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COMPUTER-AIDED GROUP PROBLEM SOLVING FOR UNIFIED LIFE CYCLE ENGINEERING (ULCE)

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Unified Life Cycle Engineering (ULCE) is a design engineering environment in which the quality of a product is improved by integrating the consideration of the design attributes of producibility and supportability with the design attributes of performance, cost, and schedule. The ULCE program has traditionally focused on developing tools and techniques for a single designer to use to accomplish this integration. The goals of the ULCE program, however, are congruent with the goals of the current simultaneous engineering programs in industry, and industry uses multi-functional design teams to accomplish these goals. The authors assert that the application of computer-aided group problem solving technology to engineering design represents an unexploited opportunity to enhance the effectiveness of simultaneous engineering design teams. Thus, the authors recommend that the ULCE program broaden its focus to include research in computer-aided group problem solving techniques and tools to be used by design teams. To support the findings and recommendations, the paper includes a survey of both industry design team practices and computer-aided group problem solving methodologies and technology.

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INSTITUTE FOR DEFENSE ANALYSES

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PREFACE

This paper is the result of work performed by the Institute for Defense Analyses (IDA) under contract number MDA 903 84 C 0031, task order T-D6-554, "Measurement Issues in Unified Life Cycle Engineering." This work was performed for the Air Force Human Resources Laboratory, Logistics and Human Factors Division, and the Under Secretary of Defense for Acquisition (USD(A)).

This paper specifically addresses subtask five of the task order and covers an investigation into current industry practices in team design, the use of computers to support group problem solving that could be employed by these teams, and the implications for the Unified Life Cycle Engineering (ULCE) Program.

This paper was reviewed by Drs. Fred Riddell and James Pennell of IDA and by Dr. Daniel Schrage of the Georgia Institute of Technology, consultant to IDA.

CONTENTS

PREFACE iii

GLOSSARY vii

EXECUTIVE SUMMARY ES-1

A. Recommendation ES-2

B. Research Issues ES-3

1. Combining Individual Judgmental Evaluations ES-3
2. Decision Audit Trails ES-3
3. Structured Group Processes ES-3

C. Summary ES-3

I. INTRODUCTION 1

II. CURRENT INDUSTRY PRACTICES FOR INTEGRATING PRODUCIBILITY AND SUPPORTABILITY CONSIDERATIONS IN EARLY DESIGN 3

A. Simultaneous Engineering 4

B. Difficulties Experienced by Simultaneous Engineering Teams 5

1. Group Dynamics in Diverse Groups 6
2. Reaching Consensus 7

C. Strategies Used by Various Companies 8

III. RESEARCH IN COMPUTER-AIDED GROUP PROBLEM SOLVING 13

A. Current Research 13

1. Chaffeured Systems 14
2. Multi-User Systems 17

B. Observations 22

1. Applications to Design 23
2. Chauffeured versus Multi-User Approach 24

IV. CONCLUSION 27
A. Recommendation 27
B. Research Issues 28
1. Combining Individual Judgmental Evaluations 28
2. Decision Audit Trails 28
3. Structured Group Processes 28
C. Summary 29
REFERENCES 31
ANNOTATED BIBLIOGRAPHY 35
Papers 35
Reports 69
Books 69
DISTRIBUTION LIST DL-1

LIST OF FIGURES

III.1. PlexCenter Facility 19
III-2. CMI Enterprise Room 19
III-3. Claremont Graduate School GDSS Facility 20

GLOSSARY

AFHRL/LR	Air Force Human Resources Laboratory, Logistics Research Division
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CIM	Computer-Integrated Manufacturing
CSCW	Computer-Supported Cooperative Work
DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
DSS	Decision Support System
DTG	Decision Techtronics Group
GDSS	Group Decision Support Systems
IDA	Institute for Defense Analyses
IM	Interactive Management
PARC	Palo Alto Research Center
SAMM	Software-Aided Meeting Management
ULCE	Unified Life Cycle Engineering
USD(A)	Under Secretary of Defense for Acquisition

EXECUTIVE SUMMARY

While investigating the various techniques currently used by industry to evaluate producibility and supportability in the early phases of the design process, it became evident that the trend in industry is toward team design where comparative evaluations of design attributes are made by a multifunctional team. This finding prompted an investigation into current industry team design practices and the use of computers to provide group problem solving support for these teams. These investigations were performed with the objective of determining the implications of the findings to the Unified Life Cycle Engineering (ULCE) Program.

ULCE is a design engineering environment in which the quality of a product is improved by integrating consideration of design attributes for producibility and supportability with design attributes for performance, cost, and schedule. At the opening of the first ULCE Decision Support System (DSS) Working Group meeting held at IDA in April 1987, Col. D. C. Tetmeyer, Chief, Air Force Human Resources Laboratory, Logistics Research Division (AFHRL/LR), characterized ULCE as follows:

> ULCE must focus on the total design process. This process must be viewed realistically as a system of people working together in a dynamically changing environment. Tools developed as a part of ULCE must be usable by today's engineers, enhance group design activity, and result in achievement of the overall goal of obtaining designs which are balanced in the producibility and supportability characteristics as well as the usual characteristics of performance, cost, and schedule.

Throughout the ULCE Implementation Plan, the proposed solution to integrating producibility and supportability considerations early in the design process is to develop Computer-Aided Design (CAD) tools for use by a single designer. In light of current industry trends, this focus appears to be too narrow.

A. RECOMMENDATION

The authors recommend that the ULCE Program broaden its focus to include research in computer-aided group problem solving. The current industry trend toward simultaneous engineering with multifunctional teams should provide strong motivation to explore computer-aided group problem solving. The greatest problems of implementing simultaneous engineering are not technical; they are problems of human coordination. Simultaneous engineering with multifunctional teams increases the problems of group dynamics in design meetings. A multifunctional team is more diverse than the multidisciplinary teams of the past. In addition to engineers from different disciplines, marketing and financial experts now participate in design meetings. The multifunctional teams also meet more often to review the design. A primary goal of computer-aided group problem solving is to improve solution quality and reduce meeting time without decreasing group member satisfaction. Findings on the current industry practices in design by multifunctional teams and the problems encountered through these practices are presented in Chapter II.

The importance of early design decisions is widely recognized. It is often stated that roughly 70 percent of the total life cycle cost of the system is determined during the conceptual phase. Due to the lack of hard data, very few traditional CAD tools are available to support the early stages of design. Considering the high leverage of the decisions made during these stages, this is an undesirable situation. As demonstrated by the Boothroyd and Dewhurst Design for Assembly (DFA) methodology, computer-aided group problem solving is a practical way to use the computer in the early stages of design when eliciting and combining the judgments of individuals who have relevant knowledge is critical. A description of DFA and other current research in computer-aided group problem solving is given in Chapter III.

The government is responsible for determining requirements, developing concepts, and evaluating proposals for the systems it acquires, and these activities can be viewed as early or conceptual design. The government should follow industry's example and use multifunctional team design. Computer-aided group problem solving tools can be used by the government to efficiently implement this concept in system acquisition. A major benefit of using computer-aided group problem solving for these tasks would be the documentation of acquisition decisions.

B. RESEARCH ISSUES

The application of computer-aided group problem solving technology to design engineering raises many research issues. Several issues the authors feel are important in the near term are described in the following sections.

1. Combining Individual Judgmental Evaluations

One of the most difficult tasks facing a multifunctional design team is the elicitation and combination of the team members' individual judgments. The Boothroyd and Dewhurst DFA evaluation methodology is one approach being used today. What other approaches could be used? The Boothroyd and Dewhurst approach is being applied to other producibility problems. Can it be applied to supportability problems as well? What are the implications of the Theory of Measurement?

2. Decision Audit Trails

One of the key benefits of computer-aided group problem solving is the ability to document decision rationales, which has long been needed for design projects. Is the current documentation produced by current computer-aided group problem solving techniques adequate for design projects? What form should this documentation take? How should the documentation of different design phases be linked?

3. Structured Group Processes

The way group members interact strongly affects how effectively the group will perform. There is strong evidence indicating that unstructured group interaction is not very effective. More than 70 different structured problem solving techniques have been offered for group use by VanGundy. [Ref. 1] What are the impacts of adding structure to the problem solving process? Which structured processes are best for design situations? What are the effects of adding structure to the way the group interacts on member participation and satisfaction?

C. SUMMARY

The application of computer-aided group problem solving technology to engineering design represents an unexploited opportunity to enhance the effectiveness of simultaneous engineering teams. While computer-aided group problem solving has not been widely used in engineering design, it has been used to solve many other types of problems. The ULCE Program should direct its research toward engineering design problems and recognize that enhancing group problem solving capabilities would benefit many situations other than design in both industry and government.

I. INTRODUCTION

While investigating the various techniques currently used by industry to evaluate producibility and supportability in the early phases of the design process, it became evident that the trend in industry is toward team design where comparative evaluations of design attributes are made by a multifunctional team. This finding prompted an investigation into current industry team design practices and the use of computers to provide group problem solving support for these teams. These investigations were performed with the objective of determining the implications of the findings to the Unified Life Cycle Engineering (ULCE) Program.

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Throughout the ULCE Implementation Plan, the proposed solution to integrating producibility and supportability considerations early in the design process is to develop Computer-Aided Design (CAD) tools for use by a single designer. In light of current industry trends, this focus appears to be too narrow.

The authors recommend that the ULCE Program broaden its focus to include research in computer-aided group problem solving. This recommendation is based on three supporting ideas, which will be expanded on in this report:

- The current industry method of incorporating consideration of producibility and supportability design attributes early in the design process is through a multifunctional design team. Computer-aided group problem solving tools are being successfully used by industry design teams and have the potential to increase the effectiveness of these design teams.
- Many of the problems faced in the early phases of design, where many of the life cycle characteristics of a system are determined, are not amenable to traditional CAD solutions. Computer-aided group problem solving is a practical way to use the computer in the early stages of design.
- Computer-aided group problem solving tools can provide greatly needed documentation of the design problem solving process.

Findings on the current industry practices in design by multifunctional teams and the problems associated with these practices is presented first. Next, a description of current research in computer-aided group problem solving is given. Recommendations and several ideas for further research conclude the paper.

In the course of this research, an extensive literature survey on computer-aided group problem solving and simultaneous engineering was conducted. The relevant papers and available abstracts are presented in the annotated bibliography at the end of this paper.

II. CURRENT INDUSTRY PRACTICES FOR INTEGRATING PRODUCIBILITY AND SUPPORTABILITY CONSIDERATIONS IN EARLY DESIGN

A few years ago, Computer-Integrated Manufacturing (CIM) with high technology robots and complex automation was seen as the answer to the US industry problems related to international competitiveness. However, automation has not paid off as expected. General Motors (GM) has spent enough money on automation to have purchased all of Toyota, yet productivity gains attributable to the automation remain elusive. Many companies are now recognizing that successful competitiveness lies not in automating their traditional ways of doing business, but in restructuring the way they do business, with a focus on design as the primary life cycle cost driver. The restructuring starts with an alteration of the product and process cycles so that the *producibility* and *supportability* of the product are considered in the early phases of design. These changes imply that the industry goals are similar to those of the Air Force ULCE Program, and like US industry, the Air Force may require more than Computer-Aided Engineering (CAE) and CAD tools for individual designers. Successful US firms have also integrated producibility and supportability experts with designers in multifunctional design teams.

Industry has come to realize that the problems of integrating producibility and supportability considerations into the design process are not just technical problems but also management and cultural problems dealing with human coordination. The trend in industry is to recognize that people, not machines, can have the greatest impact on lowering cost and increasing productivity. A recent example is that of GM's Saturn Corporation:

> Saturn's decision to put less whiz-bang technology in its plants also indicates flexibility and maturity. ... Saturn ... has shifted its emphasis from machines to people in carrying out its main stated mission... [Ref. 2]

Industry is now focusing on deriving management strategies, methodologies, and support tools that enable multifunctional design teams to work together efficiently and arrive at effective decisions based on their combined expert knowledge. This fact is emphasized by

Bart Huthwaite in the training sessions for Boothroyd and Dewhurst's Design for Assembly (DFA).

> While quantitative product design evaluation methods, CAD systems, and other techniques can significantly improve engineering efficiency, teamwork between the product and process engineering functions is absolutely essential. [Ref. 3]

The remaining sections of this chapter define simultaneous engineering, discuss problems encountered in getting multifunctional design teams to work together effectively, and describe some strategies used by various companies to overcome these problems.

A. SIMULTANEOUS ENGINEERING

Various terms are used to define the new managerial strategy in US industry that combines design engineers, manufacturing engineers, marketing and financial people, customers, and suppliers in a multifunctional design team for the purpose of working together to develop better products. These terms include "team approach," "concurrent engineering," "life cycle engineering," "design for manufacture," "parallel engineering," "integrated engineering," and "simultaneous engineering." [Ref. 4] Regardless of the term used, the concept usually associated with this strategy is that designing the product for manufacturability (process) must be done concurrently with designing the product for functionality. This idea is easily expanded to include life cycle engineering or systems engineering concepts--designing the product for producibility and supportability must be done concurrently with designing the product for performance, cost, and schedule. For example, W. David Lee, Director, Arthur D. Little Center for Product Development, defines simultaneous engineering as follows:

> Simultaneous engineering is the process in which key design engineering and manufacturing professionals provide input during the design phase to reduce the downstream difficulties and build in quality, cost reduction, and reliability at the outset. [Ref. 5]

The term "simultaneous engineering," understood to include all life cycle considerations, will be used throughout this report.

Many companies are practicing simultaneous engineering. They include Boeing Aerospace, NCR, AT&T, Deere and Company, Texas Instruments, Ford Motor, Motorola, Miles Labs, Flint Engineering Center (Buick-Oldsmobile-Cadillac Group), General Electric, Lamb Technicon, Ingersoll Milling Machine, IBM, Honeywell, and AC Spark

Plug Division of GM. Representatives from many of these companies attended the Third International Conference on Product Design for Manufacture and Assembly (DFMA), held in Newport, Rhode Island, on June 6-8, 1988. The companies that are implementing DFMA are doing so in a simultaneous engineering culture that includes multifunctional design teams.

The speakers at the conference not only provided information on the current industry practices in incorporating producibility early in the design process using various measurement methods but also spoke about the issues involved with their use of multifunctional design teams. The majority of questions posed to the speakers at the 1988 conference concerned how to get these teams to function together efficiently. The participants at the conference spoke openly about the human coordination problems they faced when implementing simultaneous engineering and shared their respective solutions with the other participants.[1] These difficulties and the strategies for handling them are described in the following sections.

B. DIFFICULTIES EXPERIENCED BY SIMULTANEOUS ENGINEERING TEAMS

Problem solving in design goes beyond mere decisionmaking. It includes defining the problem, generating alternative solutions, evaluating alternatives, selecting alternatives, and implementing the solution. Systems engineering design problems in today's environment are multileveled, multidimensional, and multidisciplinary. All of the information required to form a solution may not be available, and the information that is available may be based on judgment and experience. In the early phases of design, most of the information is qualitative. A singular optimal solution is infeasible in the early design stages and satisficing[2] solutions must be found. Also, multiple measures of merit may exist for judging the level of acceptability of a design. [Refs. 7-8] Many of these problems become more complex when the problem solving is done by a multifunctional design team.

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1 For obvious reasons, many of these problems have not been documented in the open literature.

2 Simon first used the term 'satisficing' to describe a particular form of less-than-optimal solutions. These solutions are good enough to be acceptable, but are neither exact or optimal. [Ref. 6]

1. Group Dynamics in Diverse Groups

Design of complex systems involves human interaction among engineers with various backgrounds and from various disciplines. When multiple measures of merit for judging the level of acceptability of a design exist, all may not be equally important to the functionality of the design, but certainly all are not equally important to the individual members on the design team. Add to this the fact that project design teams are no longer limited to designers from multiple disciplines--they now include marketing and financial people, customers, suppliers, and all of the specialty engineers. The multifunctional nature of the design teams further complicates the group dynamics inherent in team design. Industry has found that successful simultaneous engineering requires teamwork and a culture that fosters multifunctional involvement [Ref. 4]. Teamwork in simultaneous engineering, as in any group process, requires a certain attitude on the part of the team members, and this attitude has cultural barriers.

> A major problem for design teams, however, is learning how to function as a team. Americans have been primarily trained to think and act as individuals. Our competitors from the Far East do not suffer this barrier to effective teamwork. [Ref. 3]

Industry recognizes that until the team attitude is instilled in industry culture, additional time may be required in the early stages of the design process. Design review meetings can be delayed by the same factors that delay any meeting, such as

- preparation time for the meetings
- waiting time to assemble team members
- reflection time for the team to study and comment. [Ref. 9]

In addition to the problems of time delays, the design review meeting has traditionally been a tug-of-war where team members waste much time debating alternatives. Various companies are addressing this problem with increased training for their employees in group dynamics.

Although the successes of the team approach in industry abound, reducing the additional time needed for a project design team to finalize designs is a key issue [Ref. 10]. Considerable evidence indicates that the increased time is due to the problems of group dynamics. The following causes of productivity loss in group decisionmaking have been identified by the social science community:

- Information loss due to group pressure leading to conformity of thought
  - Discussions are dominated by certain individuals.
  - Low-status members defer to high-status members--dominant individuals exercise undue sway.
- Information distortion
  - Miscommunication among members is common.
  - Goal of solution to problem may be replaced with secondary goal of winning an argument.
- Ineffectual decisionmaking due to insufficient time being spent in problem exploration and generation of alternatives [Refs. 11-14].

2. Reaching Consensus

The success of each design project clearly depends on the ability of the team members to work together [Ref. 15], thus total team satisfaction with the process and the resulting design is an important issue. Many speakers at the DFMA conference stressed the need for developing consensus among design team members. Consensus in the design team means arriving at a design that every member can live with--each member may not think it is the best design, but in agreeing to a particular design, each member must believe that all essential design elements have been included [Ref. 16]. Having all members satisfied with the design ensures design ownership and responsibility among team members. Bucciarelli identifies the importance of reaching consensus among design team members during the design process as follows:

> ... different participants in the design process have different perceptions of the design. ... The task of design is then as much a matter of getting different people to share a common perspective, to agree on the most significant issues, and to shape consensus on what must be done next, as it is a matter of concept formation, evaluation of alternatives, costing, and sizing... .[Ref. 17]

Henry W. Stoll, Manager, Design for Manufacture, Industrial Technology Institute (Ann Arbor, MI) also stresses consensus in his "Four C's of Simultaneous Engineering":

- *Concurrence*--product and process design are done in parallel
- *Constraints*--process constraints are considered as part of the product design
- *Coordination*--product and process are closely coordinated to achieve optimal matching of needs and requirements for effective cost, quality, and schedule

- *Consensus*--high-impact product and process decisionmaking involve full team participation and consensus [Ref. 18].

The idea of consensus without compromise is extended by Morley and Pugh with their definition of design as *controlled convergent disagreement:*

> ... the process of design may be seen as having some of the characteristics of a negotiation between interdependent participants. Consequently, there are two sides to this activity, and two related criteria for negotiation success. The first type of activity is cognitive, primarily; the second is political, primarily. The former functions to help people organize their intellectual activity and think clearly about the problems they face. The latter functions to manage differences within and between groups. The cognitive processes function to make jobs no harder than they need to be. The political processes function to prevent premature commitment to decisions (designs) which have not been sufficiently well appraised. In the context of design this means controlled convergent disagreement is necessary if the best choice of design is to be made. [Ref. 19]

C. STRATEGIES USED BY VARIOUS COMPANIES

Practices for implementing simultaneous engineering with multifunctional design teams vary among companies, although structure and training both play important roles. Texas Instruments' (TI) Defense Systems Electronics Group uses the terms "functional integration" and "cross-functional" teams to describe its process and organization for simultaneous engineering. [Refs. 20-21] The teams traditionally involve people from the areas of concept design, manufacture and assembly, quality control, and purchasing. Their team management rules for efficiency include the following:

- Holding regular meetings, at least weekly
- Limiting team size to no more than eight people
- Allowing members to criticize a proposed idea only by proposing a new idea
- Using iterative steps for the development, equipment planning, quality assurance, and cost accounting decisions as follows
  (1) Analysis of alternatives--assembly, costs, variants
  (2) Comparison of alternatives
  (3) Identification of weak spots--computer-aided assessment tools, value analysis
  (4) Brainstorming for new ideas

(5) Evaluation

(6) Implementation.

AT&T calls its design process Design for "X," where X can be manufacture, assembly, reliability, maintainability, etc. [Ref. 22] Their product-process design involves manufacture and assembly, distribution and installation, service and maintenance, and end-customer requirements. The motivation behind incorporating Design for "X" was a need for a management strategy to deal with the increased complexity of relationships in the design of today's systems, the rapid evolution of technology, and the need for competitive quality.

Design guidelines used by individual companies are usually considered as proprietary information. AT&T has produced nonproprietary versions of its guidelines, which are available to customers. Included in these guidelines are the following tasks:

1. Establish process management responsibilities
2. Define process and identify customer requirements
3. Define and establish measures
4. Assess conformance to customer requirements
5. Investigate process to identify improvement opportunities
6. Rank improvement opportunities and set objectives
7. Improve process quality [Ref. 23].

The tools required to perform these tasks include many structured group techniques, such as Nominal Group Technique (tasks 1-7), brainstorming (tasks 3-5, 7), and Affinity Diagram/KJ method (tasks 4 and 7).

General Electric's (GE) Aircraft Engines Division in Cincinnati successfully used a method called "DFA for Supportable Design" in the redesign of the Advanced High Work Turbine (AHWT) Nozzle. Their design goals were to match or improve assembly efficiency at equal or less cost. The multifunctional team included members from Assembly, Quality, Materials, and Integrated Logistics Support (ILS). They used the GE/Hitachi method plus the Boothroyd and Dewhurst software (see Chapter III.A.2.c.). Biweekly design reviews were held during which a Ph.D psychologist served as a facilitator for communications. One of the keys to the success of the project was identified as "people working together" by Tony Kim, Manager, Aircraft Performance Methods, at the Third ULCE Technical Interchange Meeting. [Ref. 24]

A structured approach to design review meetings is considered the key to success in using simultaneous engineering at GE. The goal is to "avoid unstructured design review meetings where lots is said and little is accomplished." [Ref. 25] Using DFA in a structured approach has improved the Engineering and Manufacturing interface and has resulted in thorough design evaluations. Implementing DFA at GE encouraged functional groups to work together, providing better teamwork and a do-it-right-the-first-time attitude.

The product design teams at Motorola, Inc., involve about 14 to 15 people--both salaried and hourly workers drawn from engineering, manufacturing, and quality control [Ref. 26]. Teams are managed by engineering personnel. Motorola attributes the success of its teams to the fact that the team environment is interactive, with daily reviews of the concepts, and that the team is physically segregated from other plant functions. Using DFA has motivated the product designers and manufacturing engineers to thoroughly plan projects from beginning to end.

Miles Labs (medical diagnostic systems) implemented the approach of two teams working in parallel to limit team size to eight members [Ref. 15]. Team members, initially reluctant to receive team building instruction, were eventually moved off the campus for their training. They were taught the principles of group dynamics, which focused on how to work together beyond the scope of a specific product and to understand the functions of other members and how they work. (Role playing was used as a learning technique). The teams also developed mission statements for their design projects during these retreats. This process itself instilled a camaraderie among team members [Ref. 15].

NCR Corporation defines design for producibility as encompassing all elements that affect production and customer satisfaction [Ref. 27]. NCR maintains that teamwork is the key element in the success of design for manufacture and has identified the following elements as essential to team success:

- Top management support (considered to be the most important element)
- Colocation of all design team members
- Multiorganizational team membership
  - Core members (six), including a customer service representative
  - Support members (eight), including suppliers

- Multidisciplined members, to capitalize on in-house skills
- Total team acceptance of the design.

The entire NCR team begins meeting weekly at least four months before the process begins. The team design objectives are set by the members relative to their areas of expertise. As the design develops, the team meetings use CAD systems with projection capabilities to review the design. The teams continue to work on an issue until consensus is reached and the issue is resolved. Everyone on the team has veto power, and the design is not released until all team members accept the design.

The DFMA Conference speakers from NCR stressed that care must be taken to ensure that the cooperative development process does not turn into a *design-by-committee* process. The design decisions are iterated until a design is produced that everyone can live with. At no time do team members vote, nor are any decisions made by majority rule. They stated that the team may spend many days trying to concur. They also identified the keys to success as reducing the decisionmaking time and using computer tools for support to do this.

The next chapter presents the results of research in computer-aided group problem solving and discusses the applicability of computer support to group problem solving in design teams, not in the form of tools to provide *the* answer, but in the form of tools to help design team members communicate effectively, combine their expert knowledge, and reach consensus on judgmental decisions.

III. RESEARCH IN COMPUTER-AIDED GROUP PROBLEM SOLVING

A growing number of researchers are exploring ways to combine communication, computer, decision, and group process technologies and methodologies to support group efforts. The computer support can be as simple as computer-controlled audiovisuals or as complex as specially designed meeting rooms with elaborate computer networks.

The phrase "computer-supported cooperative work" (CSCW) is gaining acceptance in the research community to describe the concept of providing computer support for groups. The term "cooperative" implies a willingness to work together and does not necessarily imply that all group members share common goals and objectives.

This chapter focuses on research directed at supporting groups in face-to-face meetings. Computer systems that support such meetings are sometimes referred to as Group Decision Support Systems (GDSS) [Refs. 28-30]. "The ultimate goal of GDSS is to improve decision quality and reduce meeting time in an atmosphere conducive to group member satisfaction." [Ref. 31] The term "decision" tends to imply an orientation toward the choice phase of problem solving. The GDSS concept utilized in this paper encompasses support for all phases of group problem solving (problem definition to solution implementation).

The first section of this chapter briefly describes some of the research efforts currently underway. The second section of this chapter presents observations about the research in computer-aided group problem solving, its applicability to design situations, and a comparison of the approaches.

A. CURRENT RESEARCH

The philosophies, approaches, and problems of current research in applying computer support to group problem solving can be divided into two broad categories. These categories, *chauffeured and multi-user,* describe how the group members interact with the computer support system. *Chauffeured* systems are operated by a group leader or facilitator and attempt to support the common needs of the group. The problem solving group members interact only indirectly with the computer support system. The chauffeured concept is being explored at George Mason University, the State University of New York at Albany, and the University of Rhode Island. *Multi-user* systems provide computer support for the individual and the group by furnishing each participant with a terminal or microcomputer in addition to providing a public display. Multi-user systems are being investigated at the University of Minnesota, the University of Arizona, Claremont Graduate School, Microelectronics and Computer Technology Corporation (MCC), and Xerox Palo Alto Research Center (PARC).

1. Chauffeured Systems

a. George Mason University

Researchers at George Mason University have developed a computer-assisted management problem solving technique called Interactive Management (IM). Interactive management is based on more than 15 years of research. IM has been used to solve strategic planning, urban planning, product design, and education problems in various locations around the world. Today there are four permanent installations of IM--George Mason University, Fairfax, Virginia; City University of London, London, England; Southwest National Marine Fisheries Service, San Diego, California; and US Forest Service, Atlanta, Georgia.

IM consists of the following five components:

- *IM Facilitator*, who organizes and manages the group work.
- *Participants*, 5 to 12 individuals who possess relevant knowledge.
- *Consensus Methodologies*, which provide the opportunity for focused, open dialogue in structuring ideas, designing alternatives, and making trade offs.
- *Computer Equipment and Programs*, based on sound behavioral and technical principles. The programs are used to efficiently derive structural maps illustrating relationships among ideas and perform trade-off analyses with both qualitative and quantitative attributes.
- *Demosophia*, a room specially designed to enhance the productivity, creativity, and comfort of the participants. Ample space is provided to accommodate up to 25 observers [Ref. 32].

IM is designed specifically for task-oriented, group problem solving. IM is intended to augment current management practices to enable the solution of complex problems that have not been solved through use of conventional approaches.

b. State University of New York, Albany

The Decision Techtronics Group (DTG) is a self-supporting arm of the State University of New York at Albany. DTG employs an approach to solving complex problems called Decision Conferencing. "Decision conferences are designed for groups that need to reach consensus on complex decisions for which there is no 'formula' or objective solution but, nonetheless, must be made on time, in spite of information gaps and uncertainty." [Ref. 33] The decision conferences generally last two full days.

At least three people from DTG, a facilitator, analyst, and correspondent, support each meeting. The *facilitator,* a specialist in group dynamics, assists the group in formulating the problem and selecting a model framework. The *analyst* provides the group with computer modeling support. The *correspondent* documents the group discussion.

A unique feature of Decision Conferencing is the interactive development of a computer-based decision model of the problem. The model may include mixture of hard data and value judgments. The results from the model are projected on a large screen for group analysis. The group rarely accepts initial models and the models evolve as the group gains a better understanding of the problem. The computer-based model helps group members understand each other's perspective, evaluate alternatives under different assumptions about the future, and explore relationships among various aspects of the problem.

Decision Conferencing has been used in negotiating multi-party agreements, allocating resources, evaluating and selecting options, making judgments explicit, and analyzing dynamic systems.

c. University of Rhode Island

Drs. Geoffery Boothroyd and Peter Dewhurst of the University of Rhode Island are considered the pioneers in research on DFMA. They developed a method for evaluating the assemblability of design alternatives which has become widely used in industry. The Boothroyd and Dewhurst *Design for Assembly* (DFA) software is designed for use by a product/process team (composed of both design and manufacturing engineers) early in the design process. The software resides on a microcomputer that is operated by a designated team member. Questions posed by the software are answered by the entire team. The method uses quantitative analysis to focus the group's efforts and draw on the creative power and expertise of individual team members. The quantification of design factors aids the group interaction process in team design activities, since the group must reach a consensus on the measurement ratings used to assess a design alternative's ease of assembly.

Twelve basic rules for ease of assembly are taught to the DFA team. These rules guide all team members as they design or redesign a product. The team evaluates an existing design (for redesign) or a proposed design, either of which is called the current design during the evaluation. To evaluate a current design, the team must know the assembly sequence, geometric features, and rough dimensions. Ratings of the current design for part handling and orientation and for part insertion and securing are arrived at by the group and entered into the program. The ratings are used to calculate an assembly time for the current design.

By considering the function of each part of the current design, the team creates an ideal design, which has a theoretical minimum number of parts. The theoretical minimum number of parts is entered into the program and a theoretical time for assembly of the ideal design is calculated. An assembly efficiency rating is then calculated for the current design as compared with the ideal design.

Sharing knowledge and working together to determine ratings and establish the theoretical minimum number of parts stimulates the creativity of team members. The group readily identifies problems with the current design and constantly produces ideas for improvement. Changes to the original design are based on these new ideas. The altered design then becomes the current design, and the process is repeated. This method provides a useful relative assessment of design alternatives when used by a single product process team. The method is not useful for comparing assembly efficiency ratings for designs evaluated by different teams.

The training sessions required for the proper use of DFA stress that computer tools needed for simultaneous engineering must support the human interaction that occurs during the design team problem solving process. DFA enhances the creativity and learning of team members, helps them arrive at consensus, and enables them to make estimates when hard data are not available. DFA is also quick--the key to consistent measurements made by a group is rapid iteration. The process is as valuable as the analytical results derived from its use.

DFA research continues at the University of Rhode Island. In addition to DFA, researchers have developed software for a Design for Manufacture (DFM) series, including modules for cost estimating machined parts, material selection, and estimating the cost of injection molded components.

2. Multi-User Systems

a. University of Minnesota

At the University of Minnesota, a group decision support system development effort has been in progress for approximately two years. The purpose of the development effort is to support a research program devoted to exploring the effect of using GDSS. The goals for the University of Minnesota GDSS research project are the following:

- Build and test a theory of how groups use GDSS and the effects of GDSS on group interaction and outcomes
- Contribute to the current body of knowledge of GDSS by exploring how the design of GDSS combines with contextual factors to affect the process and outcomes of organizational meetings
- Contribute to the development of a general theory of group and organizational structuring [Ref. 34].

A key characteristic of the research program is the interdisciplinary research staff that conducts lab experiments, field studies, and case studies. The program will investigate facilitated and nonfacilitated meetings and anonymous and nonanonymous communications. The research staff is also exploring structured and unstructured methodologies.

The software being developed, Software-Aided Meeting Management.(SAMM), supports groups in face-to-face meetings in a conference room setting. Each user has a terminal to access the system. To support the research program the SAMM software is designed to be flexible to allow for customization for different research experiments. The software is also designed to be expandable to incorporate new capabilities that emerge as the research program continues.

The focus of the University of Minnesota research program is how the use of a GDSS affects both the individual and the group. Satisfaction with the meeting, attitudes toward other group members, and decision confidence are all considerations that are measured through questionnaires and semistructured interviews. Structured observation, interactive analysis of videotapes, and verbatim protocols of the group meetings are used to assess the system's effect on the process and outcome of the group meeting.

b. University of Arizona

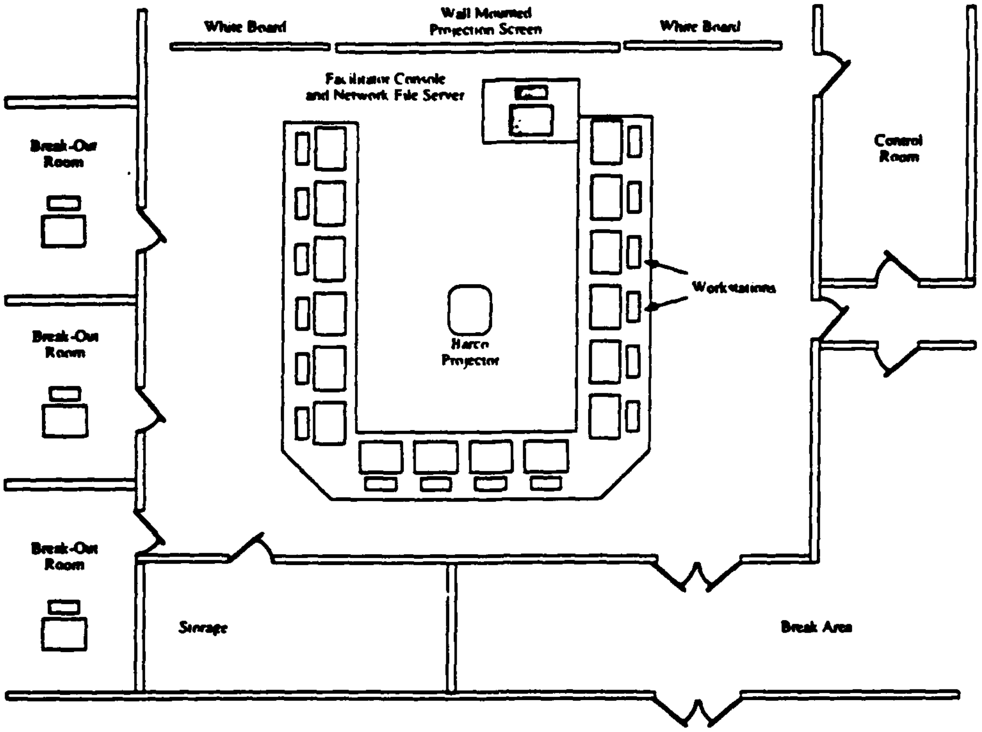
The GDSS research at the University of Arizona began in 1982. Two GDSS facilities are operating at the university, the PlexCenter and the new CMI Enterprise Room. The PlexCenter, shown in Figure III-1, has 16 networked microcomputers built into the U-shaped table, and public display is included on the network. The facility also offers small break-out rooms equipped with microcomputers attached to the network. The larger CMI Enterprise Room, shown in Figure III-2, has 24 microcomputers arranged in an amphitheater style. The microcomputers are linked in a local area network, and the room has two large public displays and extensive capabilities to record the meeting events.

The University of Arizona GDSS software includes the following modules:

- Electronic Brainstorming, an idea elicitation tool
- Issue Analysis, a tool for identification and consolidation of issues
- Voting, various voting and ranking tools
- Policy Formulation, a tool to develop policy statements
- Stakeholder Identification and Assumption Surfacing (SIAS), a tool to assess the impact of plans by identifying stakeholders
- Enterprise Analyzer, a computerized version of IBM's Business Systems Planning
- The Knowledge Base, a mechanism for storing planning knowledge.

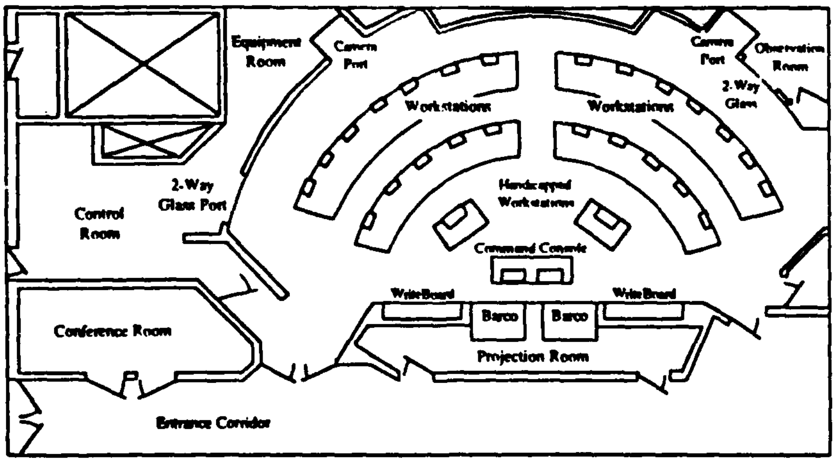
The University of Arizona researchers feel their research results should have the following implications for managers interested in using a GDSS:

- Efficiency and effectiveness gains from GDSS use are greater for groups with more than four members.
- Satisfaction with GDSS use is greater in large groups than small groups.
- Anonymous groups (groups that do not know who contributed various ideas) are less inhibited than are nonanonymous groups. Anonymity can foster a sense of participant equality, which can lead to more equal member participation [Ref. 30].



Source: Reference 30.

Figure III-1. PlexCenter Facility

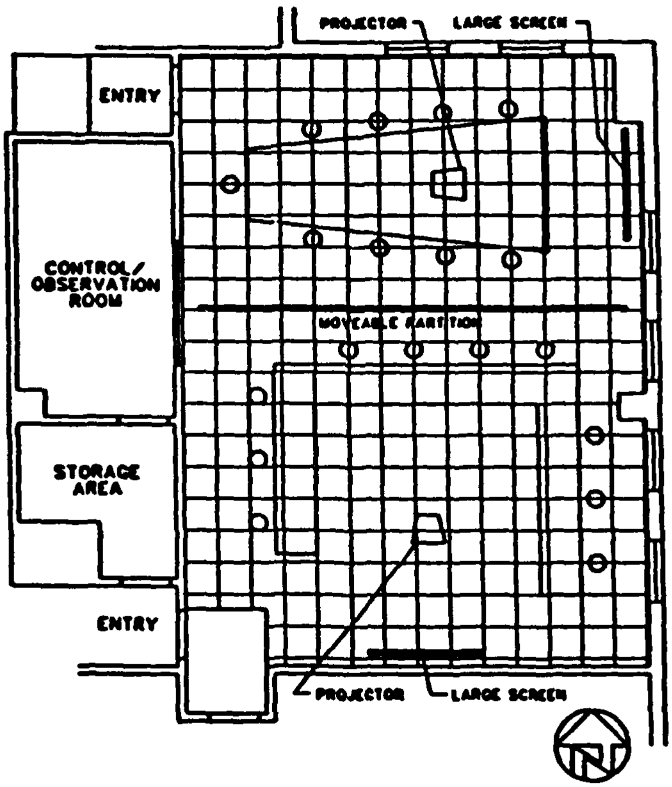


Source: Reference 30.

Figure III-2. CMI Enterprise Room

c. Claremont Graduate School

The GDSS facility of the Claremont Graduate School is shown in Figure III-3. The GDSS are designed around a conference table with imbedded microcomputers, which are networked together and can access larger computers. Claremont research has been focusing on the user interface aspects of GDSS. The individual workstations are provided with mice, touchscreens, and bitpads to explore environments that do not include keyboards. The Claremont software is oriented to supporting group efforts to reach a consensus by providing voting, ranking, and rating capabilities.



Source: Reference 29.

Figure III-3. Claremont Graduate School GDSS Facility

d. Microelectronics and Computer Technology Corporation

Project Nick, MCC Software Technology Program, Design Interface Group. The project goals are to understand the dynamics of meetings and to improve meeting results, especially within the context of large systems design. The Project Nick researchers define a meeting as a "structured communication activity that must involve two or more cooperating persons." [Ref. 35] While this definition covers a broad spectrum of meeting types, Project Nick is initially focusing on small face-to-face meetings.

The three primary components of the Project Nick research effort are capture, analysis, and presentation. The capture component centers on how information generated at a meeting is stored. Meeting information can be stored in a number of ways. Participants can take notes or white boards and video recordings can be used. Analyzing and summarizing the information from the different repositories is the focus of the analysis component. The presentation component is concerned with how the information processed in the analysis component can be displayed at subsequent meetings. Computer support for each component is also being explored.

The initial electronic meeting facilities consist of:

- Personal computers, keyboards, and private display screens for meeting participants
- A local area network connecting the personal computers within the meeting room and providing access to information stored outside the meeting room
- Group work surfaces for displaying the output from the facilitation system
- Software to display information, communicate among participants, and enter information into the group memory
- Software to capture meeting statistics and quantify some aspects of meeting effectiveness [Ref. 35].

Today, meeting information is analyzed after meetings. The Project Nick agenda includes plans for analyzing information during meetings. Other planned research activities include exploring different meeting styles and structures as well as meeting classes other than the small face-to-face meeting.

e. Xerox PARC

Researchers at Xerox PARC have developed Colab, an experimental laboratory created to study computer support of collaborative problem solving in face-to-face meetings. The Xerox PAC researchers believe that meeting environments should offer attendees the same access to computing facilities as office environments, and Colab provides up to six meeting participants with individual computer workstations. The room is also equipped with a large touch-sensitive public display, called the "liveboard."

Cognoter, a meeting tool developed for use in Colab, is designed to aid collaborative writing. With Cognoter, collaborative writing meetings are structured in three stages: brainstorming, organizing, and evaluating. During the brainstorming stage, participants can simultaneously add items to the Cognoter display. The organizing stage consists of ordering the ideas and replacing/combining similar ideas to form a group item, which is visually displayed. Ideas are linked to determine order of presentation, and links are indicated by arrows on the Cognoter display. The final stage of evaluation allows participants to evaluate the organization of the paper. The paper can be reorganized, missing details added, and irrelevant information discarded. The Cognoter system supports the abstract concept of WYSIWIS (What You See Is What I See) for multi-user interfaces. The WYSIWIS concept is that each participant sees the same information (on his or her workstation) just as if one main chalkboard is being used.

Another meeting tool being developed for the Colab is Argnoter. Argnoter, still in the early stages of development, is a tool for presenting and evaluating proposals. The theory behind Argnoter is that "much of the dispute and misunderstanding that arise in meetings about design proposals are due to three major causes: *owned positions*, that is, personal attachment to certain positions; *unstated assumptions*; and *unstated criteria*." [Ref. 36] Argnoter is intended to facilitate consensus by making the structure of arguments explicit.

The Xerox PARC researchers are also exploring the idea of "a seamless environment of tools for conversation that extends from offices to the coffee room to the formal meeting room." [Ref. 37] These tools would support the concept of portable meetings. "Seamlessness in general refers to the ability to manage and move information fluidly." [Ref. 37] Computer support for group work should be seamless between group and individual work and across locations, tools, time, and media.

B. OBSERVATIONS

Computer-aided group problem solving is a practical way to introduce the computer to the early stages of design projects. Because of the unstructured nature of most problems that exist in the early stages of design, very few traditional CAD tools are available for use during these early stages. Computer-aided group problem solving systems are designed to elicit and combine the judgments of individuals with knowledge relevant to the problem at hand. No algorithmic solution to a problem is needed.

Most computer-aided group problem solving systems can document the rationales of the decisions made during a meeting. The need for audit trails of design decisions has been widely recognized, and computer-aided group problem solving systems can satisfy this need for the early stages of design where producing design decision audit trails is especially difficult.

The following sections include some observations about applying computer-aided problem solving to design and a comparison of the chauffeuered and the multi-user systems.

1. Applications to Design

With the notable exception of Boothroyd and Dewhurst DFA, very few documented applications of computer-aided group problem solving to engineering design problems were found.[1] Two cases are worth discussing briefly.

The first case involves the design of a space-based laser strategic defense. In late 1983, a tri-Service task force was formed to demonstrate the technology base feasibility of developing three different strategic defense systems. The task force worked intermittently for six months without producing any useful conceptual designs for the space-based laser system. The task force leader decided to try the IM approach (see Chapter III.A). After 28 hours of group work, an acceptable conceptual design was completed. These results demonstrate IM's ability to effectively elicit and combine the expertise of a design team. Christakis [Ref. 38] provides more details about the space-based laser design applications and IM.

The second case involves the design of a new Marine Medium Assault Transport helicopter for the US Marine Corps. This analysis was performed for the Naval Air Systems Command by Decisions and Designs, Inc. The approach used is similar to Decision Conferencing described in Chapter III.A.2. Two 2-day design conferences were conducted with a group of Marine Corps operations personnel and design engineers from the Naval Air Systems Command. The group developed a cost-benefit model, which was used as an aid to analyze the design problem and cost-benefit trade offs of different design configurations. Details about this case have been documented by Adelman [Ref. 39]. The

[1] Even though the MCC research is directed at large systems design, no case studies of the actual application of their GDSS to a real design problem were found in the open literature.

extract of a letter from Captain Nakagawa, USN, who was Director, Systems Engineering Management Division, Naval Air Systems Command, appears at the end of Adelman's paper and provides testimony to the usefulness of this approach:

> I know of no other technique which focused so quickly upon the key issues or provided greater insight during the design or review processes now required to commit resources to support national objectives. I intend to continue to use this technique for other projects and highly recommend its use to those involved in similar efforts wherein the complexity of the decision process precludes rapid identification of optimal solutions [Ref. 39].

The widespread industry acceptance of the Boothroyd and Dewhurst DFA methodology and the cases described in the preceding paragraphs provide convincing evidence that applications of computer-aided group problem solving to design are possible and practical today.

2. Chauffeured versus Multi-User Approach

In a multi-user environment, each participant interacts with the computer. This attribute of multi-user systems raises several issues. A multi-user GDSS is viable only when the group participants are comfortable operating a computer. Although the number of people who use computers continues to increase rapidly, not everyone is comfortable operating a computer, and the user interface issues are critical to the success of multi-user GDSS. For the multi-user GDSS, each participant must become familiar with the GDSS software. This training requirement could be a significant problem, especially when the software is new and changing often. Less training is required for chauffeured systems because they are operated by the group leader only.

Another problem with the multi-user approach is that operating the computer distracts individuals and detracts from group interaction. A final criticism of multi-user systems is the cost of providing microcomputers for all meeting participants. The chauffeured systems described in this paper require only a single microcomputer with projection capability.

The cases discussed in the preceding section demonstrate that effective design applications of the chauffeured systems are possible today. All of the chauffeured systems have been designed to be portable and transferable to other organizations. It is not clear that the multi-user systems have reached this level of refinement. A thorough case study of the implementation, use, and demise of a multi-user GDSS in an industrial setting can be found in Gibson and Ludl [Ref. 40].

In the near future, chauffeured systems seem to be more practical than multi-user systems; however, multi-user systems should still be explored. For certain groups (especially computer-literate groups) issues such as training are minimized. In addition, multi-user systems also have the potential to enhance non-face-to-face meetings. GDSS is a relatively new concept and all approaches should be examined carefully.

IV. CONCLUSION

A. RECOMMENDATION

The authors recommend that the ULCE Program broaden its focus to include research in computer-aided group problem solving. The current industry trend toward simultaneous engineering with multifunctional teams should provide strong motivation to explore computer-aided group problem solving. The greatest problems of implementing simultaneous engineering are not technical; they are problems of human coordination. Simultaneous engineering with multifunctional teams increases the problems of group dynamics in design meetings. A multifunctional team is more diverse than the multidisciplinary teams of the past. In addition to engineers from different disciplines, marketing and financial experts now participate in design meetings. The multifunctional teams also meet more often to review the design. A primary goal of computer-aided group problem solving is to improve solution quality and reduce meeting time without decreasing group member satisfaction.

The importance of early design decisions is widely recognized. It is often stated that roughly 70 percent of the total life cycle cost of the system is determined during the conceptual phase. Due to the lack of hard data, very few traditional CAD tools are available to support the early stages of design. Considering the high leverage of the decisions made during these stages, this is an undesirable situation. As demonstrated by the Boothroyd and Dewhurst DFA methodology, computer-aided group problem solving is a practical way to use the computer in the early stages of design when eliciting and combining the judgments of individuals who have relevant knowledge is critical.

The government is responsible for determining requirements, developing concepts, and evaluating proposals for the systems it acquires, and these activities can be viewed as early or conceptual design. The government should follow industry's example and use multifunctional team design. Computer-aided group problem solving tools can be used by the government to efficiently implement this concept in system acquisition. A major benefit of using computer-aided group problem solving for these tasks would be the documentation of acquisition decisions.

> The taproot of many of the problems with new products is *not* technology. Rather, it is that the systems nature of the product-innovation process has been ignored. ... If new products are going to contribute consistently to aggressive market-share strategies, managers must pay a great deal more attention to the quality of integration and teamwork among the many specialists participating in product development. Fortunately, there are tools at hand to help them effect a marked improvement in teamwork. One only has to use them. The rewards for doing so are substantial. [Ref. 40]

B. RESEARCH. ISSUES

The application of computer-aided group problem solving technology to design engineering raises many research issues. Several issues recommended for near term research follow.

1. Combining Individual Judgmental Evaluations

One of the most difficult tasks facing a multifunctional design team is the elicitation and combination of the team members' individual judgments. The Boothroyd and Dewhurst DFA evaluation methodology is one approach being used today. What other approaches could be used? The Boothroyd and Dewhurst approach is being applied to other producibility problems. Can it be applied to supportability problems as well? What are the implications of the Theory of Measurement?

2. Decision Audit Trails

One of the key benefits of computer-aided group problem solving is the ability to document decision rationales, which has long been needed for design projects. Is the current documentation produced by current computer-aided group problem solving techniques adequate for design projects? What form should this documentation take? How should the documentation of different design phases be linked?

3. Structured Group Processes

The way group members interact strongly affects how effectively the group will perform. There is strong evidence indicating that unstructured group interaction is not very effective. More than 70 different structured problem solving techniques have been offered for group use by VanGundy [Ref. 1]. What are the impacts of adding structure to the problem solving process? Which structured processes are best for design situations? What are the effects of adding structure to the way the group interacts on member participation and satisfaction?

C. SUMMARY

An overview of the current industry trend toward multifunctional team design and the state of the art in computer-aided group problem solving research has been presented. The application of computer-aided group problem solving technology to engineering design represents an unexploited opportunity to enhance the effectiveness of simultaneous engineering teams.

While computer-aided group problem solving has not been widely used in engineering design, it has been used to solve many other types of problems. The ULCE Program should direct its research toward engineering design problems and recognize that enhancing group problem solving capabilities would benefit many situations other than design in both industry and government.

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38. Christakis, Alexander N., "High Technology Participative Design: The Space-Based Laser," Center for Interactive Management, George Mason University, Fairfax, VA.

39. Adelman, Leonard, "Real-Time Computer Support for Decision Analysis in a Group Setting: Another Class of Decision Support Systems," *INTERFACES 14*, #2, March-April 1984, pp. 75-83.

40. Gibson, David V. and E. Jean Ludl, "Executive Group Decision Support Systems Considered at Three Levels of Analysis," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 26-38.

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Adelman, Leonard, "Real-Time Computer Support for Decision Analysis in a Group Setting: Another Class of Decision Support Systems," *INTERFACES 14*, #2, March-April 1984, pp. 75-83.

> Real-time, decision-analytic aids developed to support group decision-making are an important subset of decision support systems (DSS). They satisfy the basic requirement to provide interactive computer support for the decisionmaking process by assisting decisionmakers in thinking about the various aspects of the decision problem(s) facing them. How a decision-analytic DSS was successfully applied to a military design problem and, more generally, why decision-analytic DSS effectively facilitate group decisionmaking are discussed. Plot of "efficient frontier" as benefit versus cost curve.

Applegate, Lynda M., Benn R. Konsynski, and J. F. Nunamaker, "A Group Decision Support System for Idea Generation and Issue Analysis in Organization Planning," *CSCW '86, Conference on Computer-Supported Cooperative Work*, August, TX, December 3-5, 1986, pp.16-34.

> The increasing reliance on group decisionmaking in today's complex business environments and advances in microcomputer, telecommunications, and graphic presentation technology have combined to create a growing interest in the design of group decision support systems (GDSS). Planning is an important group decisionmaking activity within organizations. Effective planning depends on the generation and analysis of innovative ideas. For this reason, the idea generation and management process has been chosen as the domain for the study of the design and implementation of a GDSS to support complex, unstructured group decision processes within organizations.
>
> The MIS Planning and Decision Laboratory has been constructed to provide a research facility for the study of the planning and decision process while top executives from a variety of organizations use the laboratory to conduct actual planning sessions for their organization. This paper presents the design of a system to support the idea generation and analysis process in organization planning. Results of research conducted in the MIS Planning and Decision Laboratory on the use of the Electronic Brainstorming system with more than 100 planners from a variety of organizations are presented and discussed.

The findings of the research indicate that computer brainstorming stimulates task-oriented behavior, decreases group interaction, and equalizes participation. Information presentation, network speed, and typing skills of the upper level managers were identified as possible inhibitors of the idea generation process that must be considered in the design of the system and the methodology for its use. Planners using the GDSS reported high levels of satisfaction with the process and outcome of the planning sessions. They rated the computer as an important tool for idea generation and found the computer brainstorming process an improvement over manual brainstorming.

Argyris, Chris, "Interpersonal Barriers to Decisionmaking," pp. 121-134.

This article presents the major findings of a study of executive decisionmaking in six representative companies. The findings have vital implications for management groups everywhere; though some organizations are less subject to the weaknesses described than others, all groups have them to some degree. The findings are discussed in detail and the implications for all levels of executives are examined.

Begeman, Michael, Peter Cook, Clarence Ellis, Mike Graf, Gail Rein, and Tom Smith, "PROJECT NICK: Meetings Augmentation and Analysis," *CSCW '86, Conference on Computer-Supported Cooperative Work*, Austin, TX, December 3-5, 1986, pp. 1-6.

This paper presents an overview of Microelectronics and Computer Technology Corporation's (MCC) Project Nick, which is aimed at the understanding and enhancement of meetings. One research focus is the preparation of information that is frequently done before meetings. For example, it is possible to create sophisticated diagrams and slides at one's workstation before the meeting and call them up on the electronic blackboard during the meeting. Another focus is the development of aids for the facilitator to use during the meeting. For example, the facilitator can hit a single identifying key each time that a new speaker or agenda item begins. The system will capture the interval between stroke time and generate statistics concerning how much time was spent on each agenda item and how much time was consumed by each meeting participant. The researchers envision analyses of information derived during the meeting and used to enhance the meeting in real time. Alternative meeting styles and structures are also being explored, and future research may be carried beyond the face-to-face meetings covered in this paper.

Berger, Joan, Otis Port, Mimi Bluestone, William Hampton, Zachary Schiller, and Karen Pennar, "The Push for Quality," *Business Week*, Special Report, June 8, 1987, pp. 131-144.

To beat imports, the United States must improve its products, which means a whole new approach to manufacturing.

Bogard, Timothy V., Texas Instruments, "Integrating Systems Producibility into the Design Process," *Second International Conference on Product Design for Manufacture and Assembly*, Newport, R.I., 6-8 April 1987.

The task of integrating systems producibility concepts into any corporate environment is a complex challenge. It requires

- Understanding of what producibility truly is
- Change in the engineering and management culture to provide a progressive environment for producibility concepts
  - Development of detailed procedures, guidelines, and new design methodologies.
  - Strategic planning to embed producibility concepts into the next generation of design automation systems
  - Feedback to the design/producibility/manufacturing community (measurement, ranking of yield, etc.).

The most important requirements for success are a commitment from all levels of the organization, a spirit of teamwork, and a dedication to a do-it-right-the-first-time attitude.

Branan, Bill, Motorola, Inc., "Instilling a Design for Assembly Culture," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

The average product design group has little incentive, motivation, or training to design a product for efficient factory assembly. Assembly processes are poorly characterized and represent a large source of defects. This paper describes a successful cultural change toward predicting and optimizing product designs for factory assembly. It introduces the benchmarking concept for similar products and illustrates some key concepts--including the application of Boothroyd and Dewhurst methods--required for success. A specific product example is presented showing results of that effort.

Design for assembly is more a philosophy than a strict number crunching exercise. The advantage of providing a quantitative method for analyzing designs for assembly provides an ability to really evaluate different approaches in an objective manner. Perhaps the most important advantage is that in developing a total design concept to the point where it can be analyzed for assembly makes the product designers and manufacturing engineers thoroughly plan products.

In the implementation of a DFA culture, it is important to pick a project that can be successful and leverage those results into other projects, through benchmarking of product and production variables. Some of the issues and variables believed to be important are included. The technical press abounds with success stories tha' can be used to help change the culture. Successful culture change requires changing behavior, which requires motivation and training.

Brenneman, Allen and Robert Cunningham, Miles Labs, "Simultaneous Engineering of Medical Diagnostic Systems," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

The development of Medical Diagnostic instruments requires the simultaneous design and manufacturing engineering of the electromechanical components of the system (i.e., the instrument) and the simultaneous development of the chemistries and instrument, since the end

product is a diagnostic system that returns a clinically significant result to the user.

This paper deals with experiences in developing diagnostic systems and integrating the entire development process from the chemistries to the instrument. Key to this process is the team concept that includes R&D Engineering, Advanced Manufacturing Engineering, Marketing, QA, Reagent R&D, Reagent Manufacturing, Material Control, Purchasing, Customer Service, and, at times, vendors. In addition, it covers the implementation of Design for Manufacture and Assembly into the diagnostic product cycle.

Brown, Warren, "GM's Saturn Corporation Steers New Course," *The Washington Post*, Business Section, 28 August 1988.

Saturn's decision to put less whiz-bang technology in its plants indicates flexibility and maturity. Roboticized manufacturing palaces in Michigan and elsewhere showed GM that new machines do not always produce desirable results.

GM's experience at New United Motor Manufacturing, Inc., in Fremont, California, where it is producing cars with Toyota Motor Corporation, showed that better management of people and better supplier relationships tend to yield better-quality cars.

Saturn, as a result, has shifted its emphasis from machines to people in carrying out its main stated mission: "to design and manufacture vehicles in the U.S. that are world leaders in quality, cost, and customer satisfaction."

Bui, Tung X. and Matthias Jarke,"Communications Design for Co-Op: A Group Decision Support System," *ACM Transactions on Office Information Systems*, Vol. 4, No. 2, April 1986, pp. 81-103.

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

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

Burbridge, John J. and William H. Friedman, "The Integration of Expert Systems in Post-Industrial Organizations," North Holland Human Systems Management 7, 1987, pp. 41-48.

During the emerging information age, organizations will have to adopt improved decision-group technologies and structures. One such technology will be expert systems. This paper presents a framework to ascertain the applicability of an expert system to a particular decision area. Attributes such as quality of a decision, the structure of a problem, and the necessary expertise and information influence this decision. Before this framework is presented, issues concerning the ability of an organization to assimilate such a technology and transfer that technology throughout are discussed. The paper includes Sprague's prerequisite characteristics for DSS and defines communication systems versus information systems.

Christakis, A., and D. Keever, "An Overview of Interactive Management," unpublished document, 1984.

Interactive Management (IM) is a new and versatile style of management that is to be applied intermittently in organizational settings for task-oriented, group problem-solving. IM represents a means of augmenting current management practices when solving complex, interdependent management problems. Experience has shown that these complex problems have failed to yield to conventional solution strategies, including the use of management consultants, organizational development programs, or personnel adjustments. IM has been invented to address these and other shortcomings when solving difficult management problems.

This brief overview of IM contains three sections: The Foundations of Interactive Management; Practicing Interactive Management; and A Typical Life-Cycle of Installing IM in Organizations.

Christakis, Alexander N., "High Technology Participative Design: The Space-Based Laser," Center for Interactive Management, George Mason University, Fairfax, VA.

The arena of high-technology design is inherently complex. It requires a variety of inputs from diverse knowledge disciplines and fields. When a group of experts engages in system design, new problems emerge for the designer--having to cooperate with other designers. Yet without the simultaneous participation of other designers, the Law of Requisite Variety is violated. Each participant designer is expected to learn to cooperate with other designers and appreciate the pluralities of realities relevant to the object of design. Yet each designer is physiologically and/or psychologically constrained by the Law of Requisite Parsimony. These two fundamental laws of design are superficially incompatible or contradict each other. For the efficient conduct of participative design, the two laws must be reconciled. The paper discusses how the application of the IM approach reconciles this contradiction. A specific application of IM to the conceptual design of a space-based laser system is presented.

Collins, James J., "Manage Technical Programs for Success," *Production Engineering*, April 1987, pp. 32-34.

This article presents a step-by-step procedure for the successful management of highly complex technical programs. The procedure stresses using a disciplined team approach and a goal-oriented focus, while monitoring costs.

Conklin, Jeff and Michael L. Begeman, "gIBIS: A Hypertext Tool for Exploratory Policy Discussion," MCC Software Technology Program, pp. 1-22.

This paper describes an application specific hypertext system designed to facilitate the capture of early design deliberations. It implements a specific method called Issue Based Information Systems (IBIS), which has been developed for use on large, complex design problems. The hypertext system described here, gIBIS (for graphical IBIS) uses color and a high-speed relational database server to facilitate building and browsing typed IBIS networks. gIBIS is also designed to support the collaborative construction of these networks by any number of cooperating team members spread throughout a local area network. Early experiments suggest that the IBIS method is still incomplete, but there is a good match between the tool and method even in this experimental version.

MCC's experiments with gIBIS are providing information to enhance their theory about the structure of design decisions and design rationale and are providing them with important insights about the design of the Design Journal, a hypertext-based environment for system engineering, which they will continue to design, prototype, and test in the next few years. More important, their experiences suggest that the computer is indeed a powerful medium for collaboration and debate among members of a team but that integrating computers into detailed actual tasks is attended by some major obstacles. Some of the obstacles are related to inadequate interfaces, inappropriate underlying representations, or insufficiently rich models of work practices and methods. MCC's experience with gIBIS suggests that they are just at the beginning of a long but exciting path, which will culminate when they succeed in making such tools as effective and transparent in structuring communication as the telephone is in transmitting it.

Cooke, Robert A. and John A. Kernaghan, "Estimating the Difference Between Group Versus Individual Performance on Problem-Solving Tasks, *Group & Organization Studies*, Vol. 12, No. 3, September 1987, pp. 319-342.

Extensive research has focused on the relative performance of groups versus individuals in problem-solving situations, and the results have been inconsistent. To some extent these inconsistencies can be attributed to differences in the variables used to represent individual and group output and the methods employed to compare performance. This research uses data from 61 groups (347 individuals), who completed a planning simulation to review, compare, and contrast alternative strategies (or "scoring algorithms") for estimating the differences between group versus individual performance on problem-solving tasks. Although the alternative strategies produced different estimates of the amount of gain that can be attributed to group interaction, they generally supported the conclusion that groups outperform their individual members. These results are discussed in terms of research on group performance, the use of simulations for training, and the role of groups in organizational problem solving and task performance. The article includes a discussion of Quality Circles (QCs).

Cooper, Coleen R., Mary L. Ploor, "The Challenges That Make or Break a Group," *Training and Development Journal*, April 1986, pp. 3133.

As groups work to accomplish goals, they encounter challenge points that must be addressed if participants represent different views, organizations, units in an organization, or economic sectors. This article presents an investigation into what makes a successful group. This investigation disclosed at least seven general occasions that provide a challenge for a group leader and participants. It includes a discussion of a strategic planning analysis process called SWOT analysis (internal Strengths and Weaknesses and external Opportunities and Threats).

Cortes-Comerer, Nhora, "Motto for Specialists: Give Some, Get Some," *IEEE Spectrum*, Part III, Organizing the Design Team, May 1987, pp. 41-46.

Parallel development of products and their manufacturing processes, within ever shorter lead times, is a formidable challenge for both designers and management. This article discusses how teams of diverse disciplines work in harmony to bring successful products to market.

Craig, Mark, "Managing Variation by Design Using Simulation Methods," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

In today's market, the product design engineering team is pressured to design a product for manufacturing and assembly efficiency as well as function. Statistical process control and design of experiments techniques have been widely implemented to identify, analyze, and control critical variation parameters in the manufacturing and assembly plant. These techniques, however, are used after the product is in production and do not provide the design engineering team with a method to predict variation during the design stage of a product, thus preventing or controlling undesirable variation in production. For the design team to evaluate design and assembly proposals before expensive tooling is committed, a simulation of the actual build process must be performed.

A method called Variation Simulation Analysis (VSA) provides the design engineer with the ability to evaluate the geometric effect of variation in an assembly due to component variation, processing relationships, assembly methods, and assembly sequence.

The VSA technique, properly integrated into an engineering organization, provides an effective tool to structure communication among design, manufacturing, assembly, and statistical process control.

A simultaneous engineering structure is created by using VSA to help manage the effects of variation during the design phase of a product.

Daetz, Douglas, "The Effect of Product Design on Product Quality and Product Cost," *Quality Progress*, June 1987, pp. 63-67.

Focusing on quality and manufacturability during the development phase of a product's life cycle is crucial. The level of conformance quality that may be achieved in production and the product's cost are largely determined by the design of the product.

At this time, some of the key product design measures for achieving competitive quality and competitive product cost appear to be

- Designing product and process concurrently
- Measuring and striving for assembly simplicity
- Minimizing the number of parts
- Minimizing the number of part numbers
- Using the highest possible percentage of preferred parts
- Minimizing the number of vendors.

These measures are not completely independent, and as yet a systematic analysis to quantify their individual and joint contributions to both product quality and product cost has not been done. To some extent, these measures may even seem, to product development engineers, to compound the problem of making tradeoffs in designs to satisfactorily meet functionality, schedule, and other constraints. However, giving product development engineers explicit guidelines for making their design choices should simplify their jobs. These six measures are a starting point for focusing attention on the effect of product design on product quality and product cost.

The article discusses design teams of manufacturing/product/process engineers, the Design for Assembly (Boothroyd/Dewhurst) method, and the Assemblability Evaluation Method (Hitachi/GE).

Davis, Liane and Ronald W. Toseland, "Group Versus Individual Decisionmaking: An Experimental Analysis," *Social Work with Groups*, Vol. 10, No. 2, 1987, pp. 95-110.

Task groups are often used to make decisions in social service agencies. A number of factors influence whether a decision is made by a group or an individual. The nature of the problem, political considerations, and ideology all play a significant role. Sometimes groups are used because of the belief that they make better decisions than can individuals. The paper focuses on this belief.

Should social workers use groups to make decisions because they are more likely to produce better decisions than individuals working alone? What is the evidence for the superiority of group as compared to individual decisionmaking? In this article, the results and methodological limitations of prior studies comparing group to individual decisionmaking are reviewed. Next, the results of an experiment comparing group and individual decisionmaking are described. The research design uses a problem that is relevant to social workers and parallels the types of decisions typically made in the profession. The article ends with a discussion of the implications of the findings both for research and for decisionmaking in social service agencies.

DeJean, David, "The Electronic Workgroup," *PC/Computing*, October 1988, pp. 72-84.

This article describes workgroup computing--the next logical extension of personal computing. While workgroup computing is still an undisciplined discipline, early reports on some new software programs are encouraging.

DeSanctis, Gerardine and R. Brent Gallupe, "A Foundation for the Study of Group Decision Support Systems," *Management Science*, Vol. 33, No. 5, May 1987, pp. 589-609.

Technical developments in electronic communication, computing, and decision support, coupled with new interest on the part of organizations to improve meeting effectiveness, are spurring research in the area of group decision support systems (GDSS). A GDSS combines communication, computing, and decision support technologies to facilitate formulation and solution of unstructured problems by a group of people. This paper presents a conceptual overview of GDSS based on an information-exchange perspective of decisionmaking. Three levels of systems are described, representing varying degrees of intervention into the decision process. Research on GDSS is conceived as evolving over time from the study of simple shell systems, consisting of menus of features available for selection by a group, to consideration of sophisticated rule-based systems that enable a group to pursue highly structured and novel work for research in the area. Three environmental contingencies are identified as critical to GDSS design: group size, member proximity, and the task confronting the group. Potential impacts of GDSS on group processes and outcomes are discussed, and important constructs in need of study are identified.

Tables of problems/needs and features for Levels 1, 2, and 3 GDSS, and a table of GDSS features for six task types are included in the article.

DeSanctis, Gerardine, V. Sambamurthy and Richard T. Watson, "Building a Software Environment for GDSS Research," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 3-12.

This paper describes a Unix-based, multi-user, conference-room system that has been developed to support a research project concerned with the impacts of GDSS on the processes and outcomes of group meetings. The systems development effort of this project is given as an example of one approach to implementing GDSS in a research setting. It is not argued that this approach should necessarily be used in all GDSS settings. The architecture and logical design of the system is presented, and the major features of the system are described. A key aspect of this system is its ability to allow the researcher to determine the types and sequencing of features that are made available to a group in the course of their meeting. The evolution of the system is described, along with a plan for evaluating the system and its impacts.

The system building effort described in this paper does not solve the problem of incompatibility across conferencing systems, nor does it move products in this area toward standardization. Rather, the project described here--and others like it--can be regarded as precursors to achieving standardization among face-to-face conferencing systems. Experimentation with alternative GDSS architectures, accompanied by a systematic evaluation of the technical performance, interface quality, and user and group impacts of these systems, can provide the knowledge necessary to advance the development and study of support systems for groups.

Eaton, Robert J., "Product Planning in a Rapidly Changing World," *International Journal of Technology Management*, Vol. 2, No. 2, 1987, pp. 183-189.

The paper addresses two major aspects of product planning, the technological challenge of assimilating rapidly developing technology into product design and the marketing challenge of product differentiation for shifting and segmenting markets. Both call for flexibility in planning and in manufacturing methods. To cope with this need for flexibility, the author recommends a return to the principles of Simultaneous Engineering--the breaking down of the traditional roles of Designer, Product Engineer, and Manufacturing Engineer, and their re-integration into closely knit and highly cooperative teams. Examples are given of the use of this approach at GM subsidiaries Opel, GM Trucks Group, Saturn Corporation, and Detroit Diesel Allison. The demands and the benefits of Simultaneous Engineering are both assessed.

Foote, Cornelius F., Jr., "Designing Tomorrow's Community in a Week," *The Washington Post*, June 11, 1988.

This article details how after a high-speed planning session, a town takes shape.

Forcier, Richard C. and Alfred D. Grant, "Systems Design Team: Personal Relationships in Instructional Development," *Educational Technology*, March 1973, pp. 58-59.

The team approach to instructional design and development would provide the most efficient and effective use of this talent.

Foster, Gregg and Mark Stefik, "Cognoter, Theory and Practice of a Colab-Orative Tool," *Proceedings of Conf. on Computer-Supported Cooperative Work*, 3-5 December 1986, pp 7-15.

Cognoter is a program that helps a cooperative group of people organize their thoughts for a presentation, e.g., a paper or talk. It is designed for use in the Colab, an experimental laboratory created at Xerox PARC to study computer support of cooperative real-time group problem-solving. Cognoter provides a multi-user interface and a structured meeting process. An annotated graph of ideas is built up by the group in three stages: brainstorming for idea generation, ordering for idea organization, and evaluation for choosing what will be finally be presented. Interesting aspects of Cognoter include direct spatial manipulation of ideas and their order relationships, support of parallel activity, and incremental progress toward a total ordering of ideas.

Gallupe, R. Brent, Gerardine DeSanctis, Gary W. Dickson, "The Impact of Computer-Based Support on the Process and Outcomes of Group Decisionmaking," *Proceedings of the Seventh International Conference on Information Systems*, San Diego, CA, 15-17 December 1986, pp. 81-83.

Interactive computer-based systems to support group decisionmaking (GDSS) have received increased attention from researchers and practitioners in recent years. Huber (1984) argues that as organizational environments become more turbulent and complex, decisions will have to be made in less time and with greater information exchange within decisionmaking groups.

Thus, it is imperative that studies be undertaken to determine the types and characteristics of group decision tasks most appropriate for support by a GDSS and to determine the features of a GDSS that will support those tasks.

A number of prominent researchers in the field of group decisionmaking agree that the decision task itself is probably the most important factor in determining group decisionmaking effectiveness. The characteristics of group decision tasks are many and varied, but the level of difficulty/complexity of the decision is a fundamental factor in influencing the performance of the group. Some decisions are characterized by information that is clear, concise, easily communicable, and where relationships between important factors in the decision are easily understood. In short, these decisions require relatively little effort to make and are therefore called easy decisions. Decision tasks where the information to be considered in making the decision is incomplete, difficult to understand, and where complex relationships exist within the information available are called complex or difficult decisions. The role of decision task difficulty in the effective use of GDSS is considered in this study.

This paper includes measures of effectiveness of GDSSs in terms of decision outcomes and decision process variables.

Gatenby, David A., AT&T, "Design for "X" (DFX) & CAE/CAD," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

A key to efficient, profitable product realization is Design for "X" (DFX): Design for Manufacturability (DFM), Testability (DFT), Installability (DFI), Compliance (DFC), Reliability (DFR), and other downstream considerations. This paper presents DFX as a strategic concept for product realization, shows a systematic approach for understanding DFX, and describes techniques for supporting DFX to achieve corporate productivity and quality; computer-aided engineering/computer-aided design (CAE/CAD) support of electronic and mechanical DFX is a key element of AT&T's DFX support strategy.

George, Joey F., J. F. Nunamaker, Jr., and Douglas R. Vogel, "Group Decision Support Systems and Their Implications for Designers and Managers: The Arizona Experience," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 1325.

The Department of Management Information Systems at the University of Arizona has a history of work with group decision support systems (GDSS), beginning with the development of PLEXSYS, a system development system, and with work on integrated development environments for information systems. To date, Arizona has developed two GDSS facilities. Both support group decisionmaking and group deliberation and negotiation. The PlexCenter facility has been operational since March 1985, with state-of-the-art computer hardware and software used in a boardroom setting. Executives, managers, and professional staff from organizations use the facility for organizational planning and addressing complex, unstructured decision problems. The facility has received considerable national and international attention.

The GDSS work done at the University of Arizona has helped establish the baselines for what is essential for successful GDSS use by real world groups, the groups for which GDSS are designed. Controlled experiments, currently in progress, are beginning to confirm much of the information already gathered through GDSS use and observation. Designers of GDSS and managers who use technology can both benefit from GDSS research that has been conducted at Arizona and elsewhere.

In many ways GDSS are in their infancy. There is still much to learn. One observation is that, to date, all that has been done is to use GDSS to mimic processes that are already done manually. Yet this does not reflect the true strength or promise of such systems. To tap into the true potential of GDSS, researchers need to go beyond imitation to those things that can be done only with the use of this new, and as yet incompletely explored, technology.

Gibson, David V. and E. Jean Ludll, "Executive Group Decision Support Systems Considered at Three Levels of Analysis," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp 26-38.

This research is based on a case study of the implementation, use, and eventual demise of an executive-level group decision support system (GDSS). Key issues discussed that are considered applicable to all GDSS concern executives as secretive, intuitive information processors, a critique of open communication throughout organizational hierarchies and functions, and the symbolic value of a GDSS to an organization's internal and external environments. Different levels of analysis emphasize the importance of considering group, organizational, and environmental contexts when evaluating the effectiveness of a GDSS.

Gill, Allen, "Setting Up Your Own Group Design Session," *Datamation*, 15 November 1987, pp. 88-92.

While group design techniques cannot totally break the applications logjam, they can enhance systems usability by decreasing maintenance costs and improving productivity. Recommendations are given that can ensure getting the most out of team techniques when forming group design workshops. The article includes a discussion of IBM's Joint Application Design (JAD).

Gray, Paul, "Group Decision Support Systems," *Decision Support Systems 3*, 1987, pp 233-242.

GDSS has been a rapidly emerging field of the 1980s. Whereas conventional DSS help individual decisionmakers, GDSS are designed to help groups of senior management and professional groups reach consensus. The paper focuses on one type of GDSS, a decision room in which computers and communications are used by participants during their deliberations. The paper introduces the concepts of private work, public screen, and chauffeur. It then discusses how software and hardware are used in current GDSS. Practical experience has mostly been in laboratory setting. The paper describes existing facilities and reports on the experimental evidence thus far. Special attention is given to the potentials of using gaming and the opportunity for research replication. Although it is not yet possible to prove that GDSS will be viable in the long term, some potential directions of change can be anticipated if GDSS proves successful.

The paper also lists examples of GDSS and research issues and a chart of variables in the study of GDSS.

Gray, Paul, "The User Interface in Group Decision Support Systems," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp 203-225.

The human interface is a critical success factor for GDSS. This paper describes and illustrates the interfaces used in four experimental GDSS (University of Arizona, Claremont Graduate School, University of Minnesota, and XEROX PARC). These systems are all of the single room type, where participants are present at the same time. The design problem for such systems is more complex than that for individual workstations because it involves not only consideration of both the public and private screens but also of the interaction between these screens, the physical environment of the facility, the response time of the network, and cognitive style. The interfaces described ranged in approach from simple listings, to conventional microcomputer interface, to near typewriterless interfaces using touchscreens, to a highly sophisticated "what you see is what I see" (WYSIWIS).

Following a description of the current systems, four interface design issues specific to decision support for groups are discussed--the design of the public screen, the interaction between the private screens and the public screens, the design of the individual's interaction with the system as a whole, and the effects of varying cognitive style and cultural differences among participants.

Guzzi, Maj. James F., USAF, "R&M Quality Team Concept, A New R&M 2000 Initiative," *1988 Proceedings of the Annual Reliability and Maintainability Symposium*, pp. 277-279.

The Aeronautical Systems Division's C-17 System Program Office located at Wright-Patterson AFB, Ohio, has introduced a new project management initiative. This new initiative is designed to improve the effectiveness of a company's design organization to recognize and manage the Reliability and Maintainability (R&M) Program in day-to-day design activities. The new initiative, which is called the R&M Quality Team Concept, is the idea of Major James F. Guzzi, R&M Manager for the C-17 aircraft. This aircraft is presently being developed by Douglas Aircraft Company as the airlifter of the future. The new concept uses R&M Quality Teams and a Review Council, integrated with a structured approach to focus on system level R&M issues. This new concept has been recognized by industry and the US Air Force as an innovative approach to successfully influence and institutionalize R&M management commitment throughout the total organization. The development of the R&M Quality Team Concept will be reviewed and summarized in this technical paper.

Hardaker, Maurine and Bryan K. Ward, "Getting Things Done, How to Make a Team Work," *Harvard Business Review*, November-December 1987, pp. 112-117.

Anyone who has ever run a business or organized a project has discovered how hard it can be to get the whole team on board to ensure that everyone knows where the enterprise is heading and agrees on what it will take to succeed.

IBM has used a method for some years that helps managers do just this. The technique, which is called Process Quality Management (PQM), grew out of many studies with customers to determine their needs and from internal studies as part of IBM's business quality program. PQM has been used successfully by service companies, government agencies, and nonprofit organizations, as well as manufacturers.

Harker, P.T., "Incomplete Pairwise Comparisons in the Analytic Hierarchy Process," *Mathematical Modeling*, Vol. 9, No. 11, 1987, pp. 837-848.

The Analytic Hierarchy Process is a decision-analysis tool that was developed by T. L. Saaty in the 1970s and which has been applied to different decision problems in corporate, governmental, and other international settings. The most successful applications have come about in group decisionmaking sessions, where the group structures the problem in a hierarchical framework and pairwise comparisons are elicited from the group for each level of the hierarchy. However, the number of pairwise comparisons necessary in a real problem often becomes overwhelming. For example, with 9 alternatives and 5 criteria, the group must answer 190 questions. This paper explores various methods for reducing the complexity of the preference eliciting process. The theory of a method based on the graph-theoretic structure of the pairwise comparison matrix and the gradient of the right Perron vector is developed, and simulations of a series of random matrices are used to illustrate the properties of this approach.

Hawiszczak, Robert, "Integrating Producibility Tools into a CAE Design Environment," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

Properly implementing producibility tools within a design process is a truly complex endeavor. It is this complexity that has slowed the integration of producibility tools throughout the design process. This paper seeks to unravel some of the mystery surrounding the relationship between producibility tools and the design process.

Competitive environments and corporate cultures have evolved unique design processes, and these basic design processes can be documented in standard procedures. Based on these standard procedures, disciplined design methodologies can be developed which meet organizational goals and permit the successful integration of automated CAE tools.

The next step is the development of an integrated CAE tools strategy, which itself meets the requirements of the design methodology and considers automated producibility tools. Producibility tools can then become a formal part of the design process.

Producibility tools themselves can be developed with integration into the design process as a goal. Two producibility tools are reviewed to understand how each is being integrated within unique design methodologies. A model for integrated producibility tool development is presented. It defines the need for significant planning and design prior to the actual construction and use of any producibility tool.

Defining a logical, organized, disciplined design methodology is the key to success. Chaos can't be automated.

Hein, Lars, "Boosting Product Development Ability," *International Conference on Engineering Design, ICED 87*, 17-20 August 1987, pp. 195-236.

A new basic concept for the management of industrial product development projects has been formulated. Called "Integrated Product Development" its aim is to render the process an integrated, concerted action including R&D/Engineering, Marketing, and Manufacturing.

A campaign to implement Integrated Product Development in Danish industries has been going on since spring 1985. The methods of implementation and the extent to which it has succeeded are briefly outlined.

At the present, a research project, involving a number of industries, is being undertaken in order to expand the concept of Integrated Product Development. A procedure is created by which product development can be restructured and dimensioned on the basis of the companies' product strategy, marketing strategy, and manufacturing strategy.

Hock, Gerard, "After Five Years, What has GE Learned from Design for Assembly," International Conference on Product Design for Assembly, Newport, RI, 15-17 April 1986.

Huber, George P., "Issues in the Design of Group Decision Support Systems," *MIS Quarterly*, September 1984, pp. 195-204.

This paper deals with a number of issues pertinent to the design of group decision support systems. It notes that the need for such systems, whether designed by users or vendors, is a consequence of the clash of two important forces--the environmentally imposed demand for more information sharing in organizations, and the resistance to allocating more managerial and professional time to attending meetings. The paper focuses on three major issues in the design of these systems--system capabilities, system delivery modes, and system design strategies--and discusses the relationship of these issues to system use and survival. The relevance of numeric information, textual information, and relational information in a decision-group context is examined, and various system capabilities for displaying and using such information are noted.

Huber, George P. and Reuben R. McDaniel, "The Decision-Making Paradigm of Organizational Design," *Management Science*, Vol. 32, No. 5, May 1986, pp. 572-589.

This paper introduces and explicates the decisionmaking paradigm of organizational design. The paper argues that the domains of existing design paradigms are declining in scope and that the nature of current and future organizational environments requires use of a design paradigm that responds to the increasing frequency and criticality of the decisionmaking process. The paper focuses on the fact that the decisionmaking paradigm is applicable when the organizational environments are hostile, complex, and turbulent.

The focal concept of the decisionmaking paradigm is that organizations should be designed primarily to facilitate the making of organizational decisions. The paper sets forth the paradigm's six major concepts and discusses the principal domains of its application. The paper also examines the relationships between the decision-making paradigm and the literature on organizational decisionmaking, the information processing view of organizations, and the need for compatibility between the organization's design and the design of its technologically supported information systems. The paper concludes by identifying 10 organizational design guidelines that follow from the decisionmaking paradigm.

Humphreys, Patrick, "Intelligence in Decision Support," *New Directions in Research on Decisionmaking*, B. Brehmer, H. Jungermann, P. Lourens, and G. Sevon (Editors), Elsevier Science Publishers, B.V. (North-Holland), 1986, pp. 333-361.

This paper focuses on methods for handling problems set in organizational contexts where, at the outset, there is considerable uncertainty about what is involved in handling the problem. Somewhere, within the organization, there should be considerable "intelligence" available in the form of knowledge about the nature of the organization, the genesis of the problem, and possible consequences of decisions taken in the attempt to alleviate or resolve the problem. The question then becomes how to harness this intelligence in a constructive way, providing appropriate decision support to particular people (or groups of people) involved in the problem handling process.

Humphreys, Patrick, "Levels of Representation in Structuring Decision Problems," *Journal of Applied Systems Analysis*, Vol. 11, 1984.

This paper is one of three in this volume that aims to provide a basis for developing an adequate methodology for the design, development, and implementation of decision-aiding systems for structuring ill-defined decision problems. The other two papers are "Psychological Validation of Decision Methods," by O.I. Larichev, and "Selecting Decision Support Methods in Organisations," by A. Vari and J. Vecsenyi.

An *ill-defined* problem is the term used for a problem where at the outset there is considerable uncertainty about what is involved in the problem and how to represent it. This type of problem--usual in real life--tends to be glossed over in accounts of decision theory and decision analysis, where the structure of the problem is either given in a description that was constructed *a priori*, or magically appears as part of the decisionmaker's--or analyst's--practice.

This paper examines issues involved in supporting decisionmaking in unique rather than repeated situations, where the decisionmaker cannot make the decision on the basis of holistic choice between alternatives about which he has complete information-gestalten. Cases where the decision-maker is the problem owner but who on his own has insufficient information to formulate and implement a policy for action are the focus.

Humphrey, P.C., A.I. Oldfield, and J. Allan, "Intuitive Handling of Decision Problems: A Five-Level Empirical Analysis," The London School of Economics and Political Science, *Technical Report 87-3*.

The research reported in this report posits and tests a theory that people's intuitive handling of unstructured decision problems (those problems in which neither the environment nor convention nor habit dictate an

appropriate solution) consists in five levels of subjective, psychological problem structuring. The key features of these five decisionmaking levels are

- What is qualitatively different at each decisionmaking level are the operations carried out in forming judgments about how the problem is to be handled and solved.
- The results of the operations carried out on a particular level constrain the ways operations are carried out at all lower levels.
- Any decision problem is potentially represented "in the real world" at all levels. Therefore, levels cannot be treated like a taxonomy for classifying decision problems; instead, the handling of problems at each decisionmaking level has to be examined.

In the study reported, four of these five decisionmaking levels were manipulated under four different experimental conditions. Within these conditions, subjects' discussions of a topic having significant real-life impact for them (local hazardous waste disposal) were constrained in one of four ways by interviewer-imposed constraints, each constraint corresponding to one of the posited decisionmaking levels.

A major empirical question addressed in this report is the extent to which intuitive decisionmaking is impaired or facilitated by setting constraints externally, as terms of reference or as an initial problem statement, at a particular decisionmaking level. No previous empirical research on judgment and decisionmaking has dealt with this problem. The posited five decisionmaking levels provided not only the rationale for the experimental design but also different ways of analyzing transcripts of subjects' verbal handling of the problem. These analyses led to the following conclusions:

- Imposing the minimum constraint of only specifying the problem area asks too much of people; their exploration of the problem is very limited. To help them get started in their thinking, priming them with either a bounded scenario or a frame within which to represent the problem proved very successful.
- The main tradeoff in practice has to be made between priming subjects with scenarios (level 4) or frames (level 3). Priming with a frame within which to represent the problem tended to encourage more depth (structuring within the offered frame). Priming within a scenario encouraged more breadth (exploring across intuitively selected frames). In each case, though, subjects still explored more beyond the areas in which they were primed than within the areas in which they were primed.
- Constraining subjects by giving them a fully structured problem frame (level 2), typical of psychological experiments on judgment under certainty, is counter-productive. Subjects became frustrated and apathetic. They explored less, both within and outside the frame in which they were primed, and this was not compensated for by encouraging them to give more judgments within the frame. In other words, constraining people at this level clearly underestimates their intellectual abilities, and they respond by failing to display much of what

they are capable of at any level. Thus, the conclusion made by many judgment researchers, that people are "intellectual cripples" when dealing with uncertainty, may be an artifact of the experimental constraints imposed on subjects.

- This research shows that it is impossible for the experimenter in judgmental research to maintain an objective stance. The act of stating the problem and what is required of the subject has a profound effect, well beyond the error variance associated with experimenter-induced biases, on the way subjects think about the problem. In addition, the approach used by the experimenter in analyzing the data imposes its own constraints on the conclusions that are drawn. Thus, judgment researchers will need to consider new paradigms that recognize the inseparability of experimenter and subject in investigations of problem-solving for ill-structured situations.

Humphreys, P.C. and A.D. Wisudha, "Handling Decision Problems: A Structuring Language and Interactive Modules, Second Year Annual Report, Part I: Building a Decision Problem Structuring Library: A Review of Some Possibilities," *Decision Analysis Unit*, London School of Economics and Political Science, Decision Analysis Unit Technical Report 88-1.

This report represents an extension to and update of Technical Report 87-1: "Methods and Tools for Structuring and Analyzing Decisions Problems: A Review and Catalogue" (part of the first-year technical report on this project). It examines in detail the four classes of systems and tools for decision support that need to be provided within the General Procedural Schema for handling ill-structured decision problems in order to provide a comprehensive library of microcomputer-based tools to aid the handling of such problems at strategic and lower levels. (Involvement of problem owners at a strategic level is invariably necessary where the decision problem is initially unstructured, and therefore may have new policy implications with the organization.)

Within each of the four categories, the paper selects microcomputer-based support systems and tools from the entries in the catalogue given in technical report 87-1 that have a proven track record in use in decisionmaking at the strategic level and at lower levels. Their capabilities and limitations against the support goals identified for tools in each particular category within the account of the general procedural schema are described. The tools selected within each category are not evaluated in competition with each other. Rather, a set of tools has been assembled which, taken together, indicate the state-of-the-art across the full range of support functions that could be offered by technology successfully incorporated in current tools.

This allows the authors to evaluate the capabilities of the tool set, taken as a whole, and also to consider the ease, or difficulty, of integrating information and methods across tools in the case where comprehensive support for an application may best be provided through the use of functions contained in more than one tool.

In fact, this is the most pessimistic part of the report. It shows that the selected tools all have excellent local functionality; they are all good at what

they profess to do when used to provide practical, but restricted, support on their own. However, global functionality of the set, taken as a whole, is much more difficult to achieve simply through aggregating tools bottom-up into a comprehensive tool set to comprise the library. This is because, even when choosing the members of this set very carefully as was done in the research that led to this report, one always ends up with interfacing and functional coverage problems.

It is not easy to transfer information between tools because object and parameter conceptualizations are not consistent across tools. (It is not simply a matter of incompatible data formats). Also, the support functions provided overlap between the tools, which offers redundancy, in itself not necessarily a bad thing, and, more serious, left gaps in functionality between the tools, which are not easy to solve by constructing "bolt-on" software or by decision analyst intervention in practical applications.

The paper concludes that the next step should be to take a top-down view of what is required in building a decision problem structuring library, first deriving the set of support functions and then describing how they may be clustered into super-tools that comprise functions successfully implemented in existing tools and the required but currently missing functions. Such supertools should not be defined in a closed way. The aim should be to allow any individual library builder to integrate the tools and tool functions he wishes to use (regardless of the source from which they were acquired) into his own comprehensive library, offering integrated support facilities, tailored according to the applications needs of the library users.

Humphreys, Patrick C. and Ayleen D. Wisudha, "Methods and Tools for Structuring and Analysing Decision Problems, Vol. 1: A Review," London School of Economics and Political Science, *Technical Report 87-1*, pp. 1-23 w/Appendix.

Humphreys, Patrick C. and Ayleen D. Wisudha, "Methods and Tools for Structuring and Analysing Decision Problems, Vol. 2: A Catalogue," London School of Economics and Political Science, *Technical Report 87-1*.

This report comprises a review (Volume 1), and catalogue (Volume 2) of 58 methods and tools for structuring and analyzing decision problems within a framework for effective organizational problem handling and decisionmaking in initially unstructured situations (i.e., in newly occurring, non-repeating situations, where the structure of the problems is, of necessity, initially unclear).

Huthwaite, Bart, Troy Engineering, "Product Design for Manufacture and Assembly: The Five Fundamentals," *Proceedings of the 2nd International Conference on Product Design for Manufacture and Assembly*, 1987.

How a Product Design for Manufacture and Assembly (DFMA) effort is implemented is critical for its continued success. The following five fundamental steps are shown to be major keys to success.

- Map the current product design system, then map the new simultaneous engineering system, carefully identifying the new interfaces and roles required.
- Using previous product design cost and time data, create a profile of a typical product development. Create a new cost/time profile based on

using simultaneous engineering and DFMA techniques. This idealized profile includes zero wait time between product development phases and includes only value-added engineering work.

- Set challenging quantitative benchmarks to be reached during specific time periods, based on data acquired in the preceding step.
- Provide training in DFMA design principles and techniques.
- Provide training in DFMA methodology (Boothroyd Dewhurst Method).

This paper is based, in part, on a recently completed pilot study on how companies are strengthening their manufacturing competitiveness through simultaneous engineering techniques and DFMA quantitative methods. Troy Engineering will complete the final study during late 1987.

Johnson, Cynthia Reedy, "An Outline for Team Building," *Training: The Magazine of Human Resources Development*, Vol. 23, January 1986, pp. 48-52.

Cooperation, collaboration, and communication are the ingredients of an effective team. The paper contains a questionnaire/assessment scale to be used in team building.

Keever, D.B. and A.N. Christakis, "Interactive Management for Organizational Redesign," Center for Interactive Management, George Mason University, Fairfax, VA, pp. 83-90.

Interactive Management (IM) was selected by a US government agency's top manager to assist his line and staff executives in collectively redesigning their organization for the 1990s. Some distinctive aspects of the IM system, especially useful for organizational redesign, include computer assistance for exploring the interrelationships among a large number of ideas; a specially designed situation room; selected methodologies offering neutral, yet firm and flexible guidance for design; and a clear delineation of roles between participants, as content experts, and the group manger (called the IM Facilitator), as process expert.

This paper discusses how the senior managers were successful in identifying anticipated problems for the agency of the 1990s and in proposing a set of viable options for ameliorating the situation. The options were organized in an Options Field, relevant to designing the organization of the future. The Options Field enables the managers to make strategic choices among the options in a methodical and meaningful manner.

Kersten, Gregory E., "On Two Roles Decision Support Systems Can Play in Negotiations," *Information Processing & Management*, Vol. 23, No. 6, 16 January 1987, pp. 605-614.

This paper focuses on the role of the computer system in group decision-making. Two systems used in solving negotiating problems and three procedures that can be used to develop group decision support systems are analyzed and a unified approach for the analysis is presented. The systems and procedures are based on multicriteria decision analysis and use mathematical programming models. They can play different roles--systems' intervention in the negotiating process can be used merely to facilitate the process, or the system can actively mediate negotiations; both roles are discussed in this article.

Kersten, Gregory E., "Two Aspects of Group Decision Support System Design," *VIIth International Conference on Multiple Criteria Decisionmaking--Toward Interactive and Intelligent Decision Support Systems*, 18-22 August 1986, pp. 283-292.

Two aspects of designing a computer-based system for group decisionmaking are discussed in this paper. The first is the procedure a system uses, which should be able to handle different decision problems and should support decisionmakers who represent different types of behavior. The second aspect is the user-system interface; it should possess features that increase system flexibility and expandability, and it should make possible the customization of the system.

Korhonen, Pekka, Herbert Moskowitz, Jyrki Wallenius, and Stanley Zionts, "An Interactive Approach to Multiple Criteria Optimization with Multiple Decision-Makers," *Naval Research Logistics Quarterly*, Vol. 33, 1986, pp. 589-602.

In this article, a formal man-machine interactive approach to multiple criteria optimization with multiple decisionmakers is proposed. The approach is based on some earlier research findings in multiple criteria decisionmaking. A discrete decision space is assumed. The same framework may readily be used for multiple criteria mathematical programming problems. To test the approach, two experiments were conducted using undergraduate business school students in Finland and in the United States as subjects. The context was, respectively, a high-level Finnish labor-management problem and the management-union collective bargaining game developed at the Krannert Graduate School of Management, Purdue University. The results of the experiments indicate that the presented approach is a potentially useful decision aid for group decisionmaking and collective bargaining problems.

Kozikowski, Joseph, "Team Design in the Classroom--A Case Study," *IEEE Transactions on Education*, May 1977, pp. 106-108.

This paper describes how the team approach has been applied to a design course taken by electrical engineering juniors. Course mechanics, project selection, team organization, system implementation, problems, and outcome are discussed.

Kraemer, Kenneth and John King, "Computer-Based Systems for Cooperative Work and Group Decisionmaking: Status of Use and Problems in Development, *Public Policy Research Organization*, University of California, Irvine, September 1986, pp. 1-37.

Application of computer and information technology to cooperative work and group decisionmaking has grown out of three traditions, computer-based communications, computer-based information service provision, and computer-based decision support. This paper provides an overview of the various kinds of systems that have been configured to meet the needs of groups at work, evaluates the status of these systems in the United States, evaluates the experience with them, assesses barriers to their further development and use, and draws conclusions about future work in this area that should be undertaken. An extensive set of references is provided.

Krasner, Herb, "Computer-Supported Cooperative Work '86 Conference Summary Report," *AI Magazine*, Fall 1987, pp. 87-88.

This article is the conference chairman's report on the results of CSCW '86. The report introduces the field of computer-supported cooperative work, describes the CSCW '86 program, and discusses the significance of the conference results. An introduction to the follow-on conference, CSCW '88, is also provided.

Kull, David J., "Group Decisions: Can Computers Help?," *Computer Decisions*, May 1982, pp. 70-160.

This paper documents a simulated board of directors meeting using Mindsight, a trailblazer in decision support systems, developed by Execucon (Austin, TX). It also contains useful comments from the "board" members.

Leavitt, Don, "Team Techniques in System Development," *Datamation*, 15 November 1987, pp. 78-86.

Group design techniques provide orderly ways for business professionals to work together in small groups with the Information Systems (IS) Department to determine and understand the scope and content of a proposed system. While many focus on the design phase of the development cycle, a few start even earlier by attempting to bring structure and teamwork to strategic planning.

Actually, facilitated team techniques is a more useful and accurate term for these methods, since in every case specially trained leaders are used to encourage and shape the work of the group formed to meet a perceived need. During group sessions, nontechnical end users and information systems staff meet on a common ground to gather information and hammer out system solutions that truly meet the needs of everyone--especially the needs of end-user management. The article discusses WISE Integrated System Development Method (WISDM), by Western Institute of Systems Engineering Corp., IBM's Joint Application Design (JAD), and METHOD by Performance Resources.

Lien, Professor Terje Kristoffer, "Integration of the Product Design and Process Development Activities - A Case Example," *Second International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 April 1987.

The traditional sequence of product and process development often misses the opportunity of taking advantage of new methods in production and automation. The paper describes an integrated approach that lets the product and the process develop in parallel, to integrate the latest knowledge of production methods in the product design. An example from a manufacturing company demonstrates the effect of this approach.

Lewis, Roger K., "When Working by Committee Isn't All Bad," *The Washington Post*, June 11, 1988.

The article describes how committee decisionmaking has been applied to planning for Kentlands Estate, a proposed 352-acre development in Gaithersburg being developed by Joseph Alfandre & Co., Inc.

Loy, Stephen L., William E. Pracht, James F. Courtney, Jr., "Effects of a Graphical Problem-Structuring Aid on Small Group Decisionmaking," *Proceedings of the Twentieth Annual Hawaii International Conference on Systems Sciences*, 1987, pp. 566-573.

A laboratory experiment was conducted to investigate the effectiveness of the problem-structuring aid in enhancing group decisionmaking quality and problem understanding in a semi-structured problem domain. Two commonly used group decisionmaking procedures--Nominal Group Technique (NGT) and Interacting Groups (IG)--were used to investigate the effects of the problem-structuring aid in an unstructured IG and a structured group setting (NGT). The results of the experiment indicate that group decisionmaking quality and problem understanding were enhanced by the use of the problem-structuring aid and that these effects were not related to group problem-solving structure.

Mistree, Farrokh and Douglas Muster, "Designing for Concept: A Method That Works," *International Workshop on Engineering Design and Manufacturing Management*, the University of Melbourne, Melbourne, Australia, November 21-23, 1988, pp. 1-14.

In the future, information that is useful in designing will be available almost instantly in quantity and quality heretofore not possible. Designers will negotiate solutions to open problems in a computer environment that is characterized by user friendly desk-top computers networked to much larger machines--machines with the capability to process symbols (words, pictures, numbers, logic)--and extensive data banks. The paper asserts that the principal role of an engineer in this computer environment is to make decisions associated with the design and manufacture of an artifact. The paper introduces the concept of Decision-Based Design and an approach called the Decision Support Problem Technique, which is being developed at the University of Houston. A distinction is made between designing for concept and designing for manufacture. In keeping with the goals of the workshop the Decision-Based Design was reduced to designing for concept using Decision Support Problems. Some of the principal issues associated with their development and use are highlighted. What has been achieved and what is currently available for use by industry and in classrooms is also described.

Morley, Ian E. and Stuart Pugh, "The Organization of Design: An Interdisciplinary Approach to the Study of People, Process and Contexts," *International Conference on Engineering Design, ICED 87*, 17-20 August 1987, pp. 210-222.

This paper brings together the works of Morely and Pugh in the context of total design, considering the evolution of the understanding of leadership skills in parallel with the emerging understanding of engineering design. Models of design have brought about effective communication between the authors and industry, and they are used as the catalyst to focus upon the difference in design team characteristics required in differing design situations. These differences are elaborated through a consideration of products being either conceptually static or dynamic. It concludes by firmly establishing a sound relationship between the work in the two areas.

Muster, D. and F. Mistree "The Decision-Support Problem Technique in Engineering Design," *The International Journal of Applied Engineering Education,* Vol. 4, No. 1, 1988, pp. 23-33.

Until recently, design was practiced almost solely as an art. A science of design did not exist. The real world, as it was viewed by engineers, could be characterized in terms of Newtonian science. It was a world of relative simplicity, continuity, and systems in equilibrium with each other and their environments. The assumption that engineering systems were in equilibrium or a steady-state was the starting point of all analysis. Nonlinear behavior, discontinuities, and processes that did not fit this assumption were treated as exceptions, and allowances were made in the design of artifacts that displayed such characteristics. Designers favored sequential-action methods and approaches whose limitations were of little practical concern until the advent of the modern computer. Now, the problems confronting engineers are of a larger scale, a higher order of complexity, and the pace of technology change sometimes outstrips our ability to use it effectively. In this milieu, engineers need a new approach to negotiating solutions to their problems, one that permits a designer to accept a superior, "satisficing" solution with confidence in lieu of the chimera of an optimal solution. The methods consonant with this approach must provide a designer with the means to partition the original problem in terms sufficiently simple to make finding a solution a manageable process. At the same time, the formulated problem and its model must be a close enough approximation of the real world that satisficing solutions yield useful results. In this paper, the Decision-Support Problem Technique is explained in terms of the four phases and six steps that constitute the authors' approach to design and by means of which they plan, organize, integrate, and measure their progress in the design process.

Nevins, J. L., and D. E. Whitney, "What Progressive Companies are Doing to Raise Productivity," *Charles Stark Draper Laboratory, Inc. Paper,* with attached Presentation Viewgraphs, October 1986, pp. 1-39.

Advanced technology has long been the hope of companies wishing to raise their productivity, but there is growing agreement that this cannot be accomplished through technology alone. This paper describes several strategies that stress integration of product design, process design, and total involvement of design and production employees. Such strategies allow rational mixes of technological and nontechnological methods to be designed and justified.

The focus of these strategies is the assembly process. This process is inherently integrative and forces manufacturers to consider the widest range of issues, including part fabrication, functional and process tolerances, assembly, test strategies, vendor control, and the product's life cycle. Because of the ability of this approach to encourage simultaneous integration of so many important factors, it is called the Strategic Approach to Product Design.

The Department of Defense (DoD) faces several problems in attempting to foster this strategy among its suppliers. Some are generic problems in US industry and universities while others are specific DoD issues.

First, DoD and its suppliers do not engage in a sufficiently coordinated design and procurement activity. Not enough mutual incentives exist for contractors and DoD to improve productivity or integrate product and process design.

Second, there are basic knowledge gaps and a corresponding lack of design tools to support an integrated strategy. In parallel with these gaps is a lack of university curricula that would produce manufacturing and design engineers with the needed skills.

Third, companies and DoD lack interim methods for modifying their internal organizations so that they could take advantage of this strategy even in its currently empirical form.

Possible DoD options include focused studies to find ways to encourage more communications among users, suppliers, designers, and manufacturers; establishment of productivity institutes or centers of excellence devoted to creating integrative strategies and the supporting tools and research; and innovative procurement and incentive plans that would imitate the commercial market's incentives.

Papadimitriou, Christos and John Tsitsiklis, "Intractable Problems in Control Theory," *Siam Journal of Control and Optimization*, Vol. 24, No. 4, July 1986, pp. 639-654.

This paper is an attempt to understand the apparent intractability of problems in decentralized decisionmaking, using the concepts and methods of computational complexity. First established is that the discrete version of an important paradigm for this area, proposed by Witsenhausen, is NP-complete, thus explaining the failures reported in the literature to attack it computationally. The rest of the paper shows that the computational intractability of the discrete version of a control problem (the team decision problem in this particular example) can imply that there is no satisfactory (continuous) algorithm for the continuous version. To this end, the paper develops a theory of continuous algorithms and their complexity and a quite general proof technique, which can provide interesting by themselves.

Peyronnin, Chester A., "Keeping Contemporary With the Changing Nature of Interdisciplinary Design," *International Conference on Engineering Design, ICED 87*, 17-20 August 1987, pp. 223-229.

This paper presents the changing composition of interdisciplinary design teams. Starting with simple cooperation between engineers, the paper gives examples of the problems presented by the addition of a broader spectrum of engineers, scientists, and social representatives and how they were resolved in selected situations. Lessons are then drawn from these examples.

Phillips, Lawrence, "Systems for Solutions," *Datamation Business*, April 1985, pp. 26-29.

This article examines five key problems that have limited the usefulness of decision support systems for senior executives:

- All decisions are about things that will happen in the future, but there are no data about the future.
- Computers can't assess uncertainty for unique events.

- Computers do not provide information about nonquantifiable, soft objectives.
- Computers can't specify what tradeoffs should be made among conflicting objectives.
- Computers can't form preferences.

The author recommends combining information technology with preference technology in the form of decision conferences to help executives make decisions quicker and more effectively.

Phillips, Ronald T., "An Approach to Software Causal Analysis and Defect Extinction," *GLOBECOM '86: IEEE Global Telecommunications Conference Proceedings*, 1986, pp. 412-416.

This paper briefly reviews the history of quality circles and discusses the experience of an implementation of a quality improvement team or quality circle in the software product development environment at IBM Corporation and its use of the causal analysis concept. The implemented team concept could apply to software in general as well as to communications software. The concept of the software quality team and its implemented organization is described in detail. Responsibilities of team members and management are also discussed.

The quality team allows for the extinction of errors as well as better methods of detection and prevention through causal analysis (1-2-3 process). The process of team operation and the process of defect prevention and extinction as implemented by the team are integrated within the software development process. The evolution of this implementation is reviewed from the point of view of how the quality team implementation integrates and addresses the requirement of up-to-date process documentation, the requirement for new defect prevention tools, and the requirement of process changes to prevent defects.

Highlighted in the paper are data experience and how causal analysis contributes advances in the form of several new tool implementations and process examples that can contribute significantly to continued quality improvement.

Pieptea, Dan R., Evan Anderson, "Price and Value of Decision Support Systems," *MIS Quarterly*, December 1987, pp. 515-527.

A two-dimensional framework for Decision Support Systems (DSS) cost-benefit analysis is proposed. One dimension reflects the degree to which the supported decision is structured, the level of managerial activity, the level of uncertainty and the source of information used, while the second dimension classifies DSS based on the phase of the supported decision according to Simon's model for the decisionmaking process. The review of the current literature reconciles some of the contradictory findings in the DSS cost-benefit literature and shows that the adequacy of the valuation method depends on the attributes of the system. The main DSS valuation issues are identified, and the paper discusses the potential gap between price (determined by estimated costs or the market) and the value (which is subjective). The magnitude of this gap is found to be correlated with the extent to which the supported decisions are structured.

Poole, M. S. and G. L. DeSanctis, "Group Decisionmaking and Group Decision Support Systems: A 3-Year Plan for the GDSS Research Project," *Management Information Systems Research Center School of Management*, MISRC-WP-8-02, Working Paper Series, September 1987, pp. 1-79.

The purpose of this project is to develop and test the theory necessary for the orderly progress of research and application of group decision support systems (GDSS). The project undertakes a comprehensive investigation of GDSS by a team of researchers from the fields of management science, speech communication, and public policy studies at the University of Minnesota. Group decision support systems are social technologies designed to aid organizational groups in complex decision situations. The effects of these technologies are of interest in their own right; they are also interesting because they throw group processes into sharp relief, permitting insights into the nature of group work.

Posner, Barry Z., "What's All the Fighting About? Conflicts in Project Management," *IEEE Transactions on Engineering Management*, Vol. EM-33, No. 4, November 1986, pp. 207-211.

The issues that are most likely to create conflict during a project and how the intensity of these disagreements varies over the life cycle of a project were investigated in this study. Also explored are the conflict management styles used by project managers and how these preferences are affected by individual and organizational factors (e.g., gender, age, managerial responsibilities, project size, and organizational structure). From a cross sample of organizations, 287 project managers were surveyed. Comparison with previous studies are noted.

Raine, J. K., "Design Innovation and Project Engineering--Paths to Profit," *Transactions of the Institution of Professional Engineers, New Zealand*, Vol. 13, No. 2/EMCh, July 1986, pp. 95-105.

Engineering projects today differ from those of yesteryear, both in the complexity of new technologies present, and the far greater number of components that comprise a complete system. There is a growing distinction between the creativity-intensive engineering of a new component or device, and the coordination and communication-intensive task of project engineering a large system. With the aid of intricate flow charts, this paper reviews the steps to success in the new product design process, and in the engineering of large systems. Appropriate engineering organizations are outlined with pointers towards obtaining good performance from the engineering team. This article contains a value engineering flow chart.

Rao, Ashok, Neal Thornberry, and Joseph Weintraub, "An Empirical Study of Autonomous Work Group Relationships Between Worker Reactions and Effectiveness," *Behavioral Science*, Vol. 32, 1987, pp. 66-76.

This paper reports on findings from an empirical study of 30 autonomous work groups. It deals with systems at the group level, particularly their producer and decider subsystems. Each work group operated within the same organization, making the same kind of product using the identical process. This study attempts to explain the differences between high productive and low productive autonomous work groups. The focus is on two key areas of worker perceptions, satisfaction with the job and perceptions of work group leadership. Results show the importance of establishing and communicating a policy of promotional opportunities to reward high performance. Leadership dimensions (superior orientation and consideration) that discriminate between high and low production groups are identified. These findings have implications in the selection and training of team leaders and the management of autonomous work groups.

Richman, Louis S., "Technology - Software Catches the Team Spirit," *Fortune*, June 8, 1987, pp. 125-136.

New computer programs may soon change the way groups of people work together--and start delivering the long-awaited payoff from automation.

"Groupware" aims to place the computer squarely in the middle of communications among managers, technicians, and anyone else who interacts in groups, revolutionizing the way they work. Even meetings will become more effective as today's low-tech conference rooms turn into multimedia "war rooms" controlled by software that keeps everything on course.

Richter, W., "To Design in an Interdisciplinary Team," *International Conference on Engineering Design, ICED 87,* 17-20 August 1987, pp. 231-237.

Advice and rules are provided for designers who want to work with good efficiency in an interdisciplinary team. This kind of work becomes gradually more important due to the increasing complexity of most products. A single designer who tries to handle the whole range of this complexity on his own is bound to fail sooner or later.

Schmaus, Thomas and Wolf-Dietrich Schneider, "Design for Assembly in West Germany - Experience and Trends," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

Over the last few years, German firms have been increasingly concentrating their efforts at rationalization on the area of assembly tasks. The aims pursued in this connection have by no means been restricted to assembly automation, they have also included a basic reduction in the time spent on assembly. It has become increasingly evident, however, that product design is vitally important to this objective. In the industrial projects of the Fraunhofer Institute IPA, in which automation of assembly tasks is planned, 75 percent of the products in the projects are modified or even completely redesigned. The product design measures are achieved by the greater exchange of knowledge between the various experts, which results from teamwork in firms. Computer-aided systems play a vital role in this. Numerous examples demonstrate that this method of procedure is efficient, and that in the area of product design for assembly German industry compares favorably with its international competitors.

Schweiger, David M., William R. Sandberg, and James W. Ragan, "Group Approaches for Improving Strategic Decisionmaking: A Comparative Analysis of Dialectical Inquiry, Devil's Advocacy, and Consensus," *Academy of Management Journal*, Vol. 29, No. 1, 1986, pp. 51-71.

This laboratory study compared the effectiveness of the dialectical inquiry, devil's advocacy, and consensus approaches to strategic decisionmaking by groups. Results showed that both dialectical inquiry and devil's advocacy led to higher quality recommendations and assumptions than consensus. Dialectical inquiry was also more effective than devil's advocacy with respect to the quality of assumptions brought to the surface. However, subjects in the consensus groups expressed more satisfaction and desire to continue to work with their groups and greater acceptance of their groups' decisions than did subjects in either of the two other types of group studied.

Schuman, S.P., "Computer-Assisted Conferences for Organization Planning and Design," Rockefeller College of Public Affairs and Policy, University at Albany, Albany, NY, pp. 75-81.

Organizational planning and design decisions are typically complex, involving multiple decisionmakers with diverse perspectives, competing priorities, and large amounts of information. A group decision support system (GDSS) is of great benefit in these situations by using information technology to structure, facilitate and document the decisionmaking process and by providing a framework for coalescing input from various decisionmakers and offering feedback on the implications of their assumptions. A case study of a decision conference (an intensive form of GDSS) held for the New York State Insurance Department demonstrates the advantages of decision conferencing as a combination of group facilitation techniques, decision modeling, and information technologies used to improve the decision-making process, and also exemplifies the distinction between decision support systems (DSS) and GDSS.

Sepehri, Mehran, "Manufacturing Revitalization at Harley-Davidson Motor Co.," *Industrial Engineering*, August 1987, pp. 87-93.

The article describes how setup times and inventory turns were reduced at Harley-Davidson Motor Company.

Shunk, Dan L. and Richard D. Filley, "Systems Integration's Challenges Demand a New Breed of Industrial Engineer," *Industrial Engineering*, May 1986, pp. 65-67.

The authors make several recommendations for the successful introduction of system integration into an organization's corporate culture. Among these are

- Recognize that people, not technologies, are the key to success.
- Make system integration an interdisciplinary team effort.

The decisionmakers from operations, MIS, finance, and top management must be supporters, if not team players, on any major effort to make systems integration a part of a corporation's culture.

Simon, Herbert A., "Decisionmaking and Problem Solving," *INTERFACES 17*, 5 September-October 1987, pp. 11-31.

The Management Science/Operations Research (MS/OR) community has, as its common mission, the development of tools and procedures to improve problem solving and decisionmaking. This report discusses the advances needed to combine human thinking with intelligent machines to achieve a more productive society. Areas of high potential include research in expert systems, conflict resolution, agenda setting, decisionmaking in an organizational setting, and empirical studies of individual behavior. The resources currently being applied to research in decisionmaking and problem solving are modest and are not commensurate with the opportunities or the human resources available for exploiting them.

Sines, R. Kelly, "Integrating Simultaneous Engineering Into New Product Introduction," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

Focusing on quality and manufacturability during the development phase of a product's life cycle is crucial. The level of quality that may be achieved in production and the product's cost are largely determined by the design of the product. The key product design measures for achieving competitive quality and competitive product costs are

- Designing product and process concurrently
- Measuring and striving for assembly simplicity
- Minimizing the number of parts and levels within the structure
- Using as high a percentage of preferred parts as possible
- Minimizing the number of suppliers.

The ultimate goal is to marry these measures into the product development stage using a team concept and input from suppliers and the factory floor.

Sprague, Ralph H., Jr., "A Framework for the Development of Decision Support Systems," *MIS Quarterly*, December 1980, pp. 1-26.

This article proposes a framework to explore the nature, scope, and content of the evolving topic of Decision Support Systems (DSS). The first part of the framework considers three levels of technology that have been designated DSS, the developmental approach that is evolving for the creation of a DSS, and the roles of several key types of people in the building and use of a DSS. The second part develops a descriptive model to assess the performance objectives and the capabilities of a DSS as viewed by three of the major participants in their continued development and use. The final section outlines several issues in the future growth and development of a DSS as a potentially valuable type of information system in organizations.

Sprague, William R., Sr. and John M. Wallach, "Design for Manufacturability Implementation and Elements for Success," *Third International Conference on Product Design for Manufacture and Assembly*, Newport, RI, 6-8 June 1988.

Industry is recognizing the value of Design for Manufacturability (DFM) as a strategy for competitiveness. To achieve significant results, two major obstacles must be overcome. First is how to implement a major cultural change to an organization and gain acceptance of it. The second is how to blend the tools and design process changes in the right strategic mix to maximize development effort. This paper examines how the NCR Corporation and their Cambridge, Ohio, plant have approached and succeeded with DFM by addressing these two issues.

Stabell, Charles B., "Towards a Theory of Decision Support," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 160-170.

This paper develops elements for a theory that deals with context of decision support. The paper focuses on two aspects of such a theory of decision support, how the organization shapes decision situations, decision roles, and decisionmaking behavior; and how managers view their decisionmaking roles and alternative decision support arrangements.

Two distinguishing aspects of this effort to develop a theory of decision support are given. First, the theory attempts to provide a perspective on the context of decision support that is descriptively useful. Descriptively useful means that it should also have prescriptive implications. Second, the outline should indicate that further work on a theory of decision support will be to a large èxtent work on decisionmaking in organizations as both a cognitive and organizational phenomenon.

Stefik, Mark, D. Bobrow, G. Soter, S. Lanning, and D. Tatar, "WYSIWIS Revised: Early Experiences with Multiuser Interfaces," Xerox Palo Alto Research Center, *ACM Transactions on Office Information Systems,* Vol. 5, No. 2, April 1987, pp 147-167.

WYSIWIS (What You See Is What I See) is a foundational abstraction for multiuser interfaces that expresses many of the characteristics of a chalkboard in face-to-face meetings. In its strictest interpretation, it means that everyone can see the same written information and also see where anyone else is pointing. In our attempts to build software support for collaboration in meetings, we have discovered that WYSIWIS is crucial, yet too inflexible when strictly enforced. This paper is about the design issues and choices that arose in the first generation of meeting tools based on WYSIWIS. Several examples of multiuser interfaces that start from this abstraction are presented. These tools illustrate that there are inherent conflicts between the needs of a group and the needs of individuals, since user interfaces compete for the same display space and meeting time. To help minimize the effect of these conflicts, constraints were relaxed along four key dimensions of WYSIWIS: display space, time of display, subgroup population, and congruence of view. Meeting tools must be designed to support the changing needs of information sharing during process transitions, as subgroups are formed and dissolved, as individuals shift their focus of activity, and as the group shifts from multiple parallel activities to a single focused activity and back again.

Stefik, Mark, and John Seely Brown, "Toward Portable Ideas," *Xerox Palo Alto Research Center*, 25 March 1988, pp. 1-20.

The key to effective teamwork is in the interaction of properly externalized ideas. To promote responsiveness in next-generation organizations, active and sharable workspaces for working together to develop information are proposed. These can be realized in seamless tools for computer-mediated conversation that extends from offices to coffee lounges to formal meeting rooms.

Stefik, Mark, Gregg Foster, Daniel G. Bobrow, Kenneth Kahn, Stan Lanning, and Lucy Suchman, "Beyond the Chalkboard: Computer Support for Collaboration and Problem Solving in Meetings," *Communications of the ACM*, Vol. 30, No. 1, January 1987, pp. 32-47.

Although individual use of computers is fairly widespread, in meetings we tend to leave them behind. At Xerox PARC, an experimental meeting room called the Colab has been created to study computer support of collaborative problem solving in face-to-face meetings. The long-term goal is to understand how to build computer tools to make meetings more effective.

Straub, Detmar W., Jr. and Renee Beauclair, "A New Dimension to Decision Support: Organizational Planning Made Easy with GDSS," *Data Management*, July 1987, pp. 11, 12, and 20.

Computer conferencing software supporting decision rooms, software packages such as FORUM, and distributed network tools are all organization group decision support system (GDSS) enhancement tools.

GDSS is broadly defined as any technology that is used to enhance group decisionmaking in an organization. As with Decision Support Systems (DSS), GDSS are designed to provide tools and support for decisionmaking.

This paper describes the results of a national survey on GDSS. Three generic types of GDSS structure are covered:

- Face-to-face conferences (computerized decision rooms)
- Interfaced computer conference (electronic mail)
- Face-to-face teleconferencing (decision rooms in remote areas with electronic links.

Thamhain, Hans J. and David Wilemon, "Building High Performing Engineering Project Teams," *IEEE Transactions on Engineering Management*, Vol. EM-34, No. 3, August 1987, pp. 130-137.

This article summarizes four years of research into the drivers and barriers of effective teambuilding in engineering work environments. A simple input-output model is presented for organizing and analyzing the various factors that influence team performance. The field survey results supported by correlation analysis indicate that team performance is primarily associated with six driving forces and six barriers that are related to leadership, job content, personal needs, and general work environment. Specific recommendations are made.

Turoff, Murray, and Starr Rosanne Hiltz, "Computer Support for Group Versus Individual Decisions," *IEEE Transactions on Communications*, Vol. COM-30, No. 1, January 1982, pp. 82-91.

Most decision support systems use computers to support interaction between individuals and a structured model, analytic routine, or a data base. However, many problems are unstructured or at best semistructured, and are dealt with by groups of managers within organizations. When dealing with nonroutine problems, the decisionmaking groups are often geographically and organizationally dispersed. Thus, a decision support

system for these groups must include communications, structured to support the decisionmaking process among members of the group.

This paper gives several examples of computerized conferencing systems (CCS) that have served as GDSS. In addition, the results of a controlled experiment comparing the process and outcome of group decisionmaking in a face-to-face versus a CC mode are discussed. Finally, preliminary results are presented from a second controlled experiment that explored how a CCS may best be structured to serve as a group DSS for a specific type of managerial task.

Valacich, Joseph S., Douglas R. Vogel, and J. F. Nunamaker, Jr., "A Semantic Guided Interface for Knowledge Base Supported GDSS," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 45-56.

Group Decision Support Systems (GDSS) have emerged to provide automated support for group deliberation and decisionmaking. Historically, technological complexity and lack of support for end user interaction have hindered effective use of knowledge bases in conjunction with group deliberation and decisionmaking. This paper describes a system that incorporates a semantic guided interface designed to overcome user apprehension to using Knowledge Base Management Systems developed for use with University of Arizona PlexCenter group decision support software. The semantic guided interface supports input, query, presentation, and reporting functions in conjunction with effective individual and group utilization. Time spent by group members extracting information is reduced in an atmosphere of enhanced user appreciation of knowledge base capabilities without sacrificing system integrity. Presentation of issues associated with complex questions is facilitated for group deliberation. The end result is powerful integrated support for group decisionmaking.

Valusek, LCol. John R. "Skip", "Adaptive Design of DSSs: A User Perspective," *DSS-88 Transactions*, Eighth International Conference on Decision Support Systems, Boston, 1988, pp. 105-112.

The developers of information systems recognize that decision support systems cannot be developed using a traditional systems development approach. Instead, an adaptive design approach is recommended to permit decision processes to be more adequately modeled and supported. Although many people espouse this approach, there has been little research of what is necessary to accomplish this radical change to the way we perform information engineering. The start-small-and-grow approach affects both user and builder roles in the process. DSS generators are evolving to support the builder's role. The purpose of this research is to investigate the process of adaptive design from a user's perspective of requirements evolution. The goal is to define the user's role in adaptive design and to apply technology to facilitate that role.

Varney, Glenn, "The Future of American Organizations," An Interview with Marshall Sashkin, *Group & Organization Studies*, Vol. 12, No. 2, June 1987, pp. 125-135.

The future of American management and the role organization development (OD) professionals play in organization change has emerged as a paramount concern to chief executive officers, managers, educational institutions, and many others in our society. This interview with one of the foremost thinkers on the subject of cultural and organizational change sets forth some very clear recommendations for improving American competitive positions in the world environment.

Vasilash, Gary S., "Simultaneous Engineering, Management's New Competitiveness Tool," *Production*, July 1987, pp. 36-41.

The concept is as simple as it is powerful--obtain as much information as possible as early as possible, then go to work creating world-class products and the processes that make them cost effective. However, this is not as easy as it may sound or seem.

More than a simple give-and-take between management and workers about the existing state of affairs, simultaneous engineering brings together groups that have historically had, perhaps, more friction between them than labor and management--design engineers and manufacturing engineers or product and process people. To make their jobs more difficult, they can't discuss givens, they must take concerted action on things that don't exist.

Their combined objective is, quite simply, to develop better products, whether a home appliance or an automobile. Improvements are expected to result because the two groups are working together. This may not seem extraordinary in itself; after all, both groups are engineers working for the same company. It seems only natural that the two would work in concert. However, with a few relatively recent exceptions, each group has operated in semi-impenetrable isolation within the major organizations.

Simultaneous engineering brings together not only the design and manufacturing people, but also a few more ingredients to complicate matters. For example, input from marketing and financial people becomes relevant to product and production decisions, and the original equipment manufacturers (OEMs) no longer select suppliers to work to specifications, but preselect suppliers who help develop the specs. Customers and vendors work together, sometimes in the same office.

Warfield, J. N., and A. N. Christakis, "Dimensionality," *Systems Research*, Vol. 4, No. 2, 1987, pp. 127-137.

New definitions of *dimensionality* and *dimension* are set forth that dominate older definitions. Dominance means not that older interpretations are violated but that the sense of the new interpretation substantially extends the sense of older interpretations, thereby opening up the use of the term in a much broader class of situations.

Among the benefits of the new interpretation of dimensionality are greater understanding of situations, greater effectiveness in describing situations, more lucid descriptions, better system designs, substantive cross-discipline problem-solving activities that cannot now be carried out in a common framework, and the potential for a more coherent community of scholars.

Warfield, John N., "Dimensionality," *Proceedings of the IEEE International Conference on Systems*, Man, and Cybernetics, 14-17 October 1986, pp. 1118-1121.

New definitions of dimension and dimensionality are set forth that dominate older definitions. Among the benefits of the new interpretations of these terms are greater effectiveness in describing and understanding systems, ability to accommodate quantitative and qualitative factors in the same framework, and the possibility of disciplining the design and management of complex systems to avoid calamities of the type that occur too frequently in modern society.

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