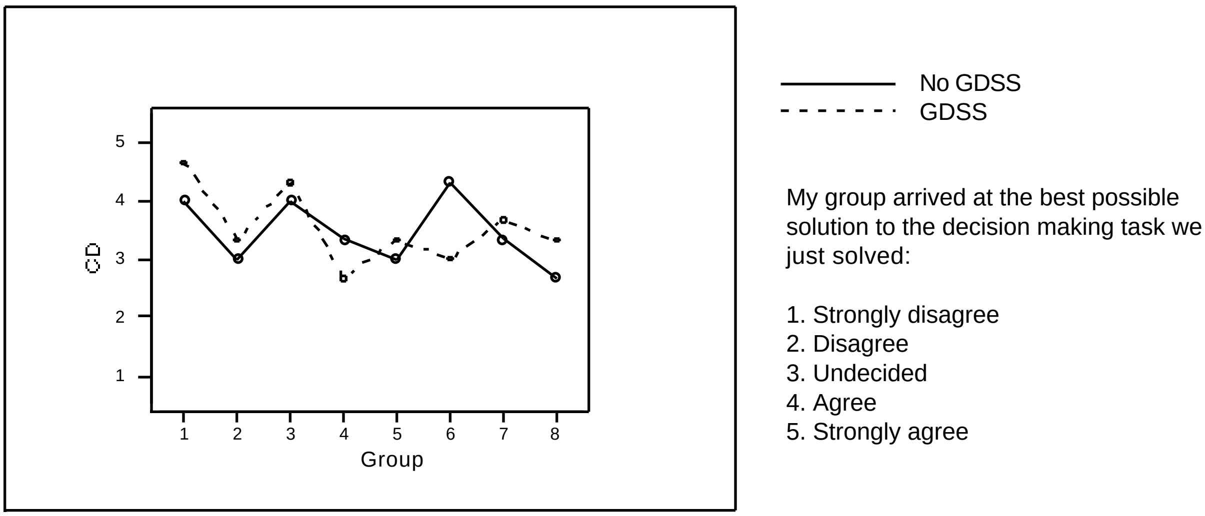


Figure 4.8: Plot of confidence on the decision data for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

Group-related outcomes

Since there was only one group-related outcome variable, a Multivariate Analysis of Variance was not possible or necessary for this category. The only variable in this category was satisfaction with the group process.

Satisfaction with the group processes (SP)

Level of technological support for decision making had a significant effect on satisfaction with the group process at the $p \leq 0.05$ level ($F=5.98$, $p=0.0444$), but in the opposite direction as that predicted by the experimental hypothesis. Groups with higher support for the decision making process showed lower satisfaction with the group process.

Figure 4.9 shows the level of satisfaction with the group process for each group under the ‘No GDSS’ and ‘GDSS’ conditions. Average satisfaction with the group process for the ‘No GDSS’ condition was 3.67 ($\sigma=0.89$) in a scale from 1 to 5. Average satisfaction with the group process for the ‘GDSS’ condition was 2.92 in a scale from 1 to 5 ($\sigma=0.79$).

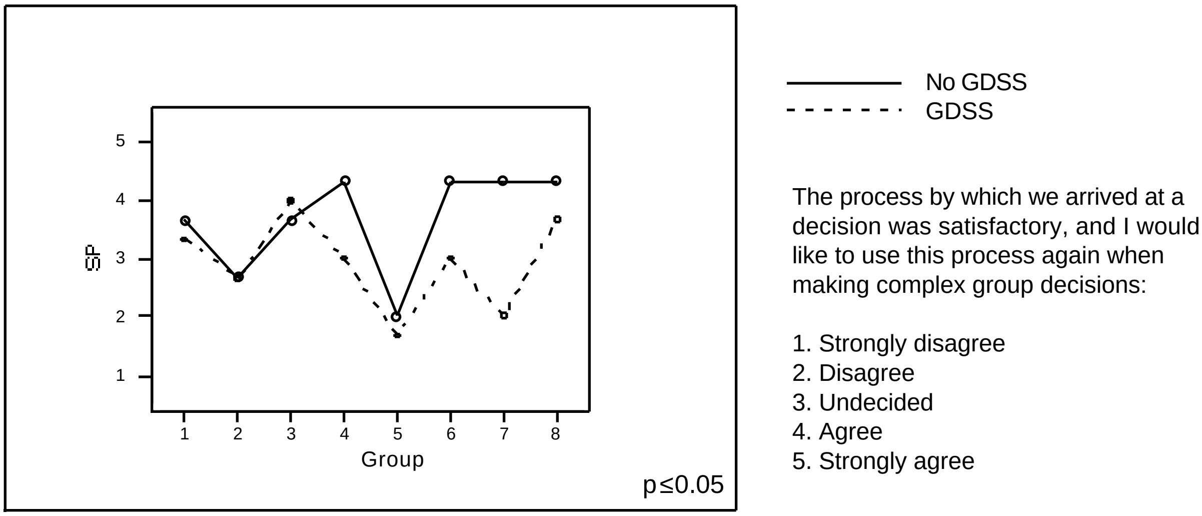


Figure 4.9: Plot of satisfaction data for each group under the 'No GDSS' and 'GDSS' conditions.

Group Process Variables

The effect of technological support for decision making on the group processes was analyzed using a multivariate analysis of variance. The results of the MANOVA were not significant at the $p \leq 0.05$ level ($F=19.014$, $p=0.175$). This indicates that level of support did not have an overall effect on the group processes. Individual analysis of variance were performed on each dependent variable related to group processes to determine if significant effects could be observed on individual variables. Table 4.3 shows a summary of the MANOVA for group process variables, including the individual univariate ANOVA results for each dependent variable. The complete MANOVA and individual ANOVA analysis for group process variables can be found in Appendix D.

Perceived consensus (PC)

The perceived degree of consensus was not significantly affected by the level of decision support. Average perceived consensus for the 'No GDSS' condition was 3.08 ($\sigma=0.53$) in a scale from 1 to 5. Average perceived consensus for the 'GDSS' condition was 3.42 in a scale from 1 to 5 ($\sigma=0.56$). Although not significant at the $p \leq 0.05$ level, perceived consensus was slightly higher for groups with higher support for the decision making process.

Table 4.4: Summary of the Multivariate Analysis of Variance test of the effect of technological support for decision making on the group processes.

MANOVA	Multivariate-F (Hotellings)	p
Group Process	19.014	0.175

ANOVA	F	p
Perceived Consensus	1.17	0.316
Measured Consensus	7.79	0.027*
Decision Time	100.00	0.001*
Information Exchange	3.72	0.095
Communication Efficiency	96.55	0.001*
Perceived Cooperation	0.05	0.823
Perceived Structure of Process	8.78	0.021*

* Significant at $p \leq 0.05$

Figure 4.10 illustrates the level of perceived consensus for each group under the 'No GDSS' and 'GDSS' conditions. It is important to note that a large number of data points – 9 out of 16 or 56% – failed to be located out of the 'undecided' range. The implications of this lack of opinion regarding consensus will be discussed in Chapter 5.

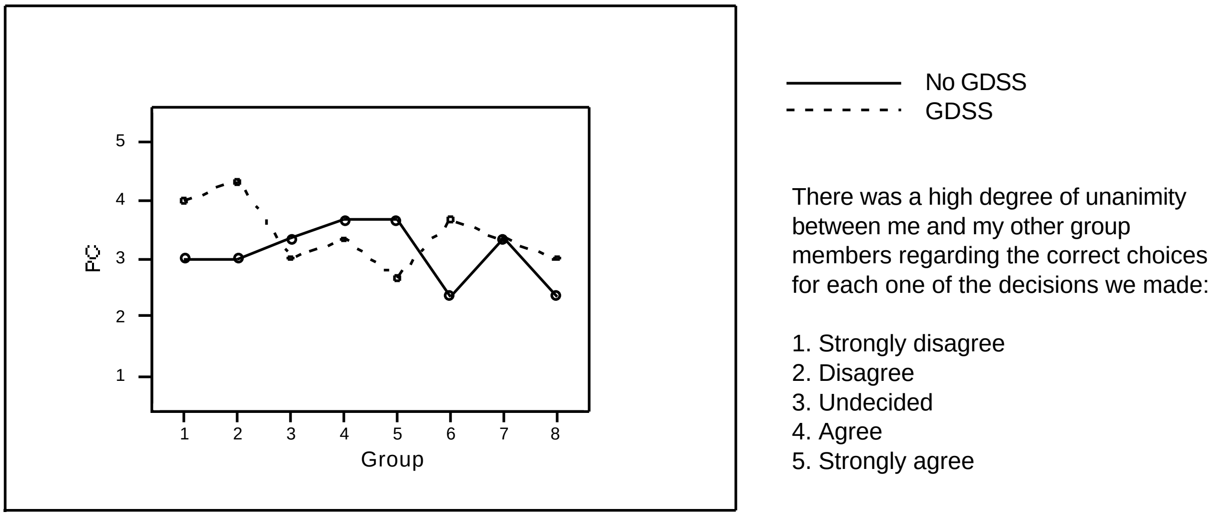


Figure 4.10: Plot of perceived consensus data for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

Measured consensus (MC)

Level of technological support for the decision making process showed a significant effect on measured consensus at the $p \leq 0.05$ level ($df=1$, $F=7.79$, $0=0.027$), rejecting the null hypothesis and confirming the experimental hypothesis that groups with higher decision support will show higher levels of consensus.

Average measured consensus in the ‘No GDSS’ condition was 0.45 ($\sigma=0.15$) in a scale from 0 to 1. Average measured consensus for the ‘GDSS’ condition was 0.70 ($\sigma=0.15$). Figure 4.11 illustrates the level of measured consensus for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

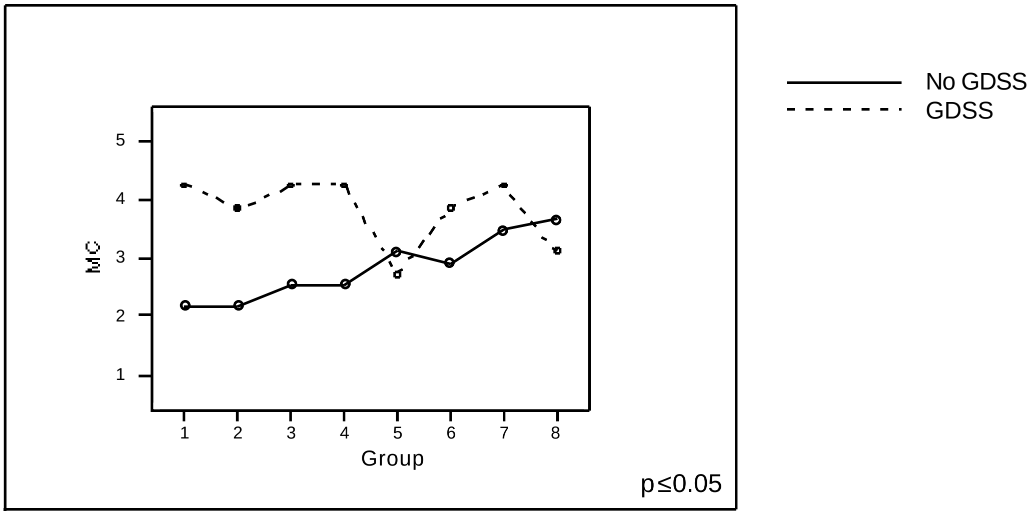


Figure 4.11: Plot of measured consensus data for each group under the 'No GDSS' and 'GDSS' conditions.

Decision making time (DT)

Level of technological support for the decision making process had a significant effect on decision time at the $p \leq 0.05$ level (df=1, F=100, p=0.001), but in the opposite direction as that predicted by the experimental hypothesis. Groups under the 'GDSS' condition took more time to complete the decision making task than groups with lower support for the decision making process.

Average decision time for the 'No GDSS' condition was 36.25 minutes (σ=4.17). Average decision time for the 'GDSS' condition was 56.00 minutes (σ=6.90). Figure 4.12 shows the level of measured consensus for each group under the 'No GDSS' and 'GDSS' conditions.

Information exchange (IE)

The amount of information exchange was not significantly affected by the level of technological support for the decision making process. Average amount of information exchange for the 'No GDSS' condition was 98% (σ=0.017). Average amount of information exchange for the 'GDSS' condition was 99% (σ=0.009).

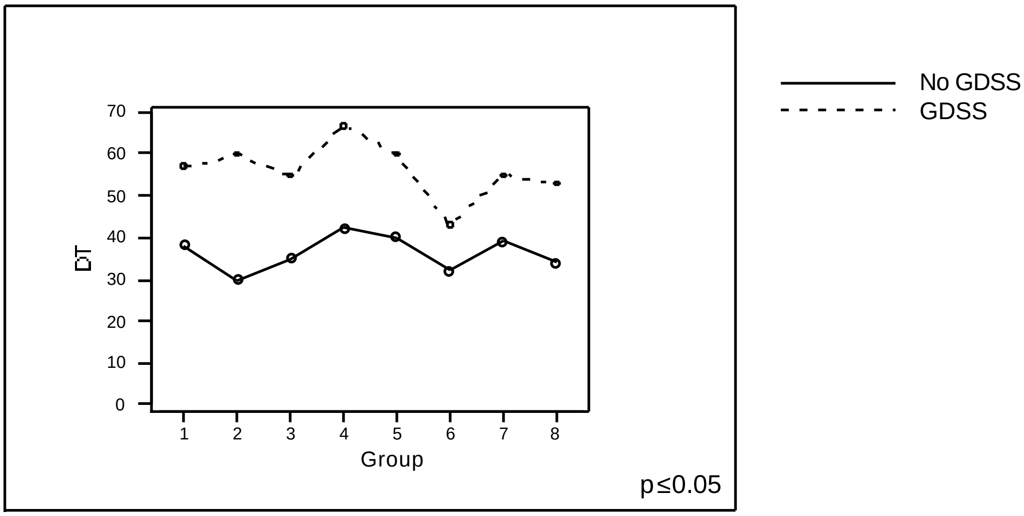


Figure 4.12: Plot of decision time data for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

Communication efficiency (CE)

Level of technological support for the decision making process had a significant effect on communication efficiency at the $p \leq 0.05$ level (df=1, F=96.55, p=0.001), rejecting the null hypothesis and confirming the experimental hypothesis that groups with higher decision support will show higher levels of communication efficiency. This was to be expected since communication efficiency is a linear combination of information exchange and decision making time.

Average communication efficiency for the ‘No GDSS’ condition was 1.48 pieces of information per minute (σ=0.16). Average communication efficiency for the ‘GDSS’ condition was 2.41 pieces of information per minute (σ=0.83).

Perceived cooperation (CO)

The degree of perceived cooperation was not significantly affected by the level of technological support for the decision making process. Average perceived cooperation for the ‘No GDSS’ condition was 3.50 in a scale from 1 to 5 (σ=0.47). Average perceived cooperation for the ‘GDSS’ condition was 3.46 in a scale from 1 to 5 (σ=0.25).

Figure 4.13 shows the level of cooperation for each group under the ‘No GDSS’ and ‘GDSS’ conditions. It is important to note that a large number of data points – 7 out of 16 or 44% – failed to demonstrate perceptions out of the ‘undecided’ range. The implications of this lack of opinion regarding cooperation will be discussed in Chapter 5.

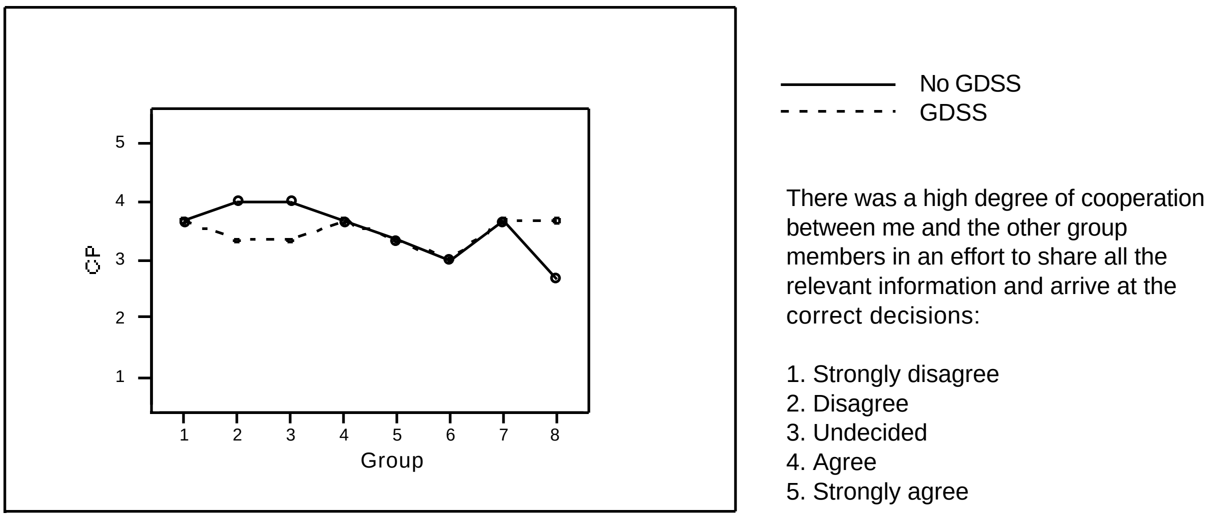


Figure 4.13: Plot of cooperation data for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

Perceived structure of the group process (DS)

Level of technological support for the decision making process showed a significant effect on the perceived structure of the group process at the $p \leq 0.05$ level (df=1`, F=8.78, p=0.021), rejecting the null hypothesis and confirming the experimental hypothesis that groups with higher decision support will show higher levels of perceived structure of the group structure.

Average perceived process structure for the ‘No GDSS’ condition was 1.624 (σ=0.88) in a scale from 1 to 5. Average perceived process structure for the ‘GDSS’ condition was 2.58 in a scale from 1 to 5 (σ=0.83). Figure 4.14 shows the level of perceived process structure for each group under the ‘No GDSS’ and ‘GDSS’ conditions.

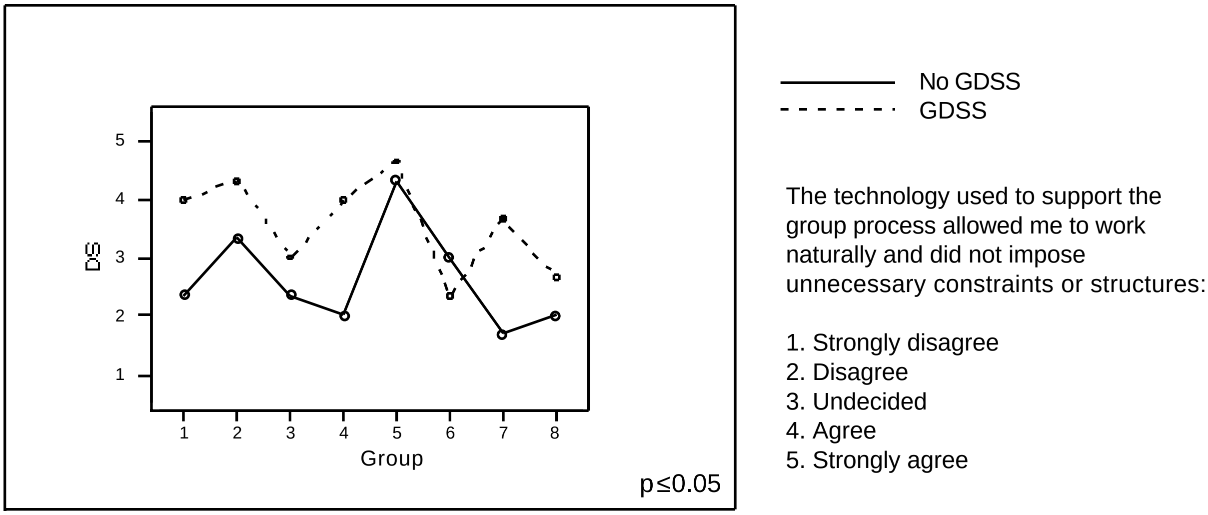


Figure 4.14: Plot of perceived process structure data for each group under the 'No GDSS' and 'GDSS' conditions.

Post-experimental exploratory analysis

Objective and subjective measures of group processes

The discrepancy observed between the significance of measured consensus and perceived consensus prompted a separate analysis of the subjective and objective variables as separate groups. The variables which represented objective measures of the group process were measured consensus, information exchange, decision time, and communication efficiency. The variables which represented subjective estimates of the group process were perceived consensus, perceived level of cooperation, and perceived structure of the process. Individual MANOVA were performed on each set of process variables. Table 4.5 summarizes the results of these two analysis.

Table 4.5: Summary of the Multivariate Analysis of Variance of the effect of technological support for decision making on subjective and objective measures of group process.

Dependent Variable	Multivariate-F (Hotellings)	P
Subjective estimates of group processes	2.858	0.144
Objective measurement of group processes	16.432	0.009*

* Significant at $p \leq 0.05$

Variables which represented objective measures of the group process were significantly affected by the level of decision making support at the $p \leq 0.05$ level. Variables which represented subjective measures of the group process were not significantly affected by level of decision-making support.

Discrepancy between perceived and measured consensus

Due to the discrepancy of the significance between perceived and measured consensus, a Pearson-r correlation coefficient was calculated between these two variables as a post-hoc exploratory analysis. The result ($r_{(PC,MC)} = 0.306$) indicates a very low level of correlation between these two related measures of consensus. This correlation was not significant. The individual group results for perceived and measured consensus are shown in Figure 4.15.

Discrepancy between perceived and observed decision quality

Due to the discrepancy of the results between decision quality and confidence on the decision, a Pearson-r correlation coefficient was calculated between these two variables as a post-hoc exploratory analysis. The results ($r_{(DA,CD)} = 0.29$ and $r_{(DE,CD)} = 0.37$) indicate a very low level of correlation between these two related measures. None of these correlations was significant. Figure 4.16 shows the decision accuracy and confidence in the decision data as a function of level of support.

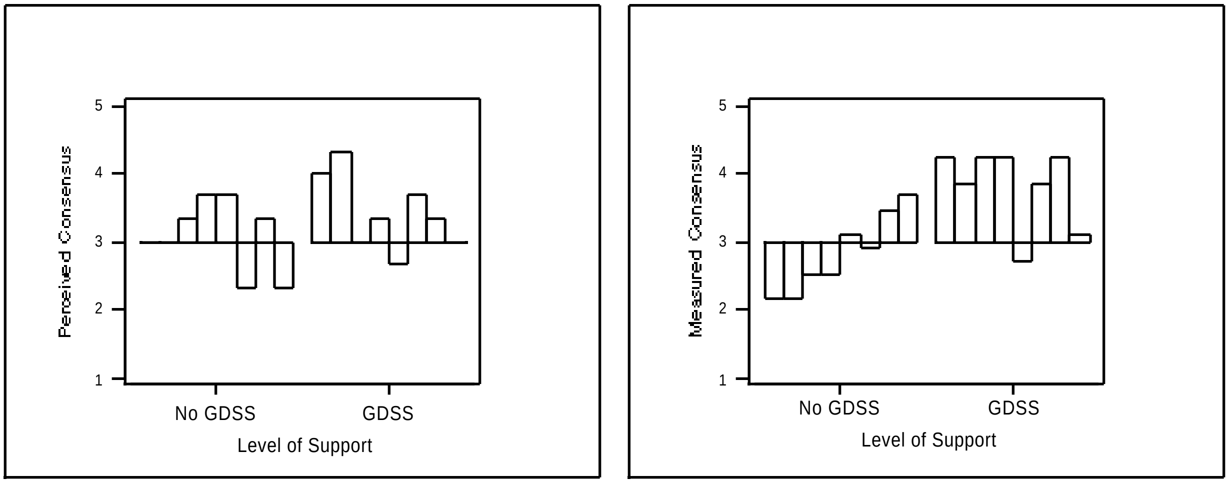


Figure 4.15: Charts of perceived and measured consensus as a function of level of support.

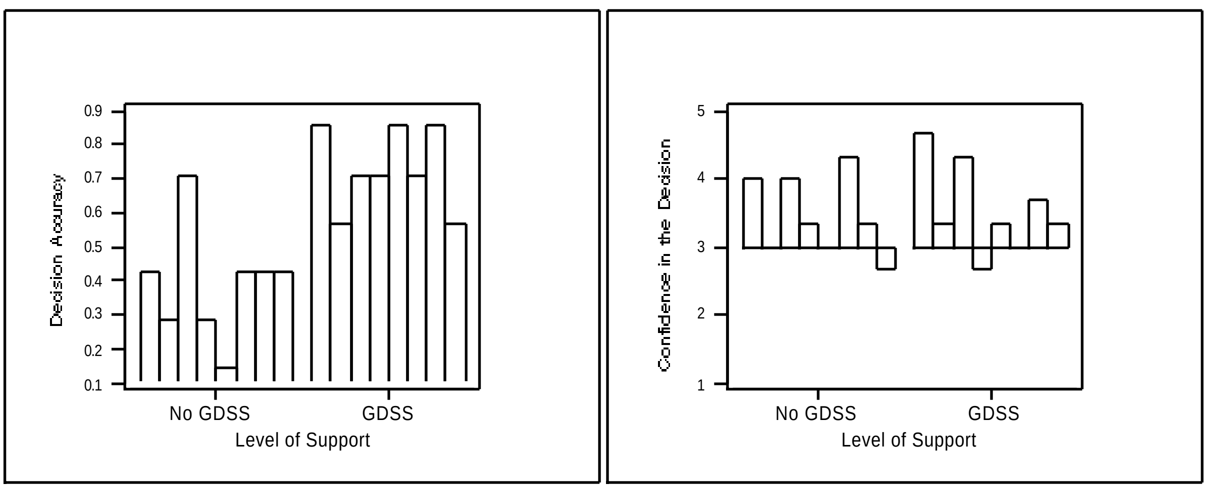


Figure 4.16: Charts for decision accuracy and confidence in the decision.

Relationship between accuracy and time

In order to obtain an estimate of the magnitude of the tradeoff between accuracy and time a Pearson-r correlation coefficient was calculated for the relationship between these two dependent variables. The significance of this correlation was also tested using a t-test of significance for correlations as described by Williges (1997). The result of this analysis (r=0.6644) indicates a significant correlation (t_{table} = 0.9608, t_{obs} = 2.175). Figure 4.17 shows a plot of decision accuracy as a function of decision time.

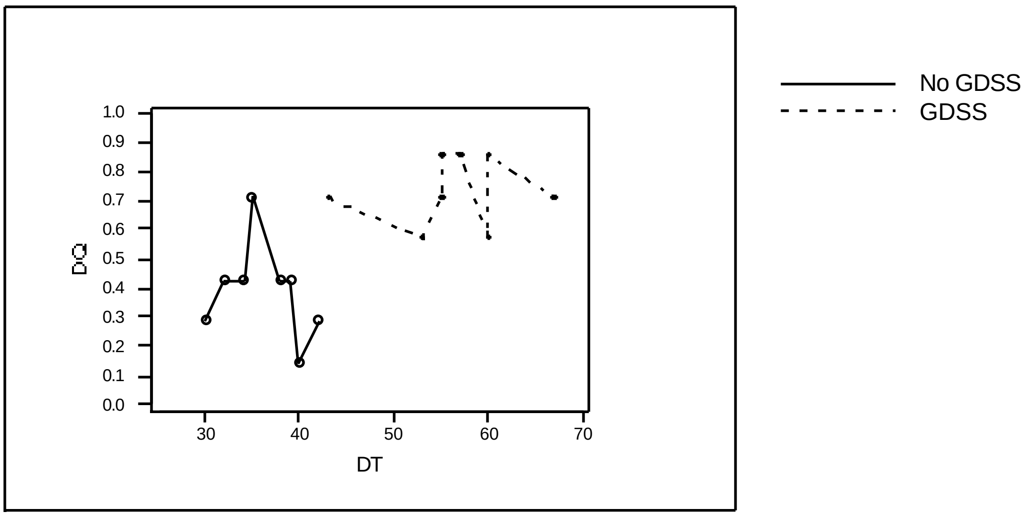


Figure 4.17: Plot of decision making accuracy vs. decision making time.

Relationship between structure and satisfaction

In order to obtain an estimate of the magnitude of the relationship between perceived structure of the process and satisfaction a Pearson-r correlation coefficient was calculated for the relationship between these two dependent variables (r=-0.805). The statistical significance of this correlation was also tested with a t-test of significance. The result of this analysis (t_{table} = 0.9608, t_{obs} = 3.324) indicates a significant correlation between these two variables. Figure 4.18 shows a plot of satisfaction with the process as a function of perceived structure of the process.

The correlation between structure and satisfaction proved significant independent of the decision support manipulation. Satisfaction with the process was significantly correlated with perceived structure in the 'No GDSS' condition (r = -0.870, $t_{table\ e}$= 0.9617, t_{obs} = 4.322) and the 'GDSS' condition (r = -0.616, t_{table} = 0.9617, t_{obs} = 1.915) independently. Since the level of structure was fixed within each condition, the perceived level of structure could be acting as a moderating factor of satisfaction with the process.

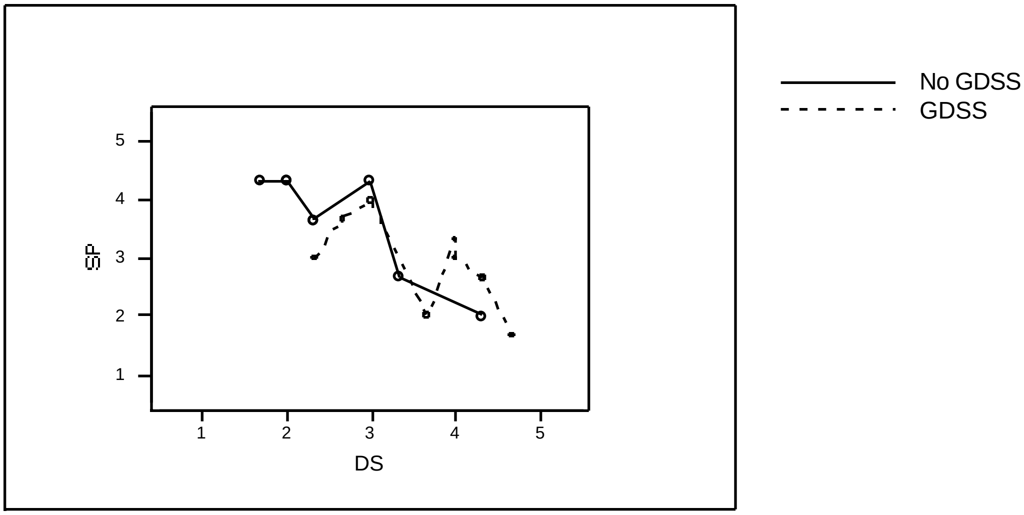


Figure 4.18: Plot of process satisfaction as a function of perceived structure of the process.

Summary of results

The goal of this research was the empirical estimation of the effect of technological support for the decision making process on the performance of distributed groups. There were three main areas of interest: Group process variables, task-related outcome variables, and group related outcomes variables. Table 4.6 summarizes the results of the statistical analysis of the empirical data.

Table 4.6: Summary of MANOVA and ANOVA tests for all dependent variables as a function of level of technological support for decision making.

Variable	Test Statistic	P value	Significant	Effect of Higher Support
Group process Variables	Hotellings-F	0.175	No	ns
Subjective measures of process	Hotellings-F	0.144	No	ns
Perceived consensus	F	0.316	No	ns
Perceived degree of cooperation	F	0.823	No	ns
Perceived structure of process	F	0.021	Yes	Higher
Objective measures of process	Hotellings-F	0.009	Yes	-
Measured consensus	F	0.028	Yes	Higher
Decision time	F	0.001	Yes	Higher †
Amount of Information exchange	F	0.095	No	ns
Communication efficiency	F	0.001	Yes	Lower *
Outcome Variables	Hotellings-F	0.008	Yes	-
Task-related outcomes	Hotellings-F	0.001	Yes	-
Decision making accuracy	F	0.003	Yes	Higher
Decision making efficiency	F	0.044	Yes	Higher
Confidence in the decision	F	0.747	No	ns
Group-related outcomes				-
Satisfaction with group processes	F	0.044	Yes	Lower †

* Only significant due to the significance of decision making time, since there was no significant difference in information exchange

† Significant in the opposite direction from that predicted in the experimental hypotheses.

Placing these experimental results in the research model presented in Chapter 1 produces a slightly different picture of the effects of a GDSS system of group process and outcomes. Figure 4.19 shows the group process model with relevant experimental results.

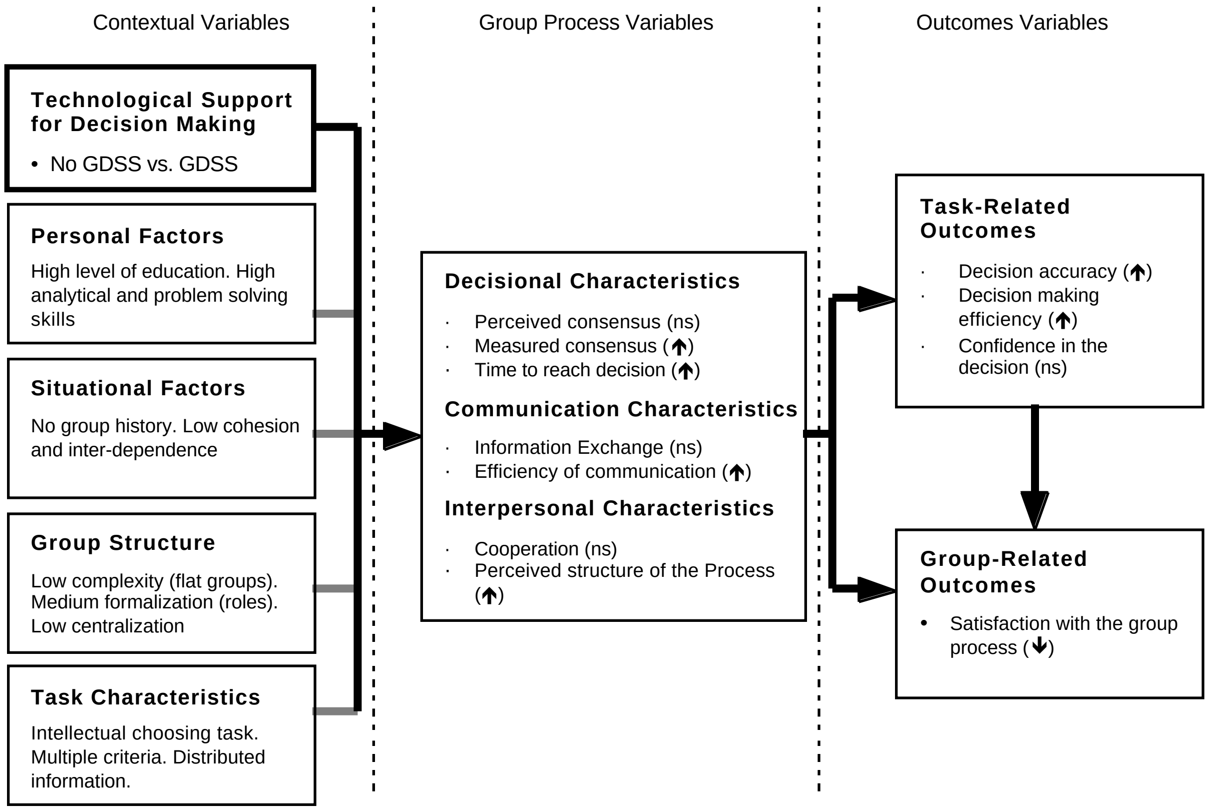


Figure4.19: Research model showing the experimental results of the effect of technological support for decision making of group process and outcome variables.

Chapter 5. Discussion

Effect of decision support on group outcomes

Results indicate the level of technological support for the decision making process had a significant effect on the outcomes of the group process. Outcome variables can be classified as task or group-related. It is important to note that existing group-process models suggest that task related outcomes have a secondary effect on group-related outcomes (McGrath, 1984). So, variations in task related outcomes are caused by variations in the group process. Variation on the group-related outcomes, on the other hand, can be caused by variation on both the group process and the task-related outcomes.

Task-related outcomes

Task related outcomes were significantly affected by the level of technological support for decision making. Groups displayed higher decision accuracy and efficiency under the ‘GDSS’ condition than when not supported by a GDSS. On the other hand, the subjective perception of decision quality failed to show a significant difference. Individual results for each task-related outcome variable are discussed below.

Decision accuracy and efficiency

One of the most important effects found to be significant in this research was on decision accuracy. Group decision accuracy under the ‘GDSS’ condition was consistently better than decision accuracy under the ‘No GDSS’ condition. These findings indicate increased technological support for the decision making process creates a tradeoff between decision accuracy and process time, with groups performing consistently better but taking considerably longer to complete the task. This tradeoff will be discussed further in a following section.

The large observed difference in decision quality can be attributed to the use of the GDSS software, but other experimental factors played a role in highlighting this effect. For example, task type can once again be identified as an important moderating variable. Previous literature indicates that intellectual choosing tasks can benefit the most from the use of a group decision support system McGrath, 1984). So, smaller differences in accuracy can be predicted for groups performing tasks were conflict resolution plays a more important role, such as preference choosing task involving personal views and values.

Another important experimental variable which may play an important role moderating the effect of GDSS on accuracy is the psycho-social characteristics of the subjects. This research used subjects with a relatively high level of education, specifically in analytical and problem solving skills. As engineers, all subjects had at least a fundamental knowledge of multi-criteria decision making. It was observed that many subjects used scrap paper during the 'No GDSS' condition to formulate decision trees, sensitivity analysis, and tradeoff tables which in effect represent decision support tools brought into the work system by the personnel subsystem in the form of skills and knowledge. Although the effectiveness of these improvised decision tools was not assessed, it is possible they influenced the performance of groups that used them during the 'No GDSS' condition. So, an even larger difference in accuracy could be predicted if group members had little or no analytical skills applicable to the task at hand.

Confidence in the decision

There was no significant GDSS effect on the confidence in the decision. If we consider confidence in the decision as a perceptual measure of decision accuracy then the results indicate a discrepancy between subjective and objective measures. This is analogous to the situation observed with the group process variables, were objective measures of the group process were significantly affected by the decision support, while subjective measures were not.

The feedback mechanisms incorporated in the computer support system could be blamed for the lack of a significant effect on the subjective measures. In the particular case of confidence in the decision it appears as if a reliable feedback mechanism was not available to the group members to determine if the answer was the correct one. The role that feedback mechanisms play in the discrepancy between subjective and objective variables is discussed further in a following section.

Group-related outcomes

There was only one group-related outcome variable studied in this research: Satisfaction with the group process. Generalizing the results of this variable to the general category of group-related outcomes, there is at least some evidence that the use of a GDSS may affect group-related outcomes.

Satisfaction with the group process

Satisfaction with the group process showed a significant GDSS effect, but in the opposite direction as that predicted by the experimental hypotheses. Group satisfaction with the process was lower under the 'GDSS' condition that under the 'No GDSS' condition. This results contradict some of the existing literature, but findings in this area were already inconclusive. Pinsonneault and Kraemer (1989) reported that although most GDSS research indicates an increase in satisfaction compared to unsupported groups, GCSS results were mixed, making interpretation difficult.

The results of satisfaction with the group process are easier to explain in the light of the results for some of the group-process variables, which may act as moderators to some group-related outcomes. Two group-process variables could have played a role in the lower satisfaction reported by groups under the 'GDSS' condition: structure of the process and process time.

This research found a significant difference in perceived structure of the process. Van de Ven and Delbecq (1974) and Steeb and Johnston (1981) found that groups supported by structure were more satisfied than groups not supported by structure. On the other hand, Gallupe (1985) and Watson (1987) found that groups supported by structure were less satisfied than unstructured groups. As suggested by Easton et. al (1989), this discrepancy may be explained by the type of structure being imposed on the group. Since the perception of structure is caused by the technological and organizational design subsystems, may be the type of technological support and / or group structure moderates the effect of structure on group processes and satisfaction. Decision time was also found to be significantly higher for groups under the 'GDSS' condition. Although there is no clear relationship between decision time and group satisfaction it is possible that process time can have a detrimental effect on group satisfaction.

Other variables could have affected satisfaction in a more positive direction, but their influence was probably diminished by the lack of feedback mechanisms discussed earlier. For example, the increased level of consensus and decision accuracy should both promote higher satisfaction with the process, but this was not the case. Since subjective measures of consensus and decision quality failed to detect any significant differences, group members were not aware of their performance in these two critical areas and could not adjust their perceptions of satisfaction accordingly.

Effect of decision support on group processes

The results of this research did not support an overall effect of decision support on the group processes of distributed groups. Analysis of individual group-process variables determined that the lack of an overall effect was due to some variables being significantly affected by the use of a GDSS while not others. A significant effect was only observed in four out of the seven group-process variables.

Once the significant and non-significant group-process variables were identified it became apparent the group-process variables could be classified into variables estimated objectively by direct measurement of the process and variables collected subjectively by post-experimental questionnaires. Separate MANOVA analysis on the subjective and objective variables confirmed that while objective measures of the group process were significantly affected by the use of decision support, subjective measures were not. This discrepancy will be further discussed below in a section specifically addressing the discrepancy between subjective and objective measures of group process and outcomes.

Subjective measures of group processes

Subjective measures of the group process did not show a significant effect of GDSS. Individual analysis of the subjective measures of the group process shows that only one group process variable – perceived structure of the process – showed a significant effect. Below the effect each individual subjective group-process variable is discussed.

Perceived consensus

The fact that perceived consensus did not show a significant GDSS effect needs to be explained in the light of the positive results for measured consensus. Under these circumstances, the most likely explanation for the lack of a significant effect on perceived consensus is that the group members did not have the appropriate feedback to perceive that under one condition there was more unanimity in the group member's judgments. This explanation is supported by the fact that over 50 percent of the groups reported results that were in the 'undecided' range, meaning group members had little to say about their perception of consensus.

Perceived cooperation

The fact that an objective measure of cooperation was not available made the interpretation of this subjective variable more difficult. The data indicates that group members did not perceive a significant difference in cooperation. What this means about the true amount of cooperation is not clear, specially given the conflicting results between objective and subjective measures of consensus.

The type of task could have played a role in diminishing the role of cooperation. Cooperation is typically viewed as a way for group members to resolve conflict. This research used an intellectual choosing task, which creates little conflict since it does not involve personal views or values, and thus relies less on cooperation (DeSanctis and Gallupe, 1987; McGrath, 1984). If task type can have such a moderating role on cooperation then groups working on more conflictive tasks, such as preference choosing, may perceive a greater effect of GDSS on cooperation. For example, Sia, Tan and Wei (1996) found that the use of a shared screen had a significant effect on groups performing a preference task, but no effect on groups performing an intellectual task. They also reported that groups performing intellectual tasks had higher influence equality than groups performing preference tasks, indicating more homogeneous participation and a diminished role for cooperation.

Structure of the process

The perceived level of structure of the group process was the only subjective group-process variable to show a significant effect due to technological support for the decision-making process. The GDSS system was perceived as imposing a higher level of structure in the group's decision-making process than the GCSS system alone.

The process of making decisions using the GDSS package was indeed very structured. Once pertinent information had been exchanged by group members, the Team ExpertChoice™ software package imposed a prescribed order in which group members had to enter judgments regarding pairwise comparisons. First, the computer would elicit group member's judgments regarding the importance of each decision criteria. After the relative importance of the criteria was determined, the GDSS software would elicit judgments regarding the preference of each alternative with respect to one criteria at a time. The order in which criteria and alternatives were compared was imposed by the software, with no user control.

Under the 'No GDSS' condition, groups followed a much more unstructured decision-making process. In this condition group members were free to discuss any aspect of the decision (criteria, alternatives, missing information, etc.) in any order they desired. Groups could follow a discussion order in which the most important criteria or alternatives were addressed first, leading the way into more subtle aspects of the decision.

It is important to note that the difference in perceived process structure does not have to be a necessary result of the use of a GDSS systems. A particular implementations of a decision-support technology can be made more or less structured by altering the degree to which information is ‘pulled’ or elicited from group members in a specific order. GDSS systems can be designed to allow more user freedom regarding the order in which judgments are provided to the system. A ‘push’ approach could be implemented for judgment acquisition without altering the underlying decision-support features of the system. In a ‘push’ system the user would be free to enter information into the system, with the system only eliciting missing information needed to perform a requested analysis.

Process structure has been found to have a significant moderating effect on other measures of group performance. Easton, Vogel, and Nunamaker (1989) found groups supported by higher levels of structure produced decisions of higher quality, generated more ideas, and had a more even distribution of participation, but took longer to complete the task. Incidentally, some of these findings are analogous to the ones of this experiment.

Process structure also showed a strong relationship with the group member’s satisfaction. This relationship is further addressed in the section discussing the results of satisfaction with the group process.

Objective measures of group-process variables

Some of the group process variables were measured by direct observation of the group process. This makes the explanation and generalization of the results much more straightforward. Technological support for the decision making process had a strong overall effect on the objective measures of group process. The effect of decision support was not consistent across all the objective group process variables, with some variables showing advantageous effects and others showing detrimental effects. The results for each individual objective group-process variable are discussed below.

Measured consensus

As opposed to perceived consensus, the effect of decision support on measured consensus was significant. Since measured consensus was estimated directly from the opinions entered by the group members in the GCSS and GDSS systems, these measures truly reflects the level of unanimity of the group member’s judgments.

Once again, the nature of the task could have a moderating effect on measured consensus. This research used an intellectual choosing task for data collection. The use of a intellectual choosing task makes the group less susceptible to conflicting motives, values, and interests (DeSanctis and Gallupe, 1987). Under these circumstances groups supported by a GDSS could easily arrive at similar answers by entering the same judgments into the support software. Measured consensus could be affected much less by a GDSS in tasks where idea generation or conflict resolution play more important roles.

Process time

The data supported a significant difference in process time due to the use of the GDSS, but in the opposite direction as that predicted in the experimental hypotheses. Groups took up to twice as long to solve the decision making task with the GDSS than without.

At least part of this difference can be explained by usability and user interface issues of the software packages used to implement the different types of technological support. Although a concise usability study of the software packages used was outside the scope of this research, some observations in this area are important.

First, the learning curves for the ‘No GDSS’ and ‘GDSS’ conditions were very different. Although no quantitative data was collected, qualitative observations made by the researcher during the course of the experimental sessions indicate a much more difficult learning process for the ‘GDSS’ condition compared to the ‘No GDSS’ condition. The concept of group decision support may be much harder to grasp than simply extending the traditional communication process to which groups are already accustomed. After the initial training groups had little problem using the Group Systems™ package under the ‘No GDSS’ condition. Also, the GCSS did not impose any new paradigms, simply implementing enhanced computer versions of common day-to-day concepts such as agendas, lists, and referenda.

When using the Team ExpertChoice™ package under the ‘GDSS’ condition group members also took much longer to go through the practice sessions and had many more questions in the initial stages of the data collection sessions. Under the GDSS condition some group members had problems understanding the way the system models a decision in the form of logical tree. Also, group members sometimes got confused when the software elicited judgments regarding combinations of criteria, alternatives, or both. It is possible that the large difference in process time could be reduced or even reversed after group members gained experience using the Team ExpertChoice™ software. This implies that research on group support technologies may need even longer training periods than those used for this study for the subjects to achieve the necessary level of proficiency. Unfortunately the study of the effect of support technologies over time was beyond the scope of this research.

Besides the steeper learning curve inherent to the group support itself, the software implementations of the GCSS and GDSS conditions also showed different levels of integration and user interface design. The software used to implement the 'No GDSS' condition was comprised exclusively of commercial packages which had been thoroughly debugged and tested (i.e. CUSeeMe™ and Group Systems™). Although several technical problems were encountered during the implementations and execution of the research, at least the user interface of both software packages was at a fairly mature level. In most cases the software packages made the complex underlying communication processes transparent to the end user. For example, information exchange using the GCSS package occurred in real-time at the click of a button, making information posted by one user available to all other users immediately.

The addition of the Team ExpertChoice™ decision support package greatly undermined the user interface of the overall system. First, group members now had to switch between two software applications, a process that was confusing to some subjects. Also, the decision support package used was still in the final development stages. Although this software implementation of the Analytical Hierarchy Process has gone a long ways from its command-based origins, it still does not have the refinements of modern group communication support packages. Users are still required to open individual files for entering their judgments. This process was made much more difficult by small design problems such as the software's inability to remember the location of files on a disk, or path, requiring the user to navigate to the location of the files each time.

Also, the Team ExpertChoice™ software still displayed some of its single-user past by not implementing real-time updating or a modern multi-user architecture. Changes to a group decision models did not automatically appear on participant screens, and had to be manually propagated to the individual user files. Also, the simple calculation of group results involved every user closing their individual files due to a single-user file management structure. All these extra operations greatly increased the amount of process time groups needed to complete the task. It is also possible that the steeper learning curve and poor user interface had an impact on other outcome variables such as confidence in the decision and satisfaction with the group processes. Is important to note that these problems are software design issues not inherent to the decision support technologies but to the user interface design of the software. Nevertheless, these issues are important since they affect the usability and effectiveness of the decision support. There are no reasons why these problems in usability cannot be addressed without affecting other observed benefits of GDSS.

Communication exchange and efficiency

The manipulation of level of technological support for the decision making process did not produce any significant difference in the amount of communication exchange. Group members were consistently able to exchange almost all relevant information, with information exchange ratios of 98% and 99% being typical, and some groups even achieving 100% information exchange.

The lack of a communication effect could be explained by a failure of the decision support to impact the communication process of the group. The way the 'GDSS' condition was implemented in this experiment made the decision support technology a 'layer' applied on top of a group communication support system. The decision making process of the experimental groups under the 'GDSS' condition began by using the group communication support and videoconferencing system to exchange and discuss information. It was not until all information was exchanged that groups moved to the decision support software to input their judgments into a group decision model. Thus, the use of the group decision software typically came too late in the process to effectively affect the communication process.

The fact that there was almost no perceived difference in level of information exchange caused communication efficiency to simply become inversely proportional to decision time. This makes an independent interpretation of decision efficiency irrelevant.

Discrepancy between objective and subjective measures

One interesting finding of this research was the discrepancy in individual and overall significance between subjective and objective variables. Variables estimated objectively by direct observation of the group processes displayed an overall effect of GDSS, while variables measured subjectively by means of a post-experimental questionnaire did not.

In two particular cases this discrepancy could be confirmed directly by variables that were measured both objectively and subjectively. First, perceived consensus failed to show a significant difference when direct measures of unanimity clearly indicated a difference. The same situation occurred with decision quality, which showed significant differences in direct measures (accuracy and efficiency) but failed to show significant differences in member perception of the decision quality (confidence in the decision).

The moderating effect of feedback on subjective variables

A number of explanations are possible for the lack of significant effect on subjective measures of the group process:

1. Technological support for decision making had no effect on group processes.

2. Due to the lack of adequate feedback and interpersonal cues, changes in group process were not perceived by group members, or were not yet fully assimilated at the time of the measurement.

3. The measurement instrument (post-experimental questionnaire) was not sensitive or reliable enough to detect an effect on perceptions of the group process.

The results from the objective data indicate a significant effect of technological support for decision making on the group process. This makes the first explanation less likely, but it is still possible that some individual group process variables were not significantly affected by GDSS.

The second explanation is supported by previous research in the area of group computer support. In a number of cases researchers have observed that groups interacting through CSCW systems did not experience the feedback necessary to adequately perceived group processes and outcomes. For example , Smith and Vanececk (1989) reported that lack of feedback is inherent to the design of many computer support systems, and that this lack of feedback reduced the perceptions of progress towards the goal. Under such circumstances the group members would have difficulty fully perceiving the dynamics of their own group process.

The third explanation has to do with deficiencies in the measurement methodology. Although it is always possible the measuring instrument failed to recognize a significant difference due to poor reliability or validity, the fact that two of these subjective factors did show significant differences seems to indicate the methodology is at least adequate. Post-experimental questionnaires based on a Likert-type verbally anchored scale are commonly used in behavioral research to obtain estimates of individual or group perceptions.

Importance of considering different levels of feedback

The importance of feedback mechanisms can be taken further by identifying specific types of feedback that relate to specific perceptions of group processes. Feedback mechanisms can be designed in multiple ways, and can provide different amounts of information regarding characteristics of the group processes and outcomes.

The most typical type of feedback is feedback about task-related outcomes. In actual situations feedback about task-related outcomes cannot be received immediately, since there are times associated with implementing a group decision and determining if it was the correct one. Because of this, task related outcome feedback could take from days to months. Even when accompanied by a large time lapse, group members could use history of task-related performance as a way to formulate their own subjective perceptions of group processes and task-related outcomes.

The lack of task-related feedback and the use of ad-hoc groups lacking any history could explain the lack of a significant effect of GDSS on confidence in the decision, which in effect is a subjective measure of decision accuracy for an intellectual choosing task. Even when decision accuracy increased in the 'GDSS' condition, group members lacked the necessary information to formulate the corresponding change in perception.

Another type of feedback provides information about characteristics of the group process. In face-to-face decision making group members use verbal and non-verbal cues to formulate a perception of different aspects of the group process and outcomes. This type of feedback provides rich information regarding the level of conflict, cooperation, consensus, and consensus change.

It is possible the geographical dispersion of the group and the reduced sense of presence eliminated many of these natural feedback mechanism regarding group processes. If this is so, GCSS and GDSS systems must be designed to support the feedback of these group process variables if subjective perceptions of group process variables are important.

Although both the GCSS and the GDSS software used in this experiment can provide certain degrees of process feedback, these capabilities were not used in this research. The Group Systems™ software package used for the GCSS provides ways for users to compare their votes with the rest of the group in order to provide feedback as to the unanimity of the group. The Team ExpertChoice™ software package takes these capabilities further by providing users with information regarding the within-member and between-member inconsistency.

Lack of process feedback could explain the lack of a significant effect on perceived consensus when direct measurement of the group process demonstrated a significant consensus change. It could also explain why the results failed to detect any significant difference in perceived cooperation. Figure 5.1

illustrates McGrath's group process model explicitly showing important feedback mechanisms. These feedback mechanisms are important for the development of valid perceptions of group processes and outcomes by the group members. Without feedback about the process, and of the task- and group-related outcomes, the group will not have the information necessary to develop a realistic perception of their group process and improve it accordingly.

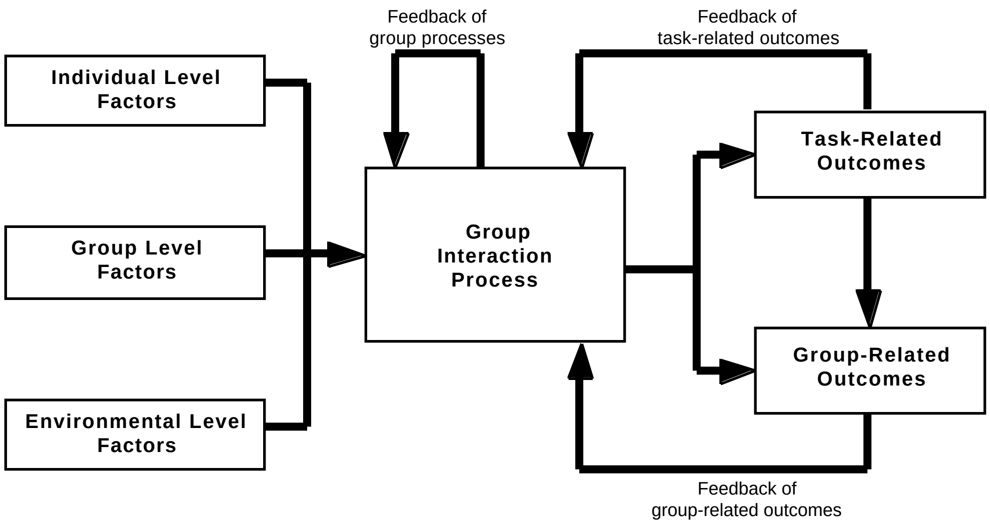


Figure 5.1: Group process model showing the different types of feedback necessary for group performance.

Relationships between process and outcomes

Relationship between accuracy and time

Decision making is ultimately aimed at producing the best possible decisions in the shortest possible time. The results of this research indicate that although groups with higher technological support for the decision making process exhibit higher decision quality, a large trade-off exists between decision making accuracy and decision making time. Groups with higher support for the decision making process had higher decision accuracy, but also took much longer to complete the decision making task than groups with no support for the decision making process. A highly significant correlation was found between decision accuracy and decision time.

The trade-off between decision quality and decision time is consistent with previous research on group decision-making performance. Easton, Vogel, and Nunamaker (1989) found the use of a structured procedure in a distributed decision-making task produced decisions of higher quality and a higher number of unique ideas, but supported groups took longer to finish the task. Petrovic and Krickl (1994) found that the use of computer support in a brainstorming meeting produced a higher number of contributions and a higher number of 'good' contributions, but computer supported meetings lasted longer.

Relationship between perceived process structure and subjective outcomes

Another interesting finding of this research was the apparent relationship between the structure of the process and satisfaction with the process. Groups which reported a higher level of process structure also reported lower levels of satisfaction. It is interesting to note that although the level of structure was fixed within each treatment condition, variations in perceived process structure within a treatment were highly and significantly correlated with variations in reported satisfaction. In other words, there was a strong inverse relationship between perception of structure and satisfaction with the process, which was independent of the decision support manipulation

These results indicate that increased structured could reduce the level of satisfaction with the group process. This seems to contradict previous findings, were higher structure was correlated with higher group satisfaction (Easton, Vogel, and Nunamaker, 1989; Petrovic and Krickl, 1994). This contradiction can be explained by the fact that subjects in these studies reported higher levels of confidence in the decision. So, it seems as if confidence in the decision, or perceived decision quality, can moderate the effect of structure on satisfaction with the process. If the increased structured is accompanied by increased confidence in the decision it could increase satisfaction with the process. Alternatively, increased structure without any perceived improvement in decision quality could decrease satisfaction with the process.

Macroergonomic and sociotechnical observations

This research studied the effect of decision making support on the performance of distributed groups. From a sociotechnical theory viewpoint it only deals with one of the three empirically identified subsystems of a work system: the technological subsystem. Although not directly manipulated by this research, the composition and design of the two remaining subsystems must be taken into consideration to properly interpret and generalize the experimental results. These two remaining subsystems are the personnel subsystem and the organizational design.

Personnel subsystem considerations

The personnel subsystem represents the human component of any work system. The psycho-social characteristics of personnel have been found to play an important role in group processes. No significant differences were found between teams, meaning that the psycho-social characteristics of the sample population were fairly homogeneous. This homogeneity of the sample population is important to consider since if affects the generalizability of the results.

This research employed groups with a moderate-to-high level of intelligence and with very analytically oriented mental models (based on their education level and choice of field of study). Also, the ad-hoc groups used lacked the history and cohesiveness that characterize most teams. So, although the results of this study can be generalized to professional and technical groups, it is harder to generalize to teams with a long evolutionary history until the effects of group history are more clearly understood.

Hackman and Morris (1975) proposed the knowledge and skill of the group members as one of three main ‘summary variables’ which account for most of the variation in group performance. Hendrick (1979) suggested that cognitive complexity, a construct correlated with education and experience, may play a moderating role in a number of group processes and outcomes, including decision quality and time.

This research employed undergraduate and graduate engineering students. It is important to note that the multi-criteria decision-making task used in this experiment, although not easy by general standards, was similar in nature to the types of analytical problems engineers are trained to solve. From this point of view, it is possible that other forms of decision support could have been applied by the participants. Also, demographic data confirmed that the participants had moderate to high computer experience and academic status which was used as an indicator of education level.

Using Perrow’s definition of technology as the necessary knowledge base for task performance (Perrow, 1967), is posible the analytical skills and level of education of the subjects could have moderated the effect of the GDSS manipulation. This possibility is supported by the post-experimental review of log sheets given to the participants to write their group answers to the decision making problem. The participants were instructed to use this log sheets as scrap paper for any other information they considered pertinent. A review of these log sheets revealed in a number of occasions the use of improvised decision trees, plots, graphs, and other analytical tools to help arrive at the correct answer in conditions of no decision-making support.

It remains to be seen if the use of subjects with a different level of analytical skills could have affected the results of the experiment. It is possible that the use of a GDSS tool for an intellectual choosing task could have a much larger effect on group processes and outcomes if the group members lacked the analytical skills necessary to solve the problems accurately. Until this proposition is confirmed by future research, generalizations of the findings of this research to groups with lower levels of education and computer experience must be made carefully.

Task type

Task type has been found to account for as much as 50% of the variance in group performance (Poole 1978). Although every task is unique, a general taxonomy of task types is useful in explaining task-related variance and advancing a general theory of group decision-making. McGrath (1984) integrates a number of previous categorization schemes into a “circumplex model” of group task types. The taxonomy proposed by McGrath’s model is shown in Table 5.1.

Table 5.1: Taxonomy of decision tasks according to McGrath’s (1984) “circumplex model” of group task types.

Category	**Type**	**Major Decision Goals**
Generating	Planing	generation of action-oriented plans
	Creativity	Generation of novel ideas
Choosing	Intellectual	Selection of correct alternative
	Preference	Selection of alternative without objective criterion of correctness
Negotiating	Cognitive conflict	Resolution of conflictive viewpoints
	Mixed motive conflict	Resolution of conflictive motives or interests

This research was interested exclusively in group decision making. Generation of ideas or conflict resolution tasks were beyond the scope of this research. Also, the type of controlled experimental estimation desired for this research suggested an intellectual task so that decision making quality could be determined in an objective fashion.

The task used in this research can be classified according to McGrath’s taxonomy as an intellectual choosing task. In this task subjects were asked to select the correct alternative from among a number of choices. Also, the task was intellectual because the criteria for selection were objective, and did not involve values, opinions, aesthetics, or other subjective factors. According to McGrath intellectual tasks create the smallest amount of conflict and require little creativity and idea generation (McGrath, 1984).

A richer taxonomy of group support systems

Existing taxonomies

Initially, research on technological support of groups concentrated on the difference between supported and unsupported groups. Failure to find many generalizable theories prompted the development of a number of taxonomies which categorized support systems according to the level of support and proposed differences between these systems. These taxonomies include DeSanctis and Gallupe (1985) Group Decision Support levels, which classified support linearly in three levels. The first two levels of DeSanctis correspond to what Pinsonneault and Kraemer (1990) classified as Group Communication Support Systems (GCSS) and Group Decision Support Systems (GDSS). Pinsonneault and Kraemer were the first to propose a number of clear theories attempting to explain how different levels of technological support affect group processes and outcomes. This later taxonomy, and the hypotheses it implied, is what initially prompted this research. The two taxonomies are shown in Figure 5.2 as a one dimensional scale of technological support for the group process.

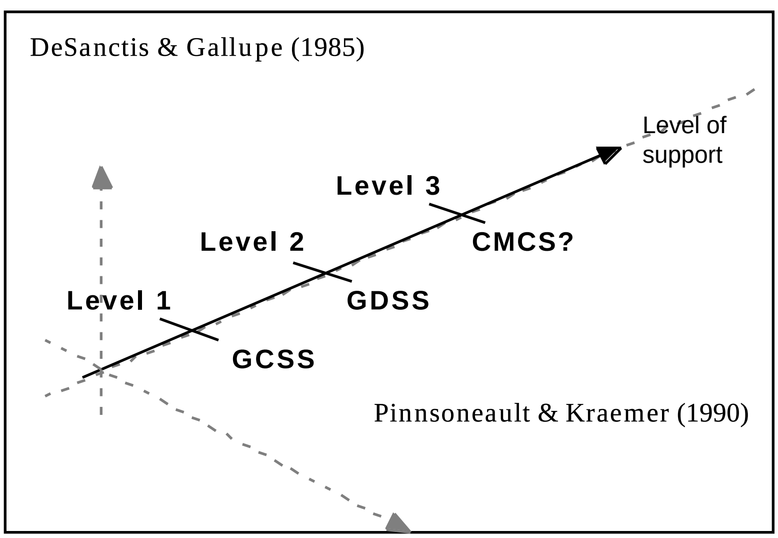


Figure 5.2: Illustration of previous taxonomies of group support as a one-dimensional continuum.

Distinguishing multiple dimensions of group support

It became apparent during the execution of this research that a richer taxonomy of technological support for groups was needed in order to develop a theory of group support in general and distributed groups in particular. Instead of a single one-dimensional continuum, this research suggests that is time to move into a richer design space where group support systems can be classified and studied. This new design space will be defined by a number of empirically derived dimensions or variables. Two variables which can be derived from previous taxonomies and the results of this research are the level of support for the communication process and the level of support for the decision making process.

A two dimensional design space for group support systems is illustrated in Figure 5.3. In this figure decision support and communication support are represented as two independent and orthogonal dimensions of group design, instead of two levels along the same continuum. Existing CSCW systems are depicted in this two dimensional space according to the level to which the communication process and the decision making process are supported. Unsupported groups are shown near the origin. Traditional GCSS and GDSS systems are also shown, providing moderate-to-high support primarily in one dimension. This research explores new grounds in the analysis of group support by combining relatively high levels of support in both of these dimensions: high communication support and high decision making support.

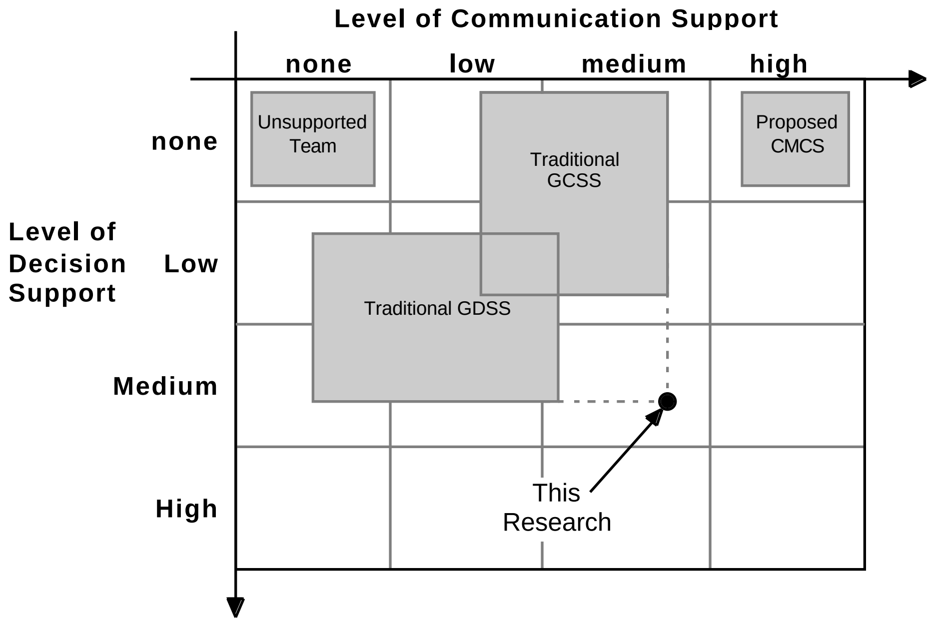


Figure 5.3: A two-dimensional design space for classification of group support systems.

Support for the sense of presence

Examining the contextual variables of this research revealed a third dimension important to CSCW system design, which is the level of technological support for geographical dispersion, or virtuality, of the system. Support for geographical dispersion attempts to produce a sense of 'presence' in the participants. Sense of presence has already being identified as an important dimension of the technological subsystem in mixed reality visual displays. The 'Extent of Presence Metaphor', defined by Milgram and Kishino (1994), is described as the extent to which the observer is intended to feel "present" within the observed scene. Extending this definition to the CSCW design domain it can be seen that technology can support to various levels the degree to which participants in a distributed group process feel "present" in the "virtual" shared work space.

Kies, Williges, and Williges (1997) define communicative presence as the capacity of a system to transfer subtle verbal and non-verbal communicative signals to participants. They proposed the maximization of the sense of presence as a guideline of videoconferencing systems. This definition can be broadened by defining Group Presence Support Systems (GPSS) as a system designed to enhance the sense of presence of a distributed group. Supporting the sense of presence of a group only makes sense in situations where the sense of presence is already hindered by geographical dispersion.

In situations where group presence support is relevant there are many possible levels of support. At the lowest level is a system which provides a text-based channel for non-task related communication. This channel can be used by group members to exchange comments which provide cues as to the state of the process. These systems are followed by audio-only conferencing systems. Medium levels of support include complete videoconferencing systems (audio and video), such as the ones employed in this experiment. Systems which allow remote members to manipulate objects remotely, or telepresense (Kies et. al., 1997), are also included in this medium level of presence support. Examples of telepresense applied to group collaboration include systems with shared whiteboards as well as systems which allow the sharing and remote manipulation of software windows. Current Group Presence Support Systems only employ these low and medium levels of technological augmentation.

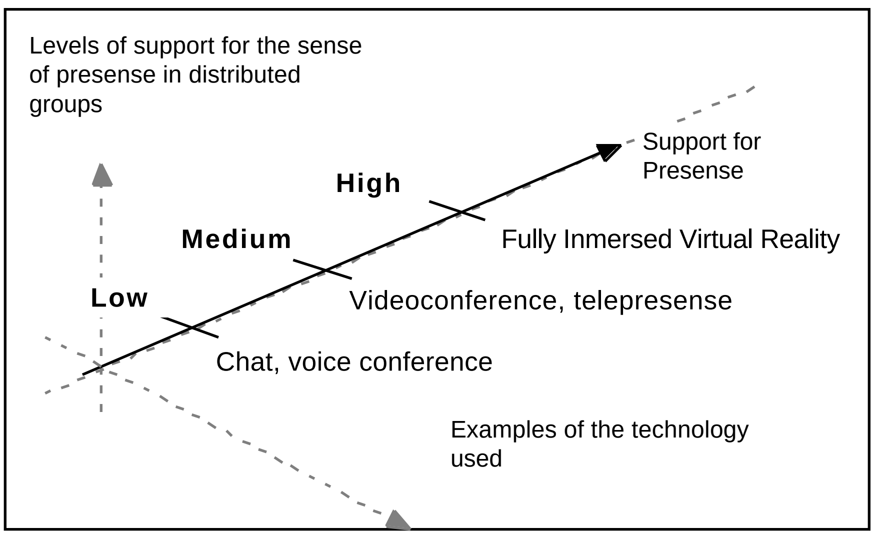


Figure 5.4: Levels of support for the sense of presence in distributed groups (GPSS)

Moving past the current level of technology one could predicts systems which would apply true virtual-reality technologies to the support of presence in distributed groups. Such a system could immerse distributed group members in a common virtual meeting-room, eliminating almost all communication barriers imposed by geographical dispersion. Figure 5.4 shows a continuum for support of the sense of presence with examples of possible technologies. Systems at the high-end of the virtuality support continuum are purely experimental at this point, and were clearly beyond the scope of this research.

Figure 5.5 shows a conceptual representation of this three-dimensional design space and the location of the 'GDSS' condition used in this research.

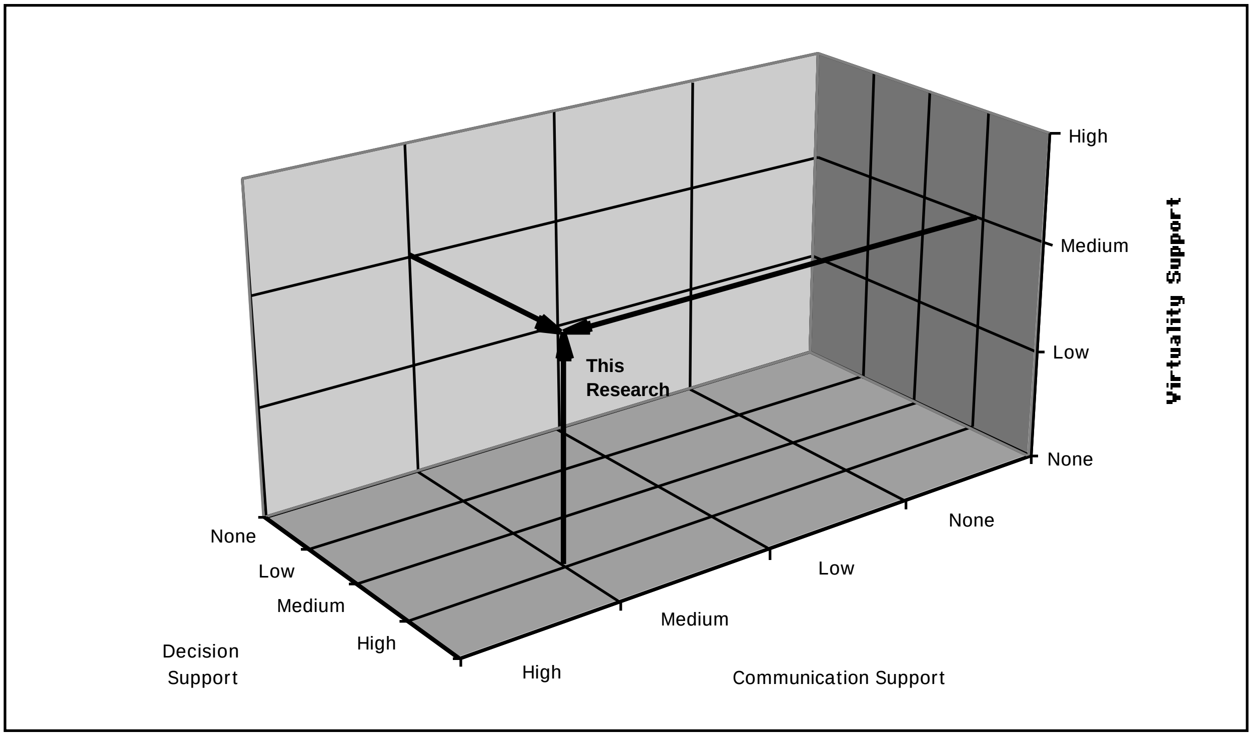


Figure 5.5: Three-dimensional design space for group support systems.

Implications for future research

By implementing multiple types of distributed group support this research has highlighted the importance of a richer taxonomy for CSCW systems. Multiple dimensions of group support imply the possibility of interactions between these factors and the way they affect group processes and outcomes. These interactions have never been explored empirically.

The results of this research also identified areas where availability of feedback may mediate or moderate certain group process variables and thereby influence task and group related outcomes. Variables such as perceived levels of cooperation, perceived consensus, and perceived decision quality could be affected by the availability of the proper feedback. The effect of different types of feedback on group process and outcomes is another area were empirical research is needed to formulate a sound theory of distributed group performance.

Finally, this research highlights the moderating action that task and psycho-social characteristics of group members can have on the effect of certain types of support. Group decision support may be much more important in intellectual tasks, where the communication and presence support systems may play a bigger role in tasks involving feelings, values, or conflict resolution. Similarly, a group decision support system may not have as large of an impact on groups already equipped with the analytical tools suitable for solving the decision making task, even if these tools are in the form of cognitive skills.

To summarize, the following research direction is proposed in order to arrive at a sound, empirically based theory of distributed group performance.

- Test for interactions between types of support (GCSS, GDSS, GPSS)
- Study the effect of feedback on perceived and objective measures of group processes and outcomes
- Study the mediating effect of task type and psycho-social characteristics on the above factors
- Develop theory of distributed group performance
- Confirm theory with distributed groups in the field.

Conclusions

This research began as an empirical estimation of the effect of decision support on the performance of distributed groups. Results in this area were mixed. As predicted by the literature, the use of a GDSS by distributed groups improved overall group consensus and decision quality. Opposite to what could be predicted by previous studies, the use of a GDSS increased decision time, and decreased overall satisfaction with the group process. No significant effects were found on perceived consensus, cooperation, amount of information exchange, and confidence in the decision.

Some interesting interactions between process and outcome variables were identified. A strong correlation was found between decision quality and decision time. This is consistent with previous literature and seems to be a tradeoff inherent to group decision making in general. An even stronger correlation was found between perceived structure of the process and satisfaction with the process. Although the previous empirical evidence in this area is mixed, an increased in process structure without a perceived improvement in decision quality (confidence in the decision) tends to reduce group satisfaction. Perception of subjective measures of the process depend on the implementation of the appropriate types of feedback. The lack of process and outcome feedback could explain the lack of a GDSS effect on perceptions of consensus, cooperation, and confidence in the decision.

Finally, this research proposes a richer taxonomy for CSCW systems by defining three orthogonal dimensions of group support: communication support, decision support, and presence support. This new taxonomy suggests a number of research directions aimed at empirically identifying contextual and design factors relevant to distributed group performance and group performance in general.

Selected bibliography

Adelman, L., Bresnick, T., Black, P.K., Marvin, F.F. and Sak, S.G. (1997). Research with patriot air defense officers: examining information order effects. Human Factors. 38(2), 250-261.

Adrianson, L. and Hjelmquist, E. (1991). Group process in face-to-face and computer mediated communication. *Behavior and Information Technology*, 10(4), 281-296.

Anderson, A.H., Newlands, A., Mullin, J., Fleming, A.M., Doherty-Sneddon, G., and Van der Velden, J. (1996). Impact of video-mediated communication on simulated service encounters. *Interacting with Computers*, 8(2), 193-206.

Angiolillo, J.S., Blanchard, H.E., and Israelski, E.W. (May/June, 1993). Video telephony. *AT&T Technical Journal*, 7-20.

Argyle, M. and Cook, M. (1976). *Gaze and Mutual Gaze.* Cambridge, U. K.: Cambridge University Press.

Baber, C.; Noyes, J. (1996) Automatic speech recognition in adverse environments. *Human Factors*, 38(1), 142-156.

Baecker, R.M. (1993). *Readings in Computer-Supported Cooperative Work.* San Mateo: Morgan Kaufmann Publishers.

Bainbridge, L., (1974). Analysis of verbal protocols from a process control task. In Edwards and Lees (Eds.), *The Operator in Process Control*. London: Taylor and Francis.

Bales, R.F. (1950). *Interaction process analysis: a method for the study of small groups*. Cambridge, MA: Addidon-Wesley.

Bhaskar, R.; and Simon, H.A. (1977) Problem solving in semantically rich domains: An example for engineering thermodynamics. *Cognitive Science*, 1, 193-215.

Böcker, M. and Mühlbach, L. (1993). Communicative presence in video communications. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, (pp. 249-253). Santa Monica, CA: Human Factors and Ergonomics Society.

Boose, J.H. (1986). *Expertise Transfer for Expert System Design.* Amsterdam: Elsevier.

Box, G.E.P. and Draper, N.R. (1987). *Empirical model building and response surfaces*. New York, NY: Wiley.

Box, G.E.P., Hunter, W.G., and Hunter, J.S. (1978). *Statistics for experimenters: An introduction to design, data analysis, and model building*. New York, NY: Wiley.

Brannick, M.T.; Prince, A., Prince, N.; and Salas, E. (1995) The Measurement of Team Processes. *Human Factors*, 37(3), 641-651

Bui, T., and Sivasankara, T.R., Fijol, Y., and Woodbury, M.A. (1987), "Identifying organizational opportunities for GDSS use: Some experimental evidence". Decision Support Systems 3, 68-75.

Bui, T., and Sivasankaran, T.R. (1987). GDSS use under conditions of group task complexity. Report, The US Naval Postgraduate School, Monterey, CA.

Caldwell, B.S. (1994). Quantitative approaches to team communication and performance: harmony of systems analysis tools. In *Proceedings of the Human Factors and Ergonomics Society*, 38th *annual meeting*, (pp. 769-773). Santa Monica, CA: Human Factors Society.

Cannon-Bowers, J.A., Salas, E. and Pruitt, J.S. (1997). Establishing the boundaries of a paradigm for decision-making research. *Human Factors.* 38(2), 193-205.

Cano, A. and Kleiner, B.M. (1996). Sociotechnical design factors of virtual team performance. *Proceedings of the Human Factors and Ergonomics Society, 40th Annual Meeting*. (pp. 786-790). Santa Monica, CA: Human Factors Society.

Chapanis, A. (1975). Interactive human communication. *Scientific American*, 232(*3*), 36-42.

Cohen, M.S., Freeman, J.T. and Wolf, S. (1997). Metarecognition in time-stressed decision making: recognizing, critiquing and correcting. *Human Factors.* 38(2), 206-219

Daft, R.L. and Lengel, R.H. (1986). Organizational information requirements, media richness, and structural design. *Management Science*, 32(5), 554-571.

DeSanctis, G., and Gallupe, R.B. (1985). A foundation for the study of group decision support systems. *Management Science.* 33(5), 589-609

Dickson, G.W., Lee, J.E., Robinson, L., and Heath, R. (1989), “Observations on GDSS interaction: Chauffeured, facilitated, and user-driven systems”, in R. Blanning and D. King (eds.), *Proceedings of the Twenty-Second Annual Hawaii International Conference on Systems and Science,* IEEE Computer Science Press, 344-352.

Dufner, D.; Hiltx, S.R.; and Turoff, M. (1994) Distributed group support: A preliminary analysis of the effects of the use of voting tools and sequential procedures. *Proceedings of the 27th Annual Hawaii International Conference on System Sciences*, 114-123.

Dyer, R.F. and Forman, E.H. (1992). Group decision support with the Analytic Hierarchy Process. *Decision Support Systems* 8, 99-124.

Easton, A.C., Vogel, D.R. Nunamaker, J.F. Jr. (1989). Stakeholder identification and assumption surfacing in small groups: An experimental Study. In R. Blanning and D. King (eds.), *Proceedings of the Twenty Second Annual Hawaii International Conference on System Science.* IEEE Computer Society Press, 344--352.

Elliott, L.R., Neville, K, and Dalyrmple, M.A. (1996). C3 Simulation, Training, and Research Systems (C^3STARS): Team performance under conditions of information ambiguity -- constructs and measures. *Proceedings of the Human Factors and Ergonomics Society, 40th Annual Meeting*. Santa Monica, CA: Human Factors Society.

Ellis, C.A., Gibbs, S.J., and Rein, G.L. (1991). Groupware: some issues and experiences. *Communications of the ACM*, 34(1), 39-58.

Ellis, C.A., Rein, G.L., and Jarvenpee, S.L. (1989). Nick experimentation: Some selected results. In R. Blanning and D. King (eds.), *Proceedings of the Twenty Second Annual Hawaii International Conference on System Science.* IEEE Computer Society Press, 370-377.

Emery, F. E., and Trist, E. L. (1960). Sociotechnical Systems. In C.W Churchman and M. Verhulst (Eds.), *Management Sciences, Models And Techniques II*. London: Pergamon.

Endsley, M.R. and Smith, R.P. (1997). Attention distribution and decision making in tactical air combat. *Human Factors.* 38(2), 232-249.

Er, M. C., and Ng, A. C. (1995). The anonymity and proximity factors in group decision support systems. *Decision Support Systems,* 14, 75-83.

Ericsson, K. A. and Simon, H. A. (1984). *Protocol Analysis: Verbal Reports as Data*. Cambridge, Mass.: MIT Press.

Ferris, S.T. (1995). *An Investigation of the Role of Computer-Mediated Communication as a Media Choice in the Facilitation of Task Performance in Small Groups. Ph.D. Dissertation*, The Pennsylvania State University.

Fisher, C. (1988). Advancing the study of programming with computer aided protocol analysis. In G. Olson, E. Soloway, and S. Sheppard (Eds.), *Empirical studies of programmers: 1987 workshop* (pp. 198-216). Norwood, NJ: Ablex.

Flin, R., Slaven, G. and Stewart, K. (1997). Emergency decision making in the offshore oil and gas industry. *Human Factors.* 38(2), 262-277.

Franz, C.R.; and Jin, K.G. (1995) The structure of group conflict in a collaborative work group during information systems development. *Journal of Applied Communication Research*, 23, 108-127.

Fuld, R. and Wickens, C.D. (1986). An investigation of operator performance in manual and automated versions of a visual monitoring task, *NASA-NAG-2-30 Technical Report*. Urbana, Illinois: Engineering Psychology Research Laboratory.

Fulk, J., Steinfield, C.W., Schmitz, J., and Power, J.G. (1987). A social information processing model of media use in organizations. *Communication Research*, 14(5), 529-552.

Gale, S. (1991). *Adding audio and video to an office environment*. In J.M. Bowers and S.D. Benford (Eds.) Studies in Computer Supported Cooperative Work. New York, NY: Elsevier Science Publishing Company, Inc.

Gallupe, R.B. (1985) *The Impact of Task Difficulty on the Use of a Group Decision Support System*. Unpublished Ph.D. Dissertation, University of Minnesota.

Gallupe, R.B., DeSanctis, G., and Dickson, G. (1988). Computer based support for group problem finding: An experimental investigation. *Management Information Systems Quarterly*. 12, 277-296

Garter, L.E. and Wellman, B. (1993). *Social impacts of electronic mail in organizations: a review of the research literature.* Technical Report. Center for Urban and Community Studies and the Ontario Telepresence Project. Toronto, Canada: University of Toronto.

Gaver, W.W. (1992). The affordances of media spaces for collaboration. In *Proceedings of CSCW '92: Computer Supported Cooperative Work.* New York, NY: The Association for Computing Machinery.

George, J.F., Easton, G.K., Nunamaker, J.F. and Northcraft, G.B. (1988). *A Study of Collaborative group work with and without computer-based support, Report*, College of Business and Public Administration, University of Arizona, Tucson, AZ.

George, J.F., Northcraft, G.B. and Nunamaker, J.F. (1987). *Implications of group decision support use for management: Report of a pilot study*. College of Business and Public Administration, University of Arizona, Tucson, AZ.

Gladstein, D. (1984). Groups in Context: A Model of Task Group Effectiveness. *Administrative Science Quarterly*, 29, 499-517.

Glass, A.L., Holyoak, K.J., and Santa, J.L., (1979). *Cognition.* Reading, Massachusetts: Addison-Wesley, Reading, Massachusetts.

Goldman, S.L., Nagel, R.N., and Preiss, K. (1995). *Agile Competitors and Virtual Organizations.* New York: Van Nostrand Reinhold.

Goodman, P.S. (1986). The impact of task and technology on group performance. In P.S. Goodman (Ed.) *Designing Effective Work Groups*, San Francisco: Jossey-Bass Publishers

Goodman, P.S., Ravlin, E., and Schminke, M. (1987). Understanding groups in organizations. In L.L. Cummings and B.M. Staw (Eds.), *Research in Organizational Behavior*, Greenwich, CT: JAI Press, Inc.

Gray, P. (1983). Initial observation from the decision room project. In: G.P. Huber (ed.), *DSS-83 Transactions, Third International Conference on Decision Support Systems.* June, 27-29, Boston, MA. 135-138

Green, C. and Williges, R.C. (1995). Evaluation of alternative media used with a groupware editor in a simulated telecommunications environment. *Human Factors*, 37(2), 283-289.

Hacker, M.E., and Kleiner, B.M. (1996). Understanding effective natural work group performance through a sociotechnical approach. In O. Brown Jr. and H.W. Hendrick (Eds.). *Human Factors in Organizational Design and Management.* Elsevier: Amsterdam. 471-474.

Hackman, J., and Morris, C. (1975). Group tasks, group interaction process and group performance effectiveness. *Advances in Experimental Social Psychology*, 8, 45- 99.

Han, S.H., Williges, B.H., and Williges, R.C. (in press). A paradigm for sequential experimentation. *Ergonomics*.

Harrison, B. L. (1991). Video Annotation and Multimedia Interfaces: From Theory to Practice. *Proceedings of the Human Factors Society 35th Annual Conference*. San Francisco, CA. September, 1991.

Harrison, R. P. (1974). *Beyond Words: An Introduction to Nonverbal Communication*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Heise, D. (1991) Event structure analysis: A qualitative model of quantitative research. In N.G. Fielding and R.M. Lee (Eds.). *Using Computers in Qualitative Research*, London: Sage

Hendrick H.W. (1984). Waging the tail with the dog: Organizational design considerations in ergonomics. *Proceedings of the Human Factors and Ergonomics Society, 28th Annual Meeting.* Santa Monica, CA: Human Factors and Ergonomics Society.

Hendrick, H. W. (1986). Macroergonomics: A conceptual model for integrating human factors with organizational design, *Human Factors in Organizational Design and Management - II*

Hendrick, H. W. (1991). Ergonomics in organizational design and management, *Ergonomics , 34,* 743-756

Hendrick, H.W. (1979). Differences in group problem solving behavior and effectiveness as a function of abstractness. *Journal of Applied Psychology, 64,* 518-525.

Hiltz, R.S., Johnson, K., and Turoff, M. (1986). Experiment in group decision making: Communication process and outcome in face-to-face versus computerized conferences. *Human Communication Research.* 13, 225-252.

Hiltz, R.S., Turoff, M. and Johnson, K., (1988). Experiment in group decision making: Disinhibition, deindividualization, and group process in pen name and real name computer conferences. *Decision Support Systems.* 5, 217-232.

Hiltz, S.R., Johnson, K., and Turoff, M. (1987). Experiments in group decision making: communication process and outcome in face-to-face versus computerized conferences. *Human Communication Research,* 13(*2*), 225-252.

Hollenbeck, J.R., Illgen, D.R., Sego, D., Hedlund, J., Major, D., and Phillips, J. (1995). Multi-level theory of team decision making: Decision making teams incorporating distributed expertise. *Journal of Applied Psychology*, 80, 292-317.

Huber, G.P. (1984). The Nature of Post Industrial Organizations. *Management Science,* 30, 928-951

Hunter, J.E., and Schmidt, F.L. (1990). *Methods of Meta-Analysis: Correcting Error and Bias in Research Findings*. Newbury Park: Sage Publications, Inc.

Idaszak, J.R. (1989). Human operators in automated systems: The impact of active participation and communication. In *Proceedings of the Human Factors Society 33rd Annual Meeting*, Denver, Colorado, pp. 778-782.

Inzana, C.M., Willis, R.P., and Kass, S.J. (1994). The effects of physical distribution of team members on team cohesiveness and performance. *Proceedings of the Human Factors Society, 38th Annual Meeting* . (pp. 953). Santa Monica, CA: Human Factors Society

Isaacs, E.A. and Tang, J.C. (1994). What video can and cannot do for collaboration: a case study. *Multimedia Systems*, 2, 63-73.

Jarvenpaa, S.L., Rao, V.S., and Huber, G.P. (1988). Computer support for meetings of groups working on unstructured problems: A field experiment. *Management Information Systems Quarterly*. 12, 645-665.

Jessup, L.M., Tansik, D.A., and Laase, T.D. (1988). Group problem solving in an automated environment: The effects of anonymity and proximity on group process and outcome with a group decision support system. Unpublished Manuscript .

Jin, Y., Levitt, R.E., Christiansen, T.R., and Kunz, J.C. (1995). The virtual design team: Modeling organizational behavior in concurrent design teams. *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing, 9,* 145-158

Johnson, P.C. (1994). *Newly Formed Group Results: A Study of Computer-Supported Group Performance And Non-Computer Supported Group Performance Within and Between Groups. Ph.D. Dissertation*, University of Oklahoma.

Kaempf, G.L., Klein, G., Thordsen, M.L. and Wolf, S. (1997). Decision making in complex naval command-and-control environments. *Human Factors.* 38(2), 220-231.

Kandel, J.J. (1991). *The Effects Of Group Homogeneity-Heterogeneity Based On Cognitive Style On The Quality Of Group Decision Making. Ph.D. Dissertation*, University of Maryland.

Kazman, R.; Al-Halimi, R.; Hunt, W.; and Mantei, M. (1996) Four paradigms for indexing video conferences. *IEEE Transactions on Multimedia*, Spring, 63-73.

Kies, J.K. (1997). *Empirical methods for evaluating video-mediated collaborative work. Ph.D. Dissertation*. Blacksburg, VA: Virginia Tech.

Kies, J.K., Williges, R.C., and Rosson, M.B. (1997). Evaluating desktop video conferencing for distance learning applications. *Computers and Education*. 28(2) 79-91

Kiesler, S., Siegel, J., and McQuire, T.W. (1984). Social psychological aspects of computer-mediated communication. *American Psychologist,* 39(10), 1123-1134.

Kleiner, B. M. (1997). *Human Factors and Ergonomics Society Macroergonomics Technical Group Web Site*, (http://mgdsl.ise.vt.edu/odam/), MGDSL Lab, Virginia Polytechnic Institute and State University.

Kleiner, B.M. (1997) An integrative framework for measuring and evaluating information management performance. *International Journal of Computers and Industrial Engineering*, 32(3), 545-555.

Kleiner, B.M. and Drury, C.G. (1998) The use of verbal protocols to understand and design skill-based tasks. *International Journal of Human Factors and Ergonomics in Manufacturing.* 8(1), 23-39.

Kolodny, H., and Kiggundu, M. (1980). Towards the development of a sociotechnical systems model in woodlands mechanical harvesting. *Human Relations*, 33, 623-645.

Kraemer, K.L. and Pinsonneault, A. (1989). The implications of group support technologies: An evaluation of the empirical research. *Proceedings of the Hawaii International Conference on System Science.* IEEE Computer Science Press. 326-336

Leblanc, L.A., and Kozar, K.A. (1987), The impact of group decision support system technology on vessel safety. Report, School of Management, Indiana University, Bloomington, IN.

Losada, M. and Markovitch, S., (1990). Group Analyzer: A system for dynamic analysis of group interaction. *Proceedings of the 23rd Annual Hawaii International Conference on System Sciences*, IEEE Computer Society, 101-110.

Lucas, H.C., and Baroudi, J. (1994). The role of information technology in organizational design. *Journal of Management Information Systems, 10*, 9-23

Lueke, E.; Pagerey, P.D.; Brown, C.R., (1987) User requirements gathering through verbal protocol analysis. In G. Salvedry (Eds.), *Cognitive Engineering in the Design of Human-Computer Interaction and Expert Systems*, Amsterdam: Elsevir Science Publishers.

Mack, R.L., Lewis, C.H., and Carroll, J.M. (1983). Learning to use word processors: Problems and prospects, *ACM Transactions on Office Information Systems*, 1, 254-271.

Mackay, W.E. (1989) EVA: An experimental video annotator for symbolic analysis of video data. *SIGCHI Bulletin*, 21, 68-71.

Martin, M.M., Williges, B.H., and Williges, R.C. (1990). Improving the design of telephone-based information systems. In *Proceedings of the Human Factors Society 34th Annual Meeting*, (pp. 198-202) Santa Monica: Human Factors Society.

Masoodian, M, Apperley, M., and Fredrickson, L. (1995). Video support for shared work-space interaction: an empirical study. *Interacting with Computers*, 7(3), 237-253.

McGrath, J. E. (1964). *Social Psychology: A Brief Introduction.* New York: Holt, Rinehart, and Winston.

McGrath, J.E. (1984). *Groups: interaction and performance*. Englewood, NJ: Prentice-Hall.

McGrath, J.E. (1986). Studying groups at work: ten critical needs for theory and practice. In P.S. Goodman (Ed.) *Designing Effective Work Groups*, San Francisco: Jossey-Bass Publishers.

McIntyre, R., and Salas, E. (1995). Measuring and managing for team performance: Emerging principles from complex environments. In R. A. Guzzo, and E. Salas (Eds.), *Team Effectiveness and Decision Making in Organizations* (pp. 9-45). San Francisco: Jossey-Bass Publishers.

Meyer, C., (1994). How the right measures help teams excel. *Harvard Business Review, 6*, 95-103

Milgram, P., and Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems special issue on Network Reality*. 12(77), 1321-1329.

Mohrman, S.A. (1993). Integrating roles and structure in the lateral organization. In J.R. Galbraith, E.E. Lawler III (Eds.) *Organizing for the Future: The New Logic for Managing Complex Organizations*, San Francisco: Jossey-Bass Publishers

Montgomery, D.C. (1997). *Design and analysis of experiments*. (4th Edition). New York: Wiley.

Muckler, F., and Seven, S. (1992). Selecting performance measures: 'Objective' versus 'subjective' measurement. *Human Factors*, 34, 441-455.

Mühlbach, L., Böcker, M, and Prussog, A. (1995). Telepresence in video communications: a study on stereoscopy and individual eye contact. *Human Factors*, 37(2), 290-305.

Myers, R.H. (1971). *Response surface methodology*. Boston, MA: Allyn and Bacon.

Newell, A. and Simon, H. (1972). *Human Problem Solving.* Englewood Cliffs, New Jersey:

Nielsen, J. (1993) *Usability Engineering*. San Diego: Academic.

Nunamaker, J.F. Jr. (1987). Collaborative management work. *Management of Information Systems Conference*.

Nunamaker, J.F. Jr., Applegate, L.M., and Konsynsky, B.R. (1987). Facilitating group creativity: Experience with a group support system. *Journal of Management Information System* 3, 6-19.

Nunamaker, J.F. Jr., Applegate, L.M., and Konsynsky, B.R. (1988). Computer aided deliberation: Model management and group decision support. *Journal of Operations Research* 6, 826-848.

Nunamaker, J.F. Jr., Vogel, D., Heminger, A., Martz, B., Grohowski, R., and McGoff, C. (1989). Experience at IBM with group support systems: A field study. *Decision Support Systems* 5, 183-196.

Ochsman, R.B. and Chapanis, A. (1974). The effects of 10 communication modes on the behavior of teams during co-operative problem-solving. *International Journal of Man-Machine Studies,* 6, 579-619.

Olson, G.M.; and Olson, J.S. (1991) User centered design of collaborative technology. *Journal of Organizational Computing*, 1, 61-83.

Parker, G.M. (1994). *Cross-functional teams: working with allies, enemies, and other strangers*. San Francisco: Jossey-Bass Publishers.

Perrow, C. (1967). A framework for the comparative analysis of organizations. *American Sociological Review , 32*, 194-208)

Petrovic, O. and Krickl, O. (1994). Traditionally moderated versus computer supported brainstorming: a comparative study. *Information and Management, 27*, 233-243.

Pinsonneault, A., and Kraemer, K.L. (1990). The effect of electronic meetings on group processes and outcomes: an assessment of the empirical research. *European Journal of Operational Research.* 46, 143-161

Pinto, M., Pinto, J., and Prescott, J. (1993). Antecedents and Consequences of Project Team Cross-functional Cooperation. *Management Science,* 39, 1281-1297.

Polley, R., Hare, A., and Stone, P., (1988) *The SYMLOG Practitioner: Applications Small Group Research*, New York, Prager,

Poole, ,M.S.; and Holmes, M.E. (1995) Decision Development in Computer Assisted Group Decision Making. *Human-Computer Research*, 22(1), 90-127.

Poole, M.S., Holmes, M., and DeSanctis, G. (1999), “Conflict management and decision support systems”, *Proceedings of the Second Conference on Computer Supported Cooperative Work,* Portland, OR.

Poole, M.S.; and Roth, J. (1989) Decision development in small groups: IV. A typology of group decision paths. *Human Communication Research*, 15, 323-356.

Poole, M.S.; Holmes, M; Watson, R.; and DeSanctis, G. (1993) Group decision support and group communication. *Communication Research*. 20(2), 176-213.

Potel, M.J. and Sayre, R.E., (1976). Interacting with the GALATEA Film Analysis System, *Proceedings. of SIGGRAPH ‘76, ACM Computer Graphics*, 10(2), 52-59. Prentice-Hall.

Prince, A., Brannick, M. T., Prince, C., and Salas, E. (1992). Team process measurement and implications for training. *Proceedings of the Human Factors Society, 36th Annual Meeting* . (pp. 1351-1355). Santa Monica, CA: Human Factors Society

Rasmussen, J. and Jensen, A., (1974). Mental procedures in real-life tasks: A case study of electronic trouble shooting, *Ergonomics*, 47, 293-307.

Ritter, F.E. (1992) *A methodology and software environment for testing process models' sequential predictions with protocols*. Unpublished Ph.D. thesis, Carnegie Mellon University, Department of Psychology, Pittsburgh.

Ritter, F.E.; and Larkin, J.H. (1994) Developing process models as summaries of HCI action sequences. *Human-Computer Interaction*, 9, 345-383.

Roshelle, J.; Pea, R.; and Trigg, R. (1990). *VideoNoter: A tool for exploratory video analysis* (Technical Report IRL 90-0021). Palo Alto, CA: Institute for Research on Learning.

Rouse, W.B., Cannon-Bowers, J.A., and Salas, E. (1992). The roles of mental models in team performance in complex systems. *IEEE Transactions on System Man, and Cybernetics. 22* , 1296-1307

Rudnicky, A.I.; Hauptmann, A.G.; and Lee, K.F. (1994) Survey of current speech technology. *Communications of the ACM*, 37(3), 52-58.

Saaty, T.L. (1980). *The Analytic Hierarchy Process.* New York: Mac Graw Hill.

Saaty, T.L. (1990). *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World.* Pittsburgh: RWS Publications.

Sanderson , P.M.; and Fisher, C. (1994) Exploratory sequential data analysis: Foundations. *Human-Computer Interaction*, 9, 251-317

Sanderson , P.M.; Scott, J.J.P.; Mainzer, J; Johnston, T.; Watanabe, L.M.; and James, J.M. (1994) MacSHAPA and the enterprise of exploratory sequential data analysis (ESDA). *International Journal of Human-Computer Studies.*

Sanderson, P.M. and Murtagh, J.M. (1988). *Predicting fault diagnosis performance: Why are some bugs hard to find?* Department of Mechanical and Industrial Engineering, University of Illinois.

Sanderson, P.M., James, J.M., and Sieder, K.S. (1989). SHAPA: An interactive software environment for protocol analysis, *Ergonomics*, 32:11, 1271-1302.

Sanquist, T.F. and Fujita, Y. (1989). Protocol analysis and action classification in the education of an advanced annunciator system design. In *Proceedings of the Human Factors Society 33rd Annual Meeting*, Denver, Colorado, pp. 1064-1067.

Schiflett, S.G. and Elliott, L.R. (1997) Personal communication.

Short, J., Williams, E., and Christie, B. (1976). *The social psychology of telecommunications*. London: Wiley.

Siegel, J., Dubrovsky, V., Kiesler, S., and McGuire, T. (1986). Group processes in computer-mediated communication. *Organizational Behavior And Human Decision Processes* 37, 157-187.

Simon, C. (1973). *Economical multifactor designs for human factors engineering experiments* (Tech. Report P73-326A). Culver City: Hughes Aircraft.

Smith, J., and Vanecek, M.T.(1989) A non-simultaneous computer conference as a component of group decision support systems. In R. Blanning and D. King (eds.), *Proceedings of the Twenty Second Annual Hawaii International Conference on System Science.* IEEE Computer Society Press, 370-377.

Smith, R.B. O'Shea, T., O'Malley, C., Scanlon, E., and Taylor, J. (1991). Preliminary experiments with a distributed, multi-media, problem solving environment. In J.M. Bowers, and S.D. Benford, S. D. (Eds.) *Studies in Computer Supported Cooperative Work.* Amsterdam: Elsevier Science Publishers B.V. (North Holland).

Spillman, B; Spillman, R.; and Bezdek, J. (1980) A fuzzy analysis of consensus in small groups. In P. Wang and S. Chang (Eds.), *Fuzzy Sets: Theory and Application to Policy Analysis and Information Systems*, (pp. 291-308). New York, NY: Plenum.

Sproull, L. and Kiesler, S. (1991). *Connections: new ways of working in the networked organization*. Cambridge, MA: MIT Press.

Steeb, R., and Johnson, S.C. (1981). A commuter-based interactive system for group decision-making. *IEEE Transactions on Communications* COM-30, 82-90.

Stefik, M., Bobrow, D.G., Foster, G., Lanning, S., and Tatar, D. (1987). WYSIWYS revised: early experiences with multi-user interfaces. *ACM Transactions on office information systems*, 5(2), 147-167.

Swigger, K.M.; and Brazile, R. (1995) Evaluating group effectiveness through a computer-supported cooperative training environment. *International Journal of Human-Computer Studies*, 43, 523-538.

Tang, J.C. and Isaacs, E. (1993). Why do users like video? studies of multimedia-supported collaboration. *Computer Supported Cooperative Work (CSCW)*, 1, 163-193.

Tannenbaum, S., Beard and Salas, E. (1992). Team Building and Its Influence on Team Effectiveness: An Examination of Conceptual and Empirical Developments. In D. Kelley, (Ed.), *Issues, Theory, and Research in Industrial/Organizational Psychology*. (pp. 117-153). Norwood, NJ: Ablex Publishing Corporation.

Tower, S.L. and Elliott, L.R. (1996). The role of communication efficiency in teams with distributed expertise: Application of the multi-level theory. *Proceedings of the International Association of Management Conference*. Toronto, Canada.

Trevino, Lengel, and Daft (1987). Media symbolism, media richness, and media choice in organizations. *Communications Research*, 14(5), 553-574.

Troyer, L. (1995). *Team Embededness: the relations between team social structures, organizational social structures, and team performance*. Ph.D. Dissertation. Stanford University.

Turoff, M.; and Hiltz, S.R. (1982) Computer support for group versus individual decisions. *IEEE Transactions on Communication*, COM-30(1), 82-90.

Umbers, T.G. (1979). A study of the control skills of gas grid control engineers, *Ergonomics*, 22, 557-571.

Urban, J.M.; Weaver, J.L.; Bowers, C.A.; and Rhodenizer, L. (1996) Effects of workload and structure on team processes and performance: Implications for complex team decision making. *Human Factors*, 38(2), 300-310.

Valacich, J.S. (1989). *Group Size and Proximity Effects On Computer-Mediated Idea Generation: A Laboratory Investigation*. Ph.D. Dissertation. University of Arizona.

Van De Ven, Andrew H. and Delbecq, Andre L., (1974). The effectiveness of nominal, Delphi, and interacting group decision making process. *Academy of Management Journal*, 17(4), 605-621.

Vogel, D., Nunamaker, J.F., Applegate, L.M., and Konsynsky, B.R. (1987). Group decision support systems: Determinants of success. *DSS-87 Transactions, Seventh International Conference on Decision Support Systems* 118-128.

Waterman, D.A.; and Newell, A. (1971) Protocol analysis as a task for artificial intelligence. *Artificial Intelligenc*e. 2, 285-318.

Waterman, D.A.; and Newell, A. (1972) *PASS-II: An interactive task-free version of an automatic protocol analysis system*. Pittsburgh: Carnegie Mellon University, Department of Computer Science.

Watson, R.T., DeSanctis, G.L., and Poole, M.S. (1988). Using a GDSS to facilitate group consensus: Some intended and unintended consequences. *Management Information Systems Quarterly* 12, 463-477.

Watts, L., Monk, A., and Daly-Jones, O. (1996). Inter-personal awareness and synchronization: assessing the value of communication technologies. *International Journal of Human-Computer Studies*, 44, 849-873.

Weaver, J.L., Urban, J.M., Maniam, N., and Bowers, C.A. (1994). Team skill acquisition: Team and individual effects of feedback. *Proceedings of the Human Factors Society, 38th Annual Meeting* . (pp. 1209-1213). Santa Monica, CA: Human Factors Society

Weeks, G.D. and Chapanis, A. (1976). Cooperative versus conflictive problem solving in three telecommunication modes. *Perceptual and Motor Skills*, 42, 879-917.

Weisbord, M. R. (1987). *Productive Workplaces*. San Francisco: Jossey-Bass Inc.

Williams, E. (1977). Experimental comparisons of face-to-face and mediated communication: a review. *Psychological Bulletin*, 84(5), 963-976.

Williges, R. C. (1981). Development and use of research methodologies for complex system / simulation experimentation. In M. Morral and K. Kraiss (Eds.), *Manned system design* (pp. 59-87). New York, NY: Plenum.

Williges, R. C. and Williges, B. H. (1982). Modeling the human operator in computer-based data entry. *Human Factors*, 24, 285-299.

Williges, R. C., Johnston, W. A., and Briggs, G. E. (1966). Role of verbal communication in teamwork. *Journal of Applied Psychology*, 50, 473-478.

Williges, R.C. (1995). Review of experimental design. In J. Weimer (Ed.), *Research techniques in human engineering.* (pp. 49-71) Englewood Cliffs: Prentice Hall PTR.

Williges, R.C. and Williges, B.H. (1989). Integrated research paradigm for complex experimentation. In *Proceedings of the Human Factors Society 33rd annual meeting.* (pp. 606-610). Santa Monica, California: Human Factors Society.

Williges, R.C. and Williges, B.H. (1995). Travel alternatives for the mobility impaired: the surrogate electronic traveler (set). In Edwards, A. D. N. (Ed.) *Extra-ordinary Human-Computer Interaction*. Cambridge, England: Cambridge University Press.

Williges, R.C., Williges, B.H., and Han, S.H. (1992). Developing quantitative guidelines using integrated data from sequential experiments. *Human Factors*, 34, 399-408.

Williges, R.C., Williges, B.H., and Han, S.H. (1993). Sequential experimentation in human- computer interface design. In R. Hartson and D. Hix (Eds.), *Volume IV, Advances in human-computer interaction*. (pp. 1-30) New York: Ablex.

Winer, B.J., Brown, D.R., Michels, K.M. (1991) *Statistical principles in experimental design* (3rd Edition). New York, NY: McGraw-Hill.

Wolfe, J. and Chacko, T.I. (1983). Team-size effects on business game performance and decision-making behavior. *Decision Sciences*, 14, 121-133

Zachary, W. (1986). A cognitively based functional taxonomy of decision support techniques. *Human – Computer Interaction*. 2, 25-63

Zalensky, M.D., and Salas, E., (1992). Measuring process in team performance and training. *Proceedings of the Human Factors Society, 36th Annual Meeting* . 1342-1345. Santa Monica, CA: Human Factors Society.

Zigurs, I., Poole, M.S., and DeSanctis, G.L. (1987). A study of influence in computer mediated decision making. Report, MIS Department, Curtis L. Carlson School of Management, University of Minnesota, Minneapolis, MN.

Zigurs, I., Poole, M.S., and DeSanctis, G.L. (1988). A study of influence in computer mediated group decision making. *Management Information Systems Quarterly* 12, 625-644.