AN ABSTRACT OF THE DISSERTATION OF

Cindy A. McNown Perry for the degree of Doctor of Philosophy in Industrial Engineering presented on September 26, 2001: Title: A Model-Based Methodology for the Evaluation of Computerized Group Decision Making

Abstract approved: Redacted for Privacy
Kenneth H. Funk II

Increased global competition is forcing organizations to increase their use of group decision making today. Computerized group decision support aids (CGDSAs) are being developed to improve the efficiency of these groups and to improve decision quality. Even though the use of CGDSAs has increased, very little research has been done on the evaluation of CGDSAs. The purpose of this research was to develop a model-based generalized methodology for CGDSA evaluation from the user's perspective.

Two models were developed as a foundation for the CGDSA evaluation methodology. The first model was a model of group decision making and the second model was a model of computer-aided group decision making. The group decision making model was based upon a basic input-output model with the problem as the input and the selected alternative as the output. Analogous to how problems are viewed in terms of classical design of experiments, independent variables affect the outcome (problem solution – the dependent variable) of the decision making process. As in design of experiments, independent variables are either noise variables or control variables. In the model presented, the independent variables are further divided into four categories

(internal, external, process, and problem) in the group decision making model as a way to help develop an exhaustive list of independent variables affecting the decision making process.

The generalized methodology for CGDSA evaluation mapped directly to the computer-aided group decision making model. Solution quality is measured directly or by measuring independent variables that have been previously been correlated to solution quality using standard design of experiment techniques.

The generalized methodology for CGDSA evaluation was applied to the assessment of ConsensusBuilder, an example of a CGDSA. As prescribed by the CGDSA evaluation methodology, usability was also assessed and practical use considerations were followed when designing the evaluation. The value of the ConsensusBuilder evaluation for this research was that it was possible to perform a thorough evaluation of ConsensusBuilder, a CGDSA, using the CGDSA Evaluation Methodology developed in this research. In addition to the ConsensusBuilder evaluation, six different CGDSA evaluations cited in the literature were assessed in terms of the CGDSA evaluation methodology.

A Model-Based Methodology for the Evaluation of Computerized Group Decision Making

by

Cindy A. McNown Perry

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented September 26, 2001
Commencement June 2002

Doctor of Philosophy dissertation of Cindy A. McNown Perry presented on September 26, 2001

APPROVED:

Redacted for Privacy

Major Professor, representing Industrial Engineering

Redacted for Privacy

Head of Department of Industrial and Manufacturing Engineering

Redacted for Privacy

Dean of Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Cindy A. McNown Perry, Author

ACKNOWLEDGEMENTS

I wish to thank my husband, Russell J. Perry, for his endless support and encouragement.

I am grateful to my research advisor, Kenneth H. Funk II, for his help, cooperation and many helpful suggestions.

This research was funded in part through a grant, DARPA SB981-003, to Camas, Inc., with David G. Ullman as principal investigator.

Cindy A. McNown Perry

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A Model-Based Methodology for the Evaluation of Computerized Group Decision Making

1. BACKGROUND

1.1. Introduction

Global competition forces companies must bring their products to the market place with lightning speed in order to compete successfully. In order to be competitive, teams must be efficient in their decision-making activities.

> "...decision making abilities of employees play a key role in the performance and success of an organization....decision making skills and group decision making skills are both critical in the modern, learning organization. Because such organizations have the goal of empowering employees by delegating decision making authority to the lowest levels, it would be wise to ensure those employees are well prepared for the task" (Middleton, 1995).

Decision support aids are meant to improve the efficiency of decision-making activities and a multitude of decision support aids is becoming available. The creators of decision support aids claim them to be beneficial. However, at this point in time, little formal methodology to evaluate the effectiveness or usefulness of decision support aids exists. Current methods include trial-by-use and popularity-by-salesmanship. The ultimate purpose of this research was to develop a methodology for the evaluation of computerized group decision support aids (CGDSAs). Models of both group decision making and computer-aided group decision making were also developed and provided the foundation for the CDGDA evaluation methodology.

According to Bernd Rohrmann and Holger Schutz (1993), evaluation research of group decision support aids is important. They assert that we can learn the following things about a GDSA that are not possible with ordinary experience.

- *Claims about the usefulness of decision aiding systems (DAS) become provable in an objective and controllable manner.*

- *Coherent thinking about the purpose and the function of the employed tool is enforced, and the crucial attributes of DAS are identified.*
- *Empirical performance data can show whether the costs of a DAS (in terms of money or time or cognitive efforts) are justified.*
- *If several different DASs are available, a criterion-based choice between alternative programs is possible.*
- *The reasons that a DAS is effective or not can be explicated (because DAS are complex programs, the causes of success or failure are not self-evident).*
- *Careful evaluation provides the best basis for systematic improvement and further development of DAS.*

In order to begin the development of an evaluation methodology for computerized group decision support aids (GDSA) a foundation must first be laid. This foundation includes an understanding of 1) the importance of decision making and decision making teams, 2) a decision making model to base discussion on, 3) problem domains or different problem types, 4) individual and group decision making biases, 5) why decision support aids are needed, 6) characteristics of GDSAs, 7) existing decision support aid software, 8) measures of problem solution quality, 9) measures of usability, 10) existing methods for the evaluation of GDSAs, 11) an understanding of evaluation approaches, and 12) previous research on GDSAs .

1.2. Importance of decision making & decision making teams

Decisions are made by individuals and groups every day. An article written for the Center for the Study of Work Teams states, "decision making is an employee skill that is critical to the success of all organizations" (Middleton, 1995). It is important to consider group decision-making since it has become an accepted way of handling issues in business and industry today. According to a 1999 Industry Week Census of manufacturers, "nearly 68% of small-company plants use teams to varying degrees." The

article further says "developing teams is necessary because technology and market demands are compelling manufacturers to make their products faster, cheaper, and better" (Strozniak, 2000).

In addition to internal teams, companies are using virtual teams. An article in Teams Magazine states, "global competition, the computer age, and excessive travel expenses have evolved to make working across continents and countries an easy, practical way to achieve superior results (George, 1996)."

1.3. Purpose of this research

The purpose of this research was to propose a model of group decision making and aided group decision making. In addition, a general methodology for the evaluation of computerized GDSAs (CGDSAs), based upon the aided group decision making model, will be presented. The value of a model-based general methodology for the evaluation of CGDSAs is the establishment of a standard by which all CGDSAs can be evaluated.

2. PROBLEM TYPES

2.1. Introduction

Decision making has been defined as "the processes of thought and action that culminate in choice behavior" (MacCrimmon, 1973). "Decision making and problem solving are interrelated topics both involving use of judgment, bridging thought and action" (Middleton, 1995). Decision-making is closely associated with problem solving. When a problem exists, decisions must be made in order to solve the problem. Problem solving involves identifying issues that require attention, processing information, generating potential problem solutions and choosing the most desirable problem solution.

The research literature sometimes describes decision making as a subset of problem solving and sometimes describes problem solving as a subset of decision making. Decision making has been described as "dealing with evaluation and choice from a set of alternatives" (Middleton, 1995). Conversely, problem solving is viewed as primarily dealing with "simple solutions that often have correct solutions, while decision making encompasses broader, more important contexts" (MacCrimmon & Taylor, 1976, p. 1397). Due to the close association of decision making and problem solving, the terms decision making and problem solving are often used interchangeably.

In an ideal situation, both the problem and the possible alternatives should be completely understood in objective measurable terms. The task of alternative selection would be fairly straightforward since the alternative that best met the criteria would be selected. If multiple criteria exist, a ranking of those criteria would enable the evaluator to select an alternative that best met the most important criteria. Many mathematical techniques exist that allow one to select an optimal solution, given complete quantifiable

information about the problem and the potential alternatives. Most "real world" problems, however, do not arrive in a neat package with complete, objective, measurable data.

Real world problems usually must be solved in non-ideal conditions. Often the problem is not completely understood until it is solved, since it is an evolving set of interlocking issues and constraints. There is uncertainty about what is wanted and about the information needed to evaluate the alternatives, the information is subjective, there is no definitive problem, and there is no definitive solution (multiple solutions may exist). The problem-solving process ends when there is no longer time, money, energy, or some other resource – not when the perfect solution emerges. The constraints on the solution, such as limited resources, may be inconsistent and change over time. Unfortunately, the luxury of improving these conditions is not possible and decisions must still be made. The challenge becomes one of making optimal decisions in less than optimal circumstances.

There are several ways to classify problems. A classification scheme is useful since it helps to identify the strategy to be used for solving the problem. It is important that the appropriate strategy be used to solve problems. An understanding of the decision/problem space is helpful here since not all problems are the same and different types of problems require different approaches. To choose the best problem-solving process, some knowledge of the problem domain is needed. This knowledge may have the general form of a production rule: if the present problem type has certain properties, then perform a certain action. Such heuristic knowledge requires that the problem types be distinguished by their properties. This leads us to a further analysis of problems.

The efficiency of problem solving is strongly determined by the way the problem is classified (problem type). Changing the problem classification scheme, e.g. analyzing the problem domain according to different dimensions, is likely to make the problem much easier or much more difficult to solve. Problem type classifications, which are near to each other in one classification scheme, may be far apart in another classification scheme for the same problem. Therefore, a solution that could be reached easily using one classification scheme may be virtually impossible to find using a different classification scheme.

Examples of problem classification schemes include: real world vs. non-real world problems; problems from different disciplines; mathematical vs. non-mathematical problems; problems based upon different solution types; objective vs. subjective problems; problem system complexity/participant classification; well-structured vs. ill-structured problems; and wicked vs. tame problems.

2.2. Problems from Different Disciplines

Different kinds of problems tend to be found in different disciplines. For example many problems found in health care are different than problems encountered in space exploration or in the public schools.

2.3. Mathematical versus Non-mathematical Problems

Some problems can be modeled mathematically, while others cannot. Problems that can be modeled mathematically are easier to solve since dependent variables can be computed from algorithms that define the relationship of dependent variables to

independent variables. The following table (Table 2.1.) provides an example of a problem classification scheme based upon the mathematical characteristics of the problem. (Verena, 1995)

Table 2.1. Mathematical Classification of Problems

Mathematical Optimization Problem Classifications		
Characteristic	***Property***	***Classification***
Number of Control Variables	One	Univariate
	More than One	Multivariate
Type of Control Variables	Continuous Real Numbers	Continuous
	Integers	Integer or Discrete
	Both continuous real numbers and integers	Mixed Integer
	Integers in Permutations	Combinatorial
Problem Functions	Linear functions of the control variables	Linear
	Quadratic functions of the control variables	Quadratic
	Other nonlinear functions of the control variables	Nonlinear
Problem Formulation	Subject to constraints	Constrained
	Not subject to constraints	Unconstrained

2.4. Problems Based upon Different Solution Types

The following table (Table 2.2.) is example of classifying problems according to the type of solution that is desired. (Reagan-Cirincione, 1991)

Table 2.2. Solution Type Classification of Problems

Problem Type	*Description*
Resource Allocation	Distributing limited organizational resources (such as time, money, and space) to competing goals, objectives, or programs; analyzing priorities and tradeoffs to build consensus.
Multiattribute Utility	Evaluating a limited number of discrete options based on multiple criteria or stakeholder perspectives; examining the strengths and weaknesses of options; development of new options and selection of the best choice.
Judgment Analysis	Establishing explicit policies for situations that require: repeated judgments over time; use of multiple technical or social criteria; specification of policies in advance of actual cases; examination of intuitive judgment-making processes.
System Dynamics	Understanding the long term implications of decision alternatives in situations where change naturally occurs over time and the complexity of change is compounded by secondary effects.
Decision Analysis	Choosing a series of actions in situations where the future outcomes, at each step along the way, are uncertain.
Knowledge Structuring	Eliciting, organizing and prioritizing information from groups (generally as an early phase leading to the development of one of the above models).

2.5. Objective versus Subjective Problems

Objective problems can be solved using objective information. The information is either descriptive or measurable, but is not subject to interpretation. Measurable data can be either be in the form of attribute or variable data. Attribute data is data that is in the form of two extremes, e.g. yes/no, or count data and variable data is represented by a numerical value. Subjective problems rely upon information that is opinion-based and can potentially vary from person to person.

An example of an objective problem would be minimization of product costs, while an example of a subjective problem would be creation of a company logo.

2.6. Problem System Complexity/Participant Classification

In their book, *Creative Problem Solving – Total Systems Intervention*, Flood and Jackson describe simple and complex systems and the relationships between individuals in problem solving teams. They propose the following grouping based upon a matrix of system complexity and participant classification (Flood & Jackson, 1991, p. 35). Suggested problem solving approaches are given within the matrix (Table 2.3.).

Table 2.3. Problem System Complexity/Participant Classification of Problems

	Unitary	***Pluralist***	***Coercive***
Simple	**Simple-Unitary** • OR • SA • SE • SD	**Simple-Pluralist** • SSD • SAST	**Simple-Coercive** • CSH
Complex	**Complex-Unitary** • VSD • GST • ST • CT	**Complex-Pluralist** • IP • SSM	**Complex-Coercive** ?

Key:

Simple System – small number of elements; few interactions between elements; predetermined attributes of elements; highly organized interaction between elements if it exists; well-defined behavior laws; no evolution over time; no sub-systems with separate goals; system is unaffected by behavior influences; system is closed to the environment

Complex System – large number of elements; many interactions between elements; attributes of elements are not predetermined; loosely organized interaction between elements; elements are probabilistic in their behavior; system evolves over time; sub-

systems are purposeful & generate their own goals; system is subjective to behavioral influences; system is largely open to the environment

Unitary – shared common interests; compatible values & beliefs; agreement on ends & means; all members participate in decision-making; all act in accordance with agreed objectives

Pluralist – compatibility of interests; values & beliefs diverge to some extent; compromise when ends and means are not agreed upon; all participate in decision-making; all act in accordance with agreed objectives

Coercive – common interests are not shared; values & beliefs are likely to conflict; compromise is not possible since ends and means are not agreed upon; some participants coerce others to accept decisions; agreement over objectives is not possible

Problem-Solving Approaches:

OR - operational research
SA – systems analysis
SE – systems engineering
SD – systems dynamics
VSD – viable system diagnosis
GST – general system theory
ST - socio-technical systems thinking
CT - Contingency Theory
SSD – social systems design
SAST – strategic assumption surface & testing
IP – interactive planning
SSM – soft systems methodology
CSH - Critical Systems Heuristics

2.7. Well-structured versus Ill-structured Problems

Middleton describes well-structured decision problems as decision problems that "allow the decision maker to apply past experience by using transformations that have worked for similar situations in the past" (1995). The transformations are described as either standard responses with a finite number of logical steps that lead to the same output or heuristics (rules of thumb) for seeking solutions. Ill-structured decision problems are described as decision problems to which the current state, the transformations or the desired state are unfamiliar to the decision maker (Middleton, 1995).

Selecting lower cost vendors in purchasing is an example of a well-structured problem, while new product design would be an example of an ill-structured problem.

2.8. Wicked versus Tame Problems

Horst Rittel and Melvin Webber invented the term "wicked problems" in an attempt to describe problems that cannot be solved with traditional operations research methods (1973). According to Rittel, "the methods of Operations Research...become operational...only after the most important decisions have been made, i.e. after the [wicked] problem has been tamed" (Rittel & Webber, 1973). Harold Nelson (1973) provides the following summary of wicked problem's characteristics:

1. Cannot be exhaustively formulated.
2. Every formulation is a statement of a solution.
3. No rule for knowing when to stop.
4. No true or false.
5. No exhaustive list of operations.
6. Many explanations for the same problem.
7. Every problem is a symptom of another problem.
8. No immediate or ultimate test.
9. One-shot solutions (no second tries).
10. Every problem is essentially unique.

A wicked problem is one in which complexity is such that after the usual data gathering and analysis, it is still not known if a solution will work. Solutions must be attempted and reactions of the system observed in order to further characterize the problem. A really wicked problem is a problem that is not fully understood until it is solved. A tame problem, by comparison is the opposite of a wicked problem. In the 1980s, Horst Rittel developed a method called Issue-Based Information System (IBIS) to provide a formal structure for discussion of wicked problems.

2.9. Problem Types based on an Information Systems Perspective

Much of the research literature on decision support systems is written from the information systems perspective. In information systems, a decision support system is defined as a computer based system that supports decision making. One categorization scheme for problem types used in information systems, divides problem types on the basis of management activities and types of decision tasks (Keen, 1978). Decision tasks are seen as structured, semi-structured and unstructured. Structured tasks are repetitive and routine to the extent that a definite procedure can be used to complete them, while unstructured tasks are novel and incapable of being structured. Semi-structured tasks require some judgment and subjective analysis. Management activities are divided into operational control, management control and strategic planning. The following table (Table 2.4.) outlines this categorization model with examples of the different problem types and suggested decision support (Keen, 1978, p. 87).

Table 2.4. Information Systems Perspective Classification of Problems

	Management Activity			
Type of Decision/Task	**Operational Control**	**Management Control**	**Strategic Planning**	**Support Needed**
Structured	Inventory reordering	Linear programming for manufacturing	Plant location	Clerical, EDP or MS models
Semi-structured	Bond Trading	Setting market budgets for consumer products	Capital acquisition analysis	**DSS** (Decision Support System)
Unstructured	Selecting a cover for Time magazine	Hiring managers	R & D portfolio development	Human intuition

2.10. Problem Type Summary

Effective models of decision making will explain all problem types. The purpose of presenting some of the different problem type classification schemes was to provide a foundation for model development. A group decision making model is developed in Chapter 3.

3. THEORY AND MODEL OF GROUP DECISION MAKING

3.1. Introduction

A theory is the collection of statements about the domain of group decision making, while a model is the structure in which the statements of this theory are interpreted as true. The model can be the diagram that maps to elements of the theory. Theories with their supportive models are developed in this research.

A decision is selecting or choosing one alternative from a group of two or more alternatives. These selections or choices each have associated consequences of varying significance. The choice of whether to have soup or salad for lunch probably is not as significant as how to select a new product line, but the mechanism for each example is essentially the same. "Problem solving proceeds by heuristic search through a large set of possibilities" (Klein & Methlie, 1995, p. 3).

3.2. A Review of Current Decision Making Theories and Models

There are three components to every problem (for which a decision must be made): criteria, alternatives, and the problem solving process. Criteria are the standards by which decision makers evaluate alternatives or the desired features of an alternative. Alternatives are the specific courses of action or options being considered, or potential problem solutions. The problem solving process links specific alternatives to specific criteria. The goal of the problem solving process is to use information to develop alternatives with criteria that meet the desired solution.

A model for decision-making that is a basic input-output model is presented in Figure 3.1. The input is the problem and the output is the selected alternative. This model is in alignment with Reitman's (1964) conceptualization of decision problems as a three component vector: the initial or current state the decision maker has available; the terminal or desired state he/she would like to achieve (target or goal); and the transformations or processes that the decision maker must go through to get from the initial condition to the desired condition. In the presented model, the problem is analogous to the initial state, the problem-solving process is analogous to the transformations, and the selected alternative is analogous to the terminal state.

The presented model (Figure 3.1.) is an instantiation of the information-processing model of decision making (Wickens, 2000, p. 295). First a problem or a situation that requires a solution is sensed or perceived. Next some sort of informal or formal problem-solving process is followed in order to arrive at an adequate solution. During the problem-solving process information is gathered, filtered and analyzed. An informed decision involves having as much information as possible about the nature of the problem, the criteria for solving the problem and the characteristics of the alternatives to assure that the selected alternative best solves the problem. This information-handling task leads to problem clarification and alternatives generation. Problem clarification is the process of identifying criteria or factors necessary for an acceptable solution to the problem. Alternatives are different possible problem solutions.

Once the alternatives have been generated, they can be assessed in terms of meeting the stated criteria. It is very possible that a number of acceptable alternatives

may offer a solution to the problem and the alternative that best meets the criteria must be selected.

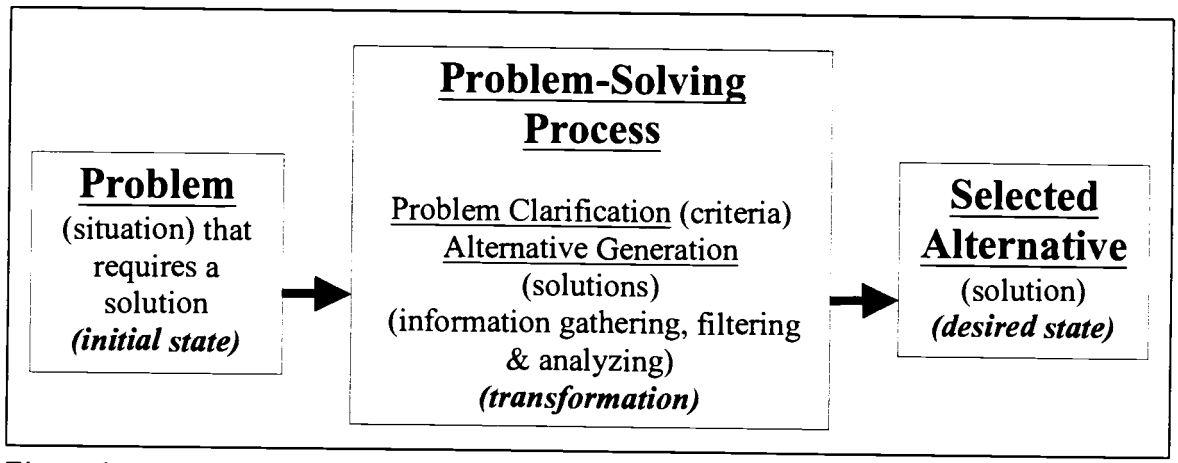

Figure 3.1. Decision-Making Model

Similar to Reitman's (1964) conceptualization of decision problems, Ronald Howard (1988) views decision making as a decision analysis cycle comprised of three steps (Figure 3.2.). Step one of this model is to formulate a model of the decision situation (referred to as 'decision basis' by Howard). Step two is to use a computation procedure to produce the recommended alternative that is logically consistent with the decision basis. Lastly, step three is the appraisal of the analysis to gain insight into the recommended alternative and check that the recommended alternative is correct.

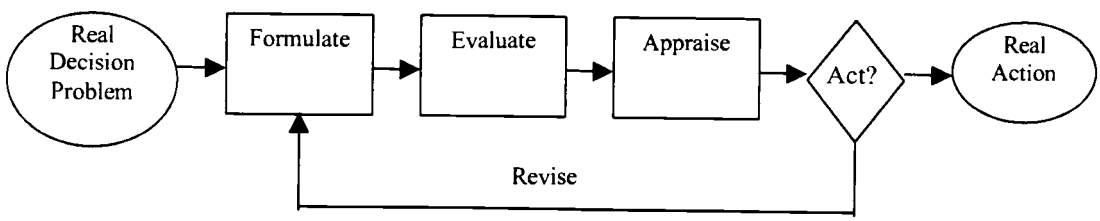

Figure 3.2. Closed Loop Decision Process (Reproduced from Howard R. (1988). Decision Analysis: practice and promise. Management Science, 34(6), 679-695.

Howard (1988) introduced the following criteria for decision quality: decision framing, decision basis, integration and evaluation with logic, balance of basis and commitment to action. Decision framing addresses whether the right problem is being analyzed. Decision basis considers the quality of the information that decisions are based upon, exhaustive search and evaluation of alternatives, and the clarity of stated values. Integration and evaluation with logic focuses on whether the procedures to select the right alternative are the correct procedures and free of logical errors. Balance of basis considers the allocation of efforts between improving information quality, generation of new alternatives and thinking about values. Commitment to action is concerned with clear indication of the right course of action and communication of that action to the decision maker (Howard, 1988).

In addition to having a model for decision making that is focused on the problem, it is useful to have a model that focuses on the decision maker. Carroll and Johnson (1990) claim that in general, a weighted-additive model (also a type of input-output model) can be used to explain a decision maker's behavior. The inputs are a set of alternatives described by attributes (attributes may then be assigned criteria for measurement) and the outputs are evaluations of alternatives made by the decision maker. Mathematically this model can be represented by:

$$Y_i = f(X_{ij})$$

where Y = overall evaluations
X = attributes
i = alternative
j = number of attributes

Techniques used to understand the decision making process attempt to analyze f by analyzing attributes and decisions, without looking directly at any of the intervening steps

in the decision process. Techniques that rely upon descriptive models attempt to explain existing judgments and provide predictions of subsequent judgments. Techniques that rely upon prescriptive models attempt to help decision makers make better decisions by "clarifying perceptions of the attributes associated with alternatives, X_{ij}, and by altering the decision rule, *f*, to avoid inconsistencies, confusions, or biases on the part of decision makers" (Carroll & Johnson, 1990).

The function (*f*) or process of decision making can be viewed from several different perspectives. Peter Keen provides a very good summary of five different types of decision making processes in his book, Decision Support Systems (1978). Another categorization of decision making processes includes the following four dimensions (McDonald, 1990): rational, consensual, empirical, and political. The following list is a combination of the categories proposed by Keen (1978) and McDonald (1990).

Economic, rational processes: These processes represent the classical normative theory of decision making, in which decision makers are able to define all attributes and evaluate all alternatives. They are dissatisfied with any solutions but the best. Rational decision processes are goal centered, logical, and efficient and include many of the processes characterized by multi-attribute utility theory. Normative theories are concerned only with how to choose from a set of alternatives. They say nothing about how to frame problems, develop alternatives, set goals or implement decisions.

Satisficing, process-oriented processes: These processes consider decision makers to be intentionally rational although cognitive limits lead to a bounded rationality; thus the goal of any decision maker is to get a good enough answer, not the best possible one. This point of view stresses the process of decision making and not just its outputs; it emphasizes the relatively limited analysis and search most managers will make and their reliance on heuristics.

Organizational procedures processes: These processes focus on the interrelations among components of the organization. It highlights organizational structure, mechanisms for communication and coordination, and the standard operating procedures by which decision making is systematized and often simplified.

Political processes: These processes regard the participants in the decision process as actors with parts to play. They have strong individual preferences and vested interests and form coalitions of organizational subgroups. Decisions are frequently dominated by bargaining and conflict, with the result that only small deviations from the status quo are normally possible. Major innovations are (quite reasonably) resisted by those whose position, interests, or simply job satisfaction will be affected.

Individual differences processes: These processes argue that an individual's personality and style strongly determine his or her choices and behavior. Personal "rationality" is subjective and behavior is very much determined by the manner in which an individual processes information.

Consensual processes: These processes demand participation and general agreement by all team members. They highlight a strong bias to democratic processes.

Empirical processes: These processes are based on the use of information or evidence and demand accountability or credibility. These processes might be subsumed under rational processes; one can be rational without being empirical, but one cannot be empirical without being rational.

Rasmussen's (1981) skill-rule-knowledge framework for human performance offers another conceptualization of how people perform and make decisions. Skill-based level performance is used for highly practiced tasks and governed by stored patterns of preprogrammed instructions. Rule-based level performance is used for familiar problems and is governed by stored rules called productions. The productions are in the form: if state, then diagnosis or if state, then action. Knowledge-based level performance is used for unfamiliar problems and actions are planned without the use of stored rules, using very limited searches of the problem space. People prefer to operate at the skill-based or rule-based level since knowledge-based reasoning is difficult and fatiguing for most people. Experts tend to be better at rule-based reasoning than most people, but they are not much better at knowledge-based reasoning than the average person.

3.3. Individual and Group Biases

3.3.1. Individual Decision Making Biases

Normative theories of decision making, i.e. classical economic theory (von Neumann & Morgenstern, 1944), propose that decision makers follow a highly rational procedure for making decisions. They assume that decision makers have consistent preferences, know their preferences, know the alternatives available, have access to information about the consequences of selecting each alternative, and combine the information according to the expected utility rule, which discounts or weights outcomes by their probability of occurrence (Dawes, 1988; Fischhoff, 1982). Research evidence, however, shows that actual decisions consistently diverge from the rational model. The expanded utility model attempts to explain the results of some of this research, but falls short in explaining everything.

There simply is not enough time in the day to systematically analyze every piece of information people encounter. People respond to situations as they interpret them, not as they exist in some objective reality " (Carroll & Johnson, 1990, p. 26). As an aid for information analysis, people develop "short-cuts" to process information that tends to follow patterns of previously processed information. The value in using these "short-cuts" is that they save effort and allow decision makers to avoid difficult tradeoffs. People often develop decision rules that do not take subjective measures into account. For example, people use budgets and other objective information in deciding what products to buy, but once products that do not meet the objective criteria are eliminated

from the group, subjective preferences are used to make the final decision. This method avoids having to assign value to subjective preferences.

Unfortunately these "short-cuts," heuristics, or rules of thumb that are used when making judgments about situations are not always correct. Even though people strive to make "good" decisions and often have high opinions of their decision making ability, research repeatedly show that decision makers may not understand their own implicit decision rules (Hammond, Stewart, Brehmer & Steinmann, 1975) and are systematically overconfident about the quality of their judgments and decisions (Fischhoff, 1975).

One may think that with experience, people get better at making decisions, but the idea that experts make better decisions than novices is also unfounded. "Studies of expert decision makers suggest that they sometimes do little (if any) better than novices, and that people sometimes learn the wrong things from 'experience'" (Carroll & Johnson, 1990). People have a difficult time unlearning flawed or incorrect decision rules. Because of incomplete feedback, delayed feedback, and uncertainty – sometimes good decisions produce bad results, and vice-versa (Einhorn, 1980).

The lack of decision making correctness is due to several biases, which affect the degree of influence a given amount of information has on our knowledge, beliefs, and decision making. Biases of notable concern for decision making are biases in how people estimate probabilities, seek information, and attach values to outcomes.

Statistical probabilities are based on empirical evidence concerning relative frequencies. Many judgments deal with one-of-a-kind situations for which it is

impossible to assign a statistical probability. People commonly make subjective probability judgments. Such judgments are an expression of a personal belief that a certain estimate is correct. An example of this kind of subjective probability estimate is that a horse has a three-to-one chance of winning a race.

Verbal expressions of uncertainty such as "possible," "probable," "unlikely," "may," and "could" are a form of subjective probability judgments, and they have long been recognized as sources of ambiguity and misunderstanding. To say that something could happen or is possible may refer to anything from a less than 1-percent to a more than 99-percent probability.

The research literature describes a number of biases that are of concern in decision making. Following is a brief summary of some of these biases (Fong, 2000; Harris, 1997; Huerer, 1999; Plous, 1993; Poulton, 1989; Sanders, 1993, Wickens, 2000).

Individual and group biases are not the only variables that affect group decision making, but since they affect virtually all decisions and are difficult to control, they are given special attention here. Additional variables that affect decision making (internal, external, process, and problem variables) are discussed in section 3.4.2.2.

3.3.1.1. Consistency

People tend to see what they expect to see, and new information is typically assimilated to existing beliefs. This is especially true when dealing with verbal expressions of uncertainty. When conclusions are couched in ambiguous terms, a reader's interpretation of the conclusions will be biased in favor of consistency with what

the reader already believes. An example of consistency bias in decision making would be failing to understand new concepts. For instance, it may be difficult for users of a decision support aid to fully understand the model and terminology associated with that decision support aid. It follows that training people in the use of a decision support aid must be done in a fashion that clearly defines concepts and terms that may be new to the user.

3.3.1.2. Availability

People are more likely to be influenced by information that is already present, handy, or easy to find than by information that requires effort to locate it. The problem is that the unavailable information, or the information that is harder to get, may actually be the more reliable or the more definitive for use in making good decisions. When using a decision support aid this bias can be reduced by making information readily accessible to the user, i.e. having data bases readily available and easy to access.

3.3.1.3. Familiarity

People tend to believe whatever is most familiar, or what is an extension of the familiar. We tend to reject and disbelieve the unfamiliar. What is made familiar enters people's beliefs with less examination than it would if unfamiliar. Repetition in training in the use of a decision aid will help improve the "believability" of concepts that may be new to first-time users.

3.3.1.4. Memorability

Information that a person finds interesting and memorable is much more likely to influence a judgment. Chance or coincidental events that are highly memorable are thus often judged to be regular or common. And, of course, information you cannot remember is not going to be used when making a decision. Anything that can be used to add interest or make information memorable will improve the likelihood that that feature will be used in decision making. Use of examples that people can identify with will be more helpful when demonstrating how to use a decision support aid than examples that are foreign to the potential users.

3.3.1.5. Recency

Most people are faced with information overload on a daily basis. New information tends to replace the old information even if the new information is incomplete or irrelevant information about the individual event. Therefore the most recently gained information tends to be favored, and decisions are made or changed due to the perception of "new" information. Order of information presentation, thus, is critical. This bias can be minimized by regular review of critical information. Help screens in a computerized decision support aid will help reduce the bias of recency.

3.3.1.6. Sequence

The two periods of greatest attention, whether in moments or months, are at the very beginning and the very end of an event. Therefore, information presented or

received first and last in a project, problem, research project, or meeting will be remembered better and given more importance than information received during the middle of the project. If decision makers overlook information discovered somewhere in the middle of a project, they are experiencing a sequence bias. Minimizing this bias can be done by repetition of critical information with varied sequences or by grouping critical information into a short time frame both at the beginning and the end of the project.

3.3.1.7. Sparkle

Lively, immediate, personal experience overwhelms theory and generalization. Many people base their personal behavior and values on generalizations formed by significant personal experiences, even when those generalizations conflict with much better established facts based on thorough empirical investigation. Abstract truths, detailed statistics, and even moral values may be ignored when a strong personal experience points to a different conclusion. If people can be convinced that they have experienced a "truth", they will often not listen to any arguments to the contrary. The emotion attached to the experience and the perception of being an "eyewitness to the truth" are too much to refute with data to the contrary. Care must be taken to avoid making decisions based upon the "sensational" rather than the "facts." Emphasis upon observable or measurable information will help to minimize this bias. Use of aesthetically pleasing graphics and illustrations with computerized decision support aids can also help minimize this bias.

3.3.1.8. Compatibility

Everyone has a set of personal values and beliefs. People tend to accept ideas that agree with their own values and beliefs and reject those that are in conflict. Even when they are wrong, they will reject what is true and continue to build a false world if it conflicts with their personal beliefs. It is important to keep the audience in mind and be aware of possible value systems that might be in conflict with information used for decision making. This bias might be observed when groups of people from different cultures are working together. For example, in some cultures it is considered disrespectful to make eye contact, while in other cultures the lack of eye contact is viewed as disinterest by that person.

3.3.1.9. Preconception

Current concerns tend to control people's perceptions and interpretations of incoming information. If it is believed that a company is having financial trouble, ambiguous data will be used to support that conclusion. Beliefs tend to be interpreted in a way consistent with expectations. People tend to see what they expect to see or wish to see; people seek and give weight to information that supports or agrees with information they already believe; and people depreciate or reject information that conflicts with beliefs or conclusions previously held. This tendency is known as *selective perception*. In most cases, information is ambiguous enough to allow more than one interpretation. For example, if people are told that the company they are working for is having financial

difficulties and it has always been the culture of the company to avoid layoffs at all costs, people would have a hard time accepting the news that a layoff is imminent.

3.3.1.10. Privilege

Information that is perceived as scarce, secret, special, or restricted takes on an automatically greater value and appears more credible than information that is perceived as common and available to anyone. (This is why most efforts at censorship fail—banning or censoring a book or film makes people think it is better and more desirable than ever.) Awareness of this tendency will help reduce its affect upon decision making.

3.3.1.11. Visual Presentation

Graphical information is often more influential than textual information. The old adage "a picture is worth a thousand words" comes to mind. Graphical items do not require the processing of symbolic manipulation that is required by text. Whenever possible, graphical images should be used rather than text to display information used for decision making, unless of course, the graphical images cannot convey the detail that only text can convey. Failure to read the textual instructions in the use of a computerized decision support aid and reliance upon flowcharts and other graphical information would be an example of a visual presentation bias.

3.3.1.12. Mental Effort

Information that is easy to understand, presented clearly and simply, described in exact and graspable terms, is much more likely to influence people than difficult, tedious,

or ambiguous information. In decision applications, graphs rather than lists of data and short, brief text bullets rather than paragraphs of text are preferable. Skipping the use of applications that are difficult to understand in a computerized decision support aid would be an example of a mental effort bias.

3.3.1.13. Hasty Generalizations

Many people formulate generalizations on the basis of very small samples, often one or two or three instances. The first two or three examples of something (especially if experiential, see *Sparkle* above) are judged to be representative, even if they are not. Generalizing from one's own limited experience and then adjusting one's interpretation of subsequent events is a major problem in information processing and may result in poor quality decisions. Groups that make decisions early after the presentation of the problem without investigating all aspects of the problem are demonstrating the bias of hasty generalizations.

3.3.1.14. Inconsistency

Most people have trouble applying consistent judgment. Often, information received in one manner will receive more favorable treatment than information received in a different manner. For example, information received in the morning may be viewed more favorably or more critically than similar information received in the afternoon. Subjective ratings of events or experiences are especially prone to inconsistency bias. This bias is especially important when human preference is used for the decision-making process rather than prescribing a consistent decision-making procedure. If users of a

computerized group decision support aid weight criteria differently each time they do it, they are demonstrating an inconsistency bias.

3.3.1.15. Pressure

Under pressure, information tends to be processed using shortcuts, simplification, and superficial analysis. Techniques such as stereotyping, pigeonholing, quick impressions, and skimming, may be used simply as a means of coping with time or resource constraints. This bias can be minimized with decision making by outlining the requirements for a successful decision prior to making it. If groups were constrained by time, this would be an example of a pressure bias.

3.3.1.16. Contrast

Differences tend to be exaggerated in order to distinguish items from one another. Contrast is relative. Often contrast depends upon the number of items considered or in a group. This bias can be minimized in decision making if all alternatives are considered together prior to selecting an alternative from the group rather than considering alternatives one at a time without comparison to all other alternatives in the group. Categorizing an issue as unimportant previously categorized as important due to the introduction of more urgent issues would be an example of a contrast bias.

3.3.1.17. Anchoring

Some natural starting point, perhaps from a previous analysis of the same subject or from some partial calculation, is used as a first approximation to the desired judgment. This starting point is then adjusted, based on the results of additional information or analysis. Typically, however, the starting point serves as an anchor or drag that reduces the amount of adjustment, so the final estimate remains closer to the starting point than it ought to be. If a group tends to make the same decision as their original decision after new information has been gathered, they may be demonstrating an anchoring bias.

3.3.1.18. Base Rate Fallacy

In assessing a situation, two kinds of data may be available—specific data about the individual case at hand, and summary data (base rate or prior probability) that summarize information about many similar cases. The base-rate fallacy is that the summary data are commonly ignored unless they illuminate a causal relationship. It is important to consider both individual data and summary data when making decisions. Decision makers that respond excessively to a one time occurrence without taking past history into account are demonstrating the base rate fallacy.

3.3.1.19. Information Framing

The way in which an uncertain possibility is presented may have a substantial effect on how people respond to it. For instance, when asked whether they would choose surgery in a hypothetical medical emergency, many more people said that they would

when the chance of survival was given as 80 percent than when the chance of death was given as 20 percent. It is important to consider how problems are framed to prevent leading people to a particular decision.

3.3.2. Group Decision Making Biases

Groups have the advantages of being able to combine information that is not held by any individual and having an increased capacity for work. Groups, however, may not always recognize the right answers when they see them or identify experts in their midst (Laughlin & Ellis, 1986). Studies that have directly compared groups and individuals on the same problems find that groups fall prey to the same errors and biases as do individuals (Argote, Seabright & Dyer, 1986; Bazerman, Biuliano, & Appelman, 1984). Therefore, groups can be expected to make as many or more of the same errors based upon cognitive heuristics and biases as individuals.

Group decisions have an added dimension of complexity over individual decisions. Errors or biases that may appear in a group may be derived from the organizational or environmental context in which they occur. Cohen, March, and Olsen (1972) were among the first to note that group decision making was heavily influenced by the organizational context in which it occurred. Examples of errors due to conceptual context include inappropriate lines of authority (Rochlin, La Porte, & Roberts, 1987) and failure to coordinate uniquely held information (Cicourel, 1990; Hutchins, 1990).

According to Scott Tindale, for tasks where a correct solution does not exist or cannot be known until some future time, some type of "majority wins" process best describes the group consensus process (Castellan, 1993). Tindale further points out, "if most individuals in the population are prone to make a particular error (i.e. the probability of a correct response is less than .50), a majority decision process will tend to exacerbate the probability of that error occurring in the distribution of group decisions.....and groups would be expected to make more errors (or more extreme errors) than individuals" (Castellan, 1993).

Various group dynamics or socially based errors affect a group's decision-making ability to generate alternatives and reach consensus in addition to the biases that affect individuals. Group difficulties may include an overemphasis on social-emotional rather than task activities (Delbecq, Van de Ven & Gustafson, 1975), failure to define a problem adequately before rushing to judgment (Maier & Hoffman, 1960), or deindividuation and diffusion of responsibility that may lead to risky decisions (Diener 1980; Latane, Williams & Harkins, 1979). Two additional group phenomena worthy of discussion are groupthink and the Abilene Paradox.

3.3.2.1. Groupthink

Irving Janis was intrigued by the imperfections of group decisions and studied the effects of group cohesiveness and conformity to group norms (Janis, 1982). He coined the term "groupthink" and defined it as "a deterioration of mental efficiency, reality testing, and moral judgment that results from in-group pressures (pressures that group

members exert upon one another)." He further described this phenomenon as a "mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when the member's strivings for unanimity override their motivation to realistically appraise alternative courses of action" (Janis, 1982, p.9). He offers a detailed conceptual framework of antecedent conditions that can give rise to concurrence-seeking (agreement for the sake of agreement), which in turn lead to symptoms of groupthink and defective decision-making, resulting in low probability of a successful outcome (Janis, 1982, p. 244).

Janis argues that "the more amiability and esprit de corps among the members of an in-group of policy makers, the greater is the danger that independent critical thinking will be replaced by groupthink" (Janis, 1982, p. 245). This points out that a smooth-running, efficient team that rarely experiences conflict, may not be an effective team since this condition may actually be an antecedent to groupthink. Janis identifies four "structural faults" within an organization that can lead to "uncritical conformity" (Janis, 1982, p. 249). The structural faults are:

group insulation – the insulation of the group from non-group members within the organization

lack of tradition of impartial leadership – "the leader does not feel constrained by any organizational tradition to avoid pushing for his own preferred policies, and instead, to encourage open, unbiased inquiry into the available alternatives" (Janis, 1982, p. 249)

lack of norms requiring methodical procedures – lack of a standard decision-making process

homogeneity of members' social background and ideology – when group members' have similar socioeconomic, educational and ideological backgrounds

Janis discusses two factors that add to a provocative situational context: the presence of high stress from external forces coupled with limited hope of arriving at a better solution than the dominant one proposed by the leader; and temporary low self-esteem of group members resulting from recent failures, the difficulty of decision making, the moral dilemmas posed by the decision-making interaction, and/or a combination of these sources (Mansfield, 1987).

If antecedent conditions lead to the existence of a concurrence-seeking tendency, Janis predicts that symptoms of groupthink may occur. His eight symptoms of groupthink can be categorized into three types: overestimation of the group, closed-mindedness, and pressures toward uniformity. These conditions, in turn, can lead to defective decision making (Mansfield, 1997). "Even when some symptoms are absent," Janis (1982, p. 175) argues, "the others may be so pronounced that we can predict all the unfortunate consequences of groupthink." The eight symptoms of groupthink follow.

Overestimation of the Group:

1) Illusion of Invulnerability – A shared illusion of invulnerability among group members creates excessive optimism and encourages taking extreme risks (Janis, 1982, p. 174).
2) Belief in Inherent Morality – Viewing their motives and actions as inherently moral can incline a group to give little heed to the ethical consequences of their decisions (Mansfield, 1987).

Closed-Mindedness:

3) Collective Rationalizations – This consists of "collective efforts to rationalize in order to discount warnings or other information that might lead the members to reconsider their assumptions before they commit themselves to their past policy decisions" (Janis, 1982, p. 174).
4) Stereotypes of Out-Groups – Non-group members are viewed as either "too evil to warrant genuine attempt to negotiate, or as too weak or stupid to counter whatever risky attempts are made to defeat their purposes" (Janis, 1982, p. 174).

Pressures Toward Uniformity:

5) Self-Censorship – This represents a tendency toward uniformity. Self-censorship of deviations from the apparent group consensus causes members to minimize the importance of their doubts or counterarguments" (Janis, 1982, p. 175).
6) Illusion of Unanimity – Unanimity results from self-censorship of deviations and from the incorrect assumption that silence means consent (Mansfield, 1987).
7) Direct Pressure on Dissenters – "Familiar forms of social pressure can be directed against any group member who questions the group's stereotypes, illusions, or commitments. If subtle pressures fail to tame the dissenter, stronger more direct pressures are employed, ultimately leading to ostracism" (Janis, 1982).
8) Self-Appointed Mindguards – This occurs when a self-appointed member or a group protects other members or an outside non-member from views that might lessen their confidence in the wisdom of policies to which they are committed. There is a tendency to avoid information that does not support the current viewpoint.

"Janis's theory postulates that antecedent conditions, concurrence-seeking tendencies, and symptoms of groupthink can lead to defective decision making. He suggests seven symptoms of defective decision making and argues that any one of them can impair the effectiveness of the group" (Mansfield, 1987). The following are symptoms of defective decision making.

Incomplete survey of alternatives

Incomplete survey of objectives (or criteria)

Failure to examine risks

Failure to reappraise initially rejected alternatives

Poor information search

Selective bias in processing information at hand

Failure to work out contingency plans

3.3.2.2. Abilene Paradox

Jerry Harvey (1974) describes a phenomenon he calls the "Abilene paradox." The name arises from an eventful trip from Coleman, Texas to Abilene. No one really wants to go to Abilene, but everyone agrees that it's a good idea for fear of not

Jerry Harvey (1974) describes a phenomenon he calls the "Abilene paradox." The name arises from an eventful trip from Coleman, Texas to Abilene. No one really wants to go to Abilene, but everyone agrees that it's a good idea for fear of not disappointing anyone else in the group. Simply stated, the Abilene Paradox states that: Groups frequently take actions contrary to what any of their members really want to do and defeat the very purposes those groups set out to achieve. Failure to communicate agreement and faulty information cause the group to do the opposite of what the group members want to do. It is the inability to manage agreement, rather than conflict, that is the problem. Four psychological principles underlying the Abilene Paradox follow (Seward, 2000).

1) Action Anxiety – When confronted with a potential conflict in a group, people know the sensible action to be taken, but when it comes time to take the action they are so anxious that they don't carry out the action that they know to be best.
2) Negative Fantasies – Negative fantasies of disasters provide justifications for not taking risks. Inaction in itself is a choice that often leads to greater risk than imagined.
3) Separation Anxiety – Fear of the Known – Group members fear being ostracized, being branded as non-team players, and separation from the group so they agree with the group.
4) Psychological Reversal of Risk and Certainty – The risk of separation causes the separation that is feared. The fear to take action by a group member results in failure by the group and then the group rejects the group member for failing to take action.

The trip to Abilene can be avoided by encouraging group members to confront the group with their own beliefs and feelings. The group must first, agree on the nature of the situation and what each member wants to do. Second, everyone must communicate the agreement. Third, take action toward what the group really wants to do.

3.4. Group Decision Making Theory and Model

3.4.1. Introduction

Although various theories and models exist to explain the decision making process, the literature does not provide explanations for the role CGDSAs play in the decision making process with any clearly articulated models. A descriptive model for group decision making (Figure 3.3.) based upon the basic input-output model discussed previously (Figure 3.1.), is developed here. Although the structure of the proposed model is unique, the various components of the model are based upon common themes found in the literature on decision making, problem solving, group dynamics and human factors.

The proposed group decision making model (Figure 3.3.), begins with Reitman's (1964) previously discussed conceptualization of decision problems as a three component vector (Figure 3.1.). The theory of group decision making illustrated in the model presented here says that noise and control variables affect solution quality in decision making and that noise and control variables can be divided into internal, external, process and problem variables. Individual and group biases, one type of internal variables, were extensively discussed in the previous sections. The *problem-solving process* with the associated *problem*, *noise variables* and *control variables* leads to the output in the model - the *solution*.

3.4.2. Group Decision Making

3.4.2.1. The Group Problem Solving Process

Many different procedures recommended for problem solving and decision making exist in the literature with a variety of proposed steps. One example of problem solving approach can be found in Ullman's book "12 Steps to Robust Decisions: Building Consensus in Product Development and Business" (Ullman, 2001). A summary of components that are predominant in the various recommendations include the following (order not important): group training, process documentation, information source identification, problem identification & clarification, identify, solution criteria development & weighting, alternative solutions identification & development, alternatives evaluation in terms of criteria, and preferred alternative selection.

The order of components varies from recommendation to recommendation and not all recommendations contain all of the identified components. A brief description of each component follows.

3.4.2.1.1. Train the Group

Group training is the preparation work necessary to prepare a group of people require to work together as a problem solving team. A group of people that are selected to work together may not possess the skills necessary to work together efficiently or effectively. Training may include training in group dynamics, problem solving or in the use of the specific group decision support aid to be used. The purpose of group training is to improve the group's efficiency and effectiveness for problem solving tasks.

3.4.2.1.2. Document the Process

Process documentation involves using either an electronic or written record of the problem solving process. A record of what has been done prevents having to repeat activities due to poor recollection, aids in communication between group members (especially if they are not physically in the same location), and provides the basis for deciding what to do next.

3.4.2.1.3. Identify Information Sources

Both criteria and alternative identification and development are limited by available knowledge. Increases in information have the potential to affect the criteria upon which alternatives will be evaluated as well as increase the number of alternatives considered. Acquiring information, however, has associated costs that must be the potential benefits of that acquisition. Information is acquired, filtered and analyzed throughout the entire problem solving process.

3.4.2.1.4. Identify and Clarify the Problem

Problem identification not only involves identifying that a problem exists, but involves determining whether the "correct" problem is being solved. Problem clarification involves identifying the boundaries of the problem in order to maintain focus during the problem solving process. It is possible that what was thought to be the problem at the onset of the problem solving process, changes during that process. There are numerous examples of situations where solutions have been found for the wrong problems.

3.4.2.1.5. Identify, Develop & Weight the Solution Criteria

A problem is a current condition or situation that is different than a desired condition or situation. Criteria represent the attributes or characteristics of the desired condition or situation (the problem solution). If the problem is clearly understood, it is fairly easy to identify the solution criteria. If, however, the problem is "fuzzy" or the issues associated with the problem are not clearly understood, identification of the solution criteria will be more difficult. In the case of the "fuzzy" problem, solution criteria will be developed as the understanding of the problem and its associated issues improves. Information acquisition and analysis will aid this process.

As solution criteria are identified and developed, the relative importance of the different criteria must also be determined. Agreement on solution criteria weighting between different group members will invariably increase as the knowledge level of problem understanding increases. An exception may exist for solution criteria depend upon differing personal values between group members.

3.4.2.1.6. Identify and Develop Alternative Solutions

Many problems involve selecting one alternative from a group of two or more alternatives. Information acquisition may increase the number of known available alternatives from which to choose. Other problems may involve development of alternatives that do not currently exist, i.e. design problems.

Many of these problems, however, may also be viewed as selection problems since the developed alternative(s) were a combination of features that were selected from

groups of features. An exception would be a "discovery" type problem that is not based upon any known technology.

3.4.2.1.7. Evaluate the Alternatives in Terms of the Criteria

Once a satisfactory number of alternatives have been identified or developed (often limited by available time or money), the alternatives are evaluated in terms of the solution criteria. The evaluation may include algorithms that rank the preference of the alternatives in terms of their ability to meet the solution criteria, possibly taking into consideration the criteria weighting.

3.4.2.1.8. Select the Preferred Alternative

With or without the assistance of the evaluation outcomes, the group will select a preferred alternative from the group of identified and developed alternatives.

3.4.2.2. Variables That Affect the Group Decision Making Process

The group decision making model (Figure 3.3.) shows that control variables and noise variables affect the problem-solving process and the resultant solution quality. The control and noise variables (Figure 3.3. and Figure 3.4.) represent the independent variables. The logic for this model (Figure 3.3.) follows the principles of classical design of experiments (Kuehl 2000, Launsby 1999, Montgomery 1997, Wheeler 1992), which attempts to control or measure independent variables so they can be eliminated as causal factors for the experimental results. Independent variables affect the problem solution - a collection of dependent variables. Noise variables are not controlled either because

they have not been identified or it is impossible to control them. It is often difficult to identify all the noise variables. Control variables, on the other hand, are identified variables that are controlled at a known level.

As previously discussed, solution quality has been shown to be correlated to a number of the control and noise variables (independent variables) identified here. Selecting a variable to be a control variable allows testing of whether or not that variable and interaction effects between that variable and the other control variables has an impact upon the problem solution. Variables that are noise variables do not provide information about the impact of those variables upon the problem solution

Both noise variables and control variables can be further subdivided into internal variables, external variables, process variables, or problem variables. The purpose of this classification is to aid the development of a reasonably exhaustive list of independent variables. The detailed variables shown in Figure 3.4 were generated with literature references and multiple brainstorming sessions by the researcher and David G. Ullman.

3.4.2.2.1. Internal Variables

Internal variables (Figure 3.3. and Figure 3.4.) are team member associated parameters. Internal variables are the characteristics that group members bring to the group and characteristics of the group itself. Some of these characteristics are the result of the psychosocial interactions that occur within the group. The individual and group biases previously discussed in this chapter are examples of internal variables. Variation in these characteristics will affect how the group functions, which in turn will affect how

the group makes decisions and the ultimate problem solution. These effects may either be positive or negative with regard to solution quality.

3.4.2.2.2. External Variables

External variables (Figure 3.3. and Figure 3.4.) are influences imposed upon team members. External variables are forces that are not within the control of the group members. These forces are external to the group itself, but they do have influence on the group member's perceptions of the group and its ability to function. Similar to internal variables, variation in these external forces will affect how the group functions, how the group makes decisions, and ultimately the group's problem solution.

3.4.2.2.3. Process Variables

Process variables (Figure 3.3. and Figure 3.4.) are associated with the problem solving process. Process variables are characteristics of the procedures used to make decisions. These characteristics may be a part of a controlled, defined problem solving methodology or they may be characteristics of an ad hoc approach to problem solving. The major functions in the problem solving process are criteria development and assessment, alternative generation and assessment, and selection of a preferred alternative or problem solution. Process variables also include characteristics of the information used in the problem solving process since one of the main functions in the problem solving process is to filter, interpret and apply information. Similar to internal and external variables, variation in these process characteristics will affect how the group functions, how the group makes decisions, and ultimately the group's problem solution.

3.4.2.2.4. Problem Variables

Problem variables (Figure 3.3. and Figure 3.4.) are associated with the problem being solved. Problem variables are characteristics of the problem and its alternative solutions. As was mentioned earlier, the type of problem often dictates the method to be used to solve that problem. Problem type can be defined in a number of different ways, e.g. skill based, rule based, knowledge based. Similar to internal variables, external variables and process variables, variation in problem characteristics will affect how the group functions, how the group makes decisions, and ultimately the group's problem solution.

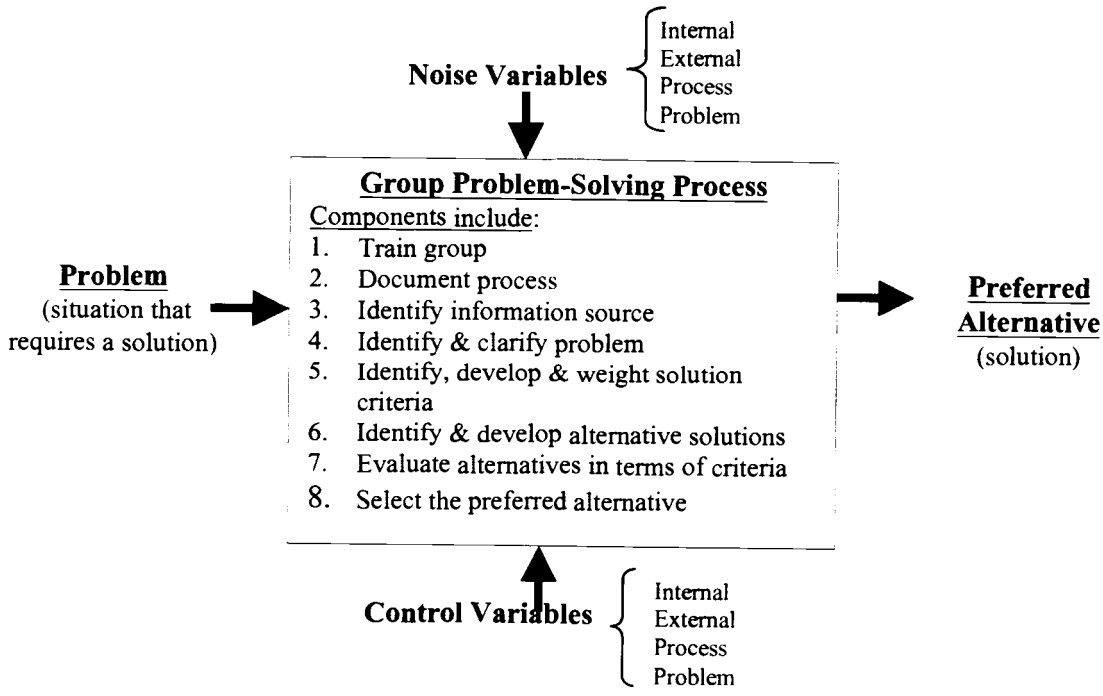

Figure 3.3. Group Decision-Making Model

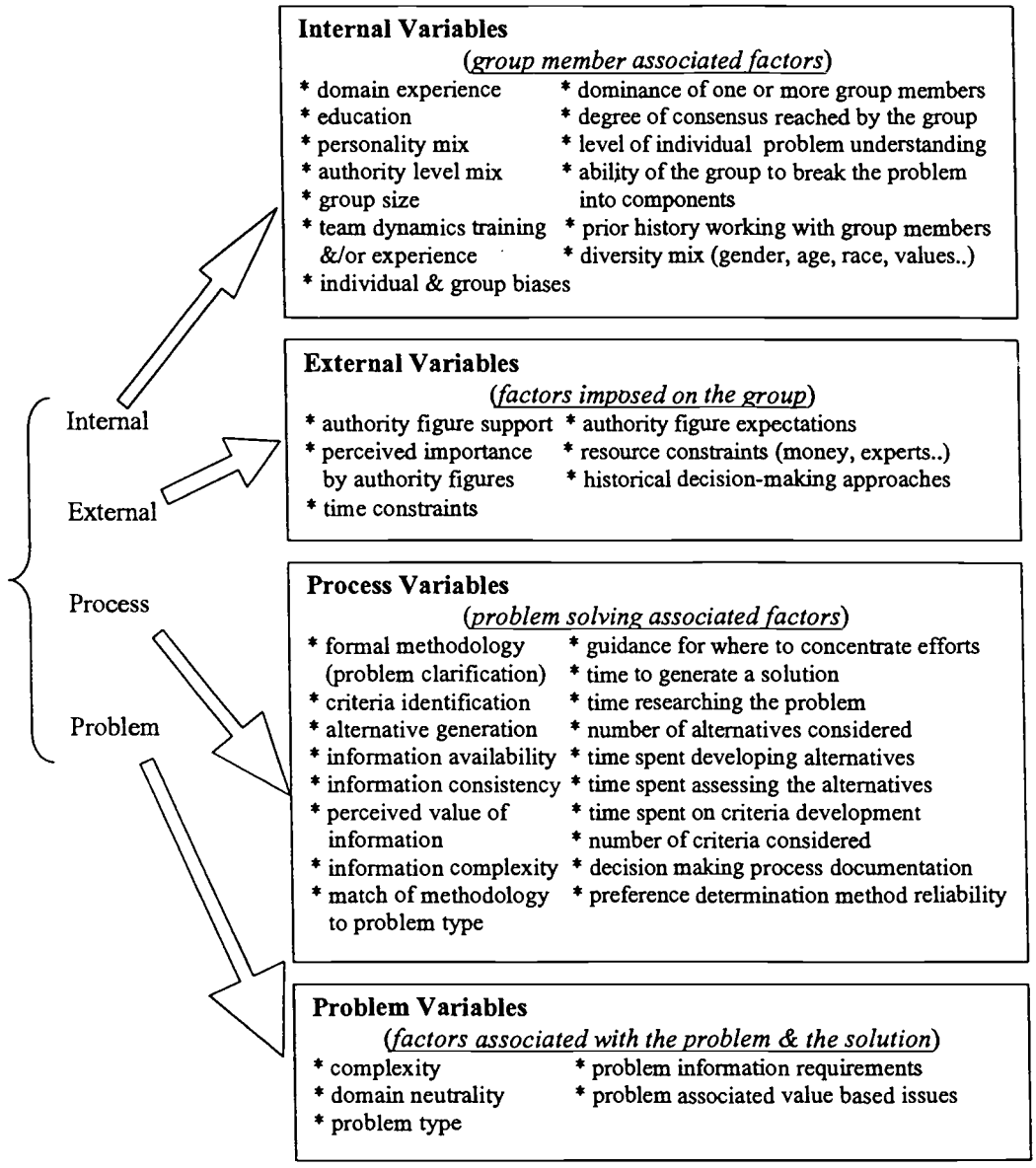

Figure 3.4. Control & Noise Variables in Decision Making

4. A THEORY AND MODEL OF COMPUTER-AIDED GROUP DECISION MAKING

4.1. Introduction - The Need for Computerized Group Decision Support Aids

Since "individuals and groups are prone to error, behave inconsistently and may not realize when their decisions are of better or worse quality, they could use some help" (Carroll & Johnson, 1990). In addition to prescriptions offered by psychologists, economists, operations researchers, "entire fields such as decision analysis (Keeney & Raiffa, 1976; von Winterfeldt & Edwards, 1986) have arisen for the purpose of helping people measure their own preferences and judgments and follow explicit procedures and rules so as to make better decisions. Decision support systems, expert systems, and artificial intelligence applications are ways to capture the knowledge of experts and either assist them in making better decisions or replace them with automated decision systems" (Carroll & Johnson, 1990).

Findings in a survey conducted by Kepner-Tregoe (June 2000) demonstrate that problems do indeed exist with decision-making in American business. Key findings included:

- Both managers and workers are being called upon to make an increasing number of decisions in the same or less time.
- Although speed has become a defining quality of successful decision making, nearly three-quarters of workers and four-fifths of managers say they miss opportunities because they don't make decisions quickly enough.
- When asked to compare the speed of their organization's decision making to that of rivals, only one-quarter of workers and less than one-third of managers said they are moving faster than the competition.
- While fast decision making is an imperative, so is smart decision making. Respondents reported seeing quality suffer when speed took precedence in decision making. Quality suffered in the areas of budgeting/finance,

organizational restructuring, personnel/human resources, customer service, and quality/productivity.

- When asked in which ways decision making was compromised under time pressures, nearly half of all respondents pointed to poor information sharing. Other frequent reasons were failure to involve the right people, failure to agree up front what they wanted to accomplish, failure to obtain enough information, and failure to get commitment to a decision prior to its implementation.
- Over forty percent of both managers and workers cited the need for multiple approvals as the most encountered reason for decision-making delays. Other roadblocks included organizational politics, changing priorities, and getting people to agree up front on what they wanted the decision to accomplish.
- Information technology was seen as the most important source of information for decision making in budgeting/finance, purchasing and customer service. Others that closely followed were daily production management, quality/productivity, personnel/human resources and process improvement.
- Information on which to base decisions has shifted from real to virtual sources
- over the past three years. There has been an increase in use of e-mail, the Internet and the World Wide Web. More than 60 percent of both groups reported that the use of in-house developed computer systems is on the rise. More than half of both groups reported that the information available to decision makers is on the rise and the quality of that information is improving in addition to the quantity.
- Over half the respondents from both groups reported that the shift in information resources has improved decision-making speed and quality, but one-quarter of both groups said it either had no effect or a negative effect upon decision making.
- About one-third of the respondents use artificial intelligence in decision making and only 12 to 13 percent of them believe it has increased the speed and quality of their decisions.

Less than 10 percent of the respondents said their organization retains a database of information on past decision making and nearly 80 percent of these respondents couldn't access the utility of the database.

Fifty-seven percent of workers and 64 percent of managers said they make

- decisions with people from different locations or shifts on a routine basis. E-mail, teleconferencing, and videoconferencing were pointed to as the most common tools used to facilitate this remote decision-making. Fourteen percent of this group said their organization has done little to nothing to enable remote team members to work together more effectively.

Over 4/5ths of both groups said that either they did not know or that there is not a common decision-making process or approach used within their organization. Of those that reported that a common decision making process available, 31 percent of the workers and 29 percent of managers said their management takes no action to ensure that the approach is used.

If problems always had optimal solutions due to effective decisions, there would be no need for decision support aids. This, however, is not the case. Put very simply, less than optimal solutions to problems are due to criteria, alternative or problem solving process issues. Criteria may have been incorrectly developed, improperly weighed against other criteria or actually not identified and considered. A sub-optimal problem solving process could lead to a lack of problem understanding and poor use of information needed to solve the problem. And finally, failure to discover all possible alternatives could lead to a sub-optimal problem solution. The use of group decision support aids can improve problem understanding, criteria development, information use, and alternatives generation. According to Stuart Nagel (1993), decision aiding software enhances the following decision making skills:

1. Choosing among alternatives, where each alternative is a lump-sum choice, meaning that one cannot generally choose parts or multiples of such an alternative. The situation can involve mutually exclusive alternatives, or it can allow for combinations.
2. Allocating scarce resources such as money, time, or people to such objects as places or activities. The allocating can be with or without minimum or maximum constraints on how much each object can receive.
3. Explaining and predicting behavior, including individual cases or relations, in either the past or the future.
4. Teaching decision making, as well as actually making or prescribing decisions.

Nagel (1993, p. *xi*) further claims that decision aiding software can help overcome obstacles such as multiple dimension on multiple goals, multiple missing information, multiple alternatives that are too many to analyze each one separately, multiple and possibly conflicting constraints and the need for simplicity in drawing and presenting

conclusions in spite of all that multiplicity. "Benefits form using decision aiding software include:

1. Being more explicit about goals to be achieved, alternatives available for achieving them, and relations between goals and alternatives.
2. Being stimulated to think of more goals, alternatives, and relations than one would otherwise be likely to do.
3. Being able to handle multiple goals, alternatives, and relations without getting confused and without feeling the need to resort to a single composite goal or a single go/no-go alternative.
4. Being encouraged to experiment with changes in the inputs into one's thinking to see how conclusions are affected.
5. Being better able to achieve or more than achieve goals when choosing among alternatives or allocating scarce resources.
6. Being better able to predict future occurrences and explain past occurrences.
7. Being better able to teach decision making and other related skills to students in courses that involve controversial issues.
8. Being able more effectively to handle multidimensionality, missing information, and multiple constraints as surmountable obstacles to systematic decision making.
9. Being more able to deal with diverse subject matter as a result of having a cross-cutting decision analytic framework that is easy to use.
10. Becoming more capable of systematic decision analysis, even when the software is not available" (Nagel, 1993, p. *xii*).

4.2. Characteristics and Requirements of CGDSAs

A decision support aid is a tool that supports decision-making. The definition of a decision support aid seems to include everything from a pocket calculator to the human brain. The term implies that "anything" that assists (aids) decision-making could be considered a decision support aid. It does not provide the solution itself. A decision support aid can be something as simple as a check sheet or as complex as an automated prescribed process for making decisions with computerized access to large volumes of information.

> *The term "decision support system" was coined at the beginning of the 1970s to denote a computer program that could support a manager in making decisions when facing ill-structured problems. This concept is a result of research in two areas: theoretical studies of human problem solving and decision making done at the Carnegie Institute of Technology during the 1950s and 1960s, and the work on interactive computer systems at the Massachusetts Institute of Technology in the 1960s (Klein & Methlie, 1995, p. 2).*

Increased availability and use of computers has speeded up the development of decision support systems (DSS). DSSs emphasize data retrieval and numeric calculations, applying quantitative models to management. DSSs represented the merge descriptive, behavioral theories, and prescriptive, rationalistic theories. In the 1960s the concept of expert systems for solving managerial problems. Expert systems rely on large amounts of domain knowledge stored in memory accessed by pattern recognition. Next Knowledge-based Decision Support Systems (KB-DSS) were introduced which incorporated specialized knowledge and expertise into the DSS. This added the capability of reasoning into to DSS, enabling it to give advice on specific problems (Klein & Methlie, 1995).

Identifying the essential components of a group decision support aid depends upon one's definition of a group decision support aid and the problem type being considered. Varied definitions from different disciplines exist in the research literature. For the purposes of this research a decision support aid will be defined as a single component of a decision support system. "A DSS can be defined as a computer program that provides information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill-structured tasks" (Klein & Methlie, 1995, p. 112). Sprague and Carlson (1982) emphasize the interactive nature of a DSS by defining

it as "an interactive computer based system that helps decision-makers use data and models to solve ill-structured, unstructured or semi-structured problems." DSS has also "been extended by some authors to include any system that makes some contribution to decision making" (Sprague & Carlson, 1982, p. 4). Huber (1984) defined a group decision support system (GDSS) as "software, hardware, and language components and procedures that support a group of people engaged in a decision-related meeting."

A taxonomy (Figure 4.1.) of different types of decision support system models follows (Forrester, 1961).

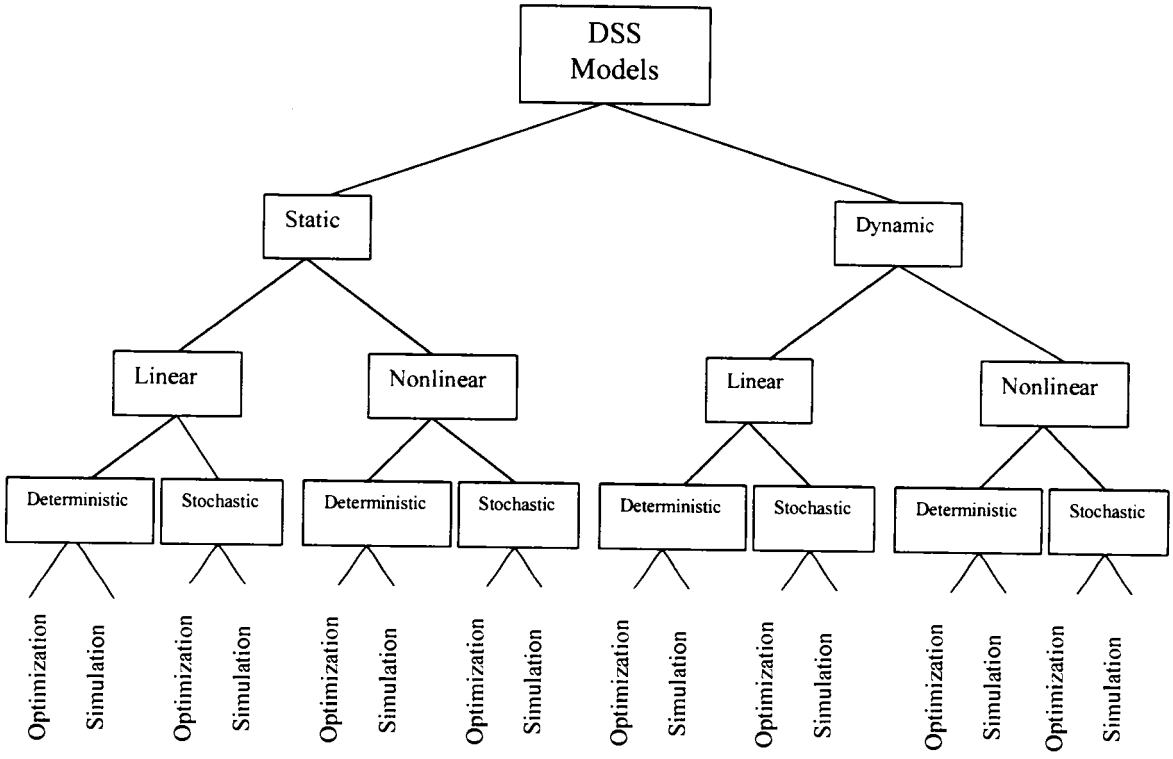

Figure 4.1. Typology of Models

Static models do not take time explicitly into account. Models of this type include linear programming, non-linear programming and game theory. Many static models are deterministic and solutions can be obtained by analytical techniques such as optimality calculus and mathematical programming. Dynamic models deal with time-lagging interactions between variables. Examples include simulation of business cycles, macroeconomic growth, and financial planning models (Klein & Methlie, 1995).

Deterministic models contain variables that cannot take on more than one value at the same time, while stochastic models contain at least one variable that is uncertain and described by a probability function. The adequacy of analytical techniques for obtaining solutions in stochastic models is often limited and simulation is the only effective solution (Klein & Methlie, 1995). Simulation looks backward and attempts to provide a model to explain a set of characteristics, while optimization looks forward and provides a process for improvement.

In addition to characterizing the decision analysis cycle, Howard (1988) introduced the following criteria of decision quality: decision framing, decision basis, integration and evaluation with logic, balance of basis and commitment to action. Decision framing addresses whether the right problem is being analyzed. Decision basis considers the quality of the information that decisions are based upon, exhaustive search and evaluation of alternatives, and the clarity of stated values. Integration and evaluation with logic focuses on whether the procedures to select the right alternative are the correct procedures and free of logical errors. Balance of basis considers the allocation of efforts between improving information quality, generation of new alternatives and thinking

about values. Commitment to action is concerned with clear indication of the right course of action and communication of that action to the decision maker (Howard, 1988). The purpose of a decision support system (DSS) is to assist the decision maker in the tasks necessary to arrive at a quality decision. DSS in concerned with both improving decision efficiency and decision effectiveness. The tasks the decision maker performs include: problem recognition; problem diagnosis and structuring; decision problem modeling and alternative generation; choosing between alternatives; and monitoring the decision. Functions provided by a DSS to assist the decision maker with these tasks may include one or more of the following: information access and mining (drill-down); reporting (including exception reporting); decision situation structuring and modeling; computation of decision criteria; decision analysis; and communication (Klein & Methlie, 1995, p. 119).

According to Klein and Methlie (1995, p. 122), DSS software has the following requirements: "end-user usage and interactivity; end-user definition; easy access to pertinent information; high interaction between users, the system and the learning situation; capacity to adapt to fast evolution of user needs; portability and peripheral support; reliability; and performance. Further explanations of these requirements follow.

end-user usage and interactivity – "The application interface providing the means of interaction between the user and the system has to be specifically designed for end users so the interface is as small as possible. The support of a DSS application is related to the display of menus, to the syntax of the command language, to the dialog boxes, to the resources available in the DSS (data bases, data files, reports, interfaces) or the problem solving methodology itself" (Klein & Methlie, 1995).

end-user definition – This requirement says that the user of the DSS should be involved in the definition or design of the DSS. It is possible, however, that the user define the DSS as it is used. The DSS may simply provide an environment for the decision maker to work.

easy access to pertinent information – A "DSS application usually includes information about the problem domain and information about the support capabilities of the systems" (Klein & Methlie, 1995).

high interaction between users, the system and learning situation – "High interaction implies the existence of an interface and command language to let the user define what he or she wants the system to accomplish. ...the key to success...is to continuously improve the search ability of the system user; to help him acquire better heuristics; and to improve his knowledge of the limits and applicability of the tools he has at his disposal" (Klein & Methlie, 1995).

capacity to adapt to fast evolution of user needs – "This evolution can be in terms of extensions with respect to: new algorithms at the toolbox level; new solvers at the decision model level; new entities at the database level; new interface; and new presentation of information" (Klein & Methlie, 1995).

portability and peripheral support – 'It is important to be able to transfer applications easily to run under new operating systems and hardware" (Klein & Methlie, 1995).

reliability – The software must be bug-free and operational on a continual basis and "to restart in the case of incident without losing more than the last transactions" (Klein & Methlie, 1995).

performance – This requirement refers to the need for hardware resources to adequately support the many applications integrated in a DSS.

Ralph Sprague and Eric Carlson (1982, p. 26) offer another list of DSS requirements that takes group decision making into account.

1. A DSS should provide support for decision making, but with emphasis on semi structured and unstructured decisions. These are the types of decisions that have had little or no support from EDP, MIS, or management science/operations research (MS/OR) in the past...
2. A DSS should provide decision-making support for users at all levels, assisting in integration between the levels whenever appropriate. This requirement evolves from the realization that people at all organizational levels face "tough" problems. Moreover, a major need articulated by decision makers is the need for integration and coordination of decision making by several people dealing with related parts of a larger problem.
3. A DSS should support decisions that are interdependent as well as those that are independent. Much of the early DSS work implied that a decision maker would sit at a terminal, use a system, and develop a decision alone. DSS development experience has shown that DSS must accommodate

decisions that are made by groups or made in parts by several people in sequence.

4. A DSS should support all phases of the decision making process.
5. DSS should support a variety of decision making processes, but not be dependent on any one. ...there is no universally accepted model of the decision making process... There are too many variables, too many different types of decisions, and too much variety in the characteristics of decision makers. Consequently, a very important characteristic of DSS is that it provide decision makers with a set of capabilities to apply in a sequence and form that fits each person's cognitive style. In short, DSS should be process independent and user driven (or controlled).
6. Finally, a DSS should be easy to use. A variety of terms have been used to describe this characteristic, including flexible, user-friendly, and non-threatening.

Sprague and Carlson (1982, p. 96) offer an approach referred to as ROMC for DSS design to assure that it contains the important capabilities from the user's point of view. These capabilities are "*representations* to help conceptualize and communicate the problem or decision situation, *operations* to analyze and manipulate those representations, *memory aids* to assist the user in linking the representations and operations, and *control mechanisms* to handle and use the entire system" (Sprague & Carlson, 1982, p. 96).

A characteristic of importance for a decision support aid that should not be overlooked is the interface (computer screen, mouse, keyboard...) that supports the man-machine interaction involved when using the decision support aid. "Menus and icons enable the user to select functions to:

- access and display information needed for problem solving;
- access statistical algorithms to study and describe in a more condensed manner the available information;
- display forms to input data needed to run decision models;
- display and print reports;
- solve decision models to obtain decision criteria;
- help him select between alternatives;

- store the decision and monitor it;
  transform objects into icons and the reverse" (Klein & Methlie, 1995).

4.3. Existing Types of CGDSAs

Selecting the appropriate software for decision making/problem solving depends on the type of decision to be made or problem to be solved. A review of DSS literature demonstrates that a DSS can "take on many different forms and can be used in many different ways" (Alter, 1980, p. 71). For this reason, decision support software can be classified in a number of different ways. In 1980, Steven Alter (pp 73-93) proposed a taxonomy of DSSs based on a seven category typology based on the generic operations it performs, independent of type of problem. His seven types included: file drawer systems, data analysis systems, analysis information systems, accounting and financial models, representational models, optimization models and suggestion models. Alter's first three types of DSS have been called data-oriented or data driven; the second three types have been called model-oriented or model-driven; and his suggestion type has been called intelligent or knowledge-driven DSS (Dhar & Stein, 1997; Holsapple & Whinston, 1996).

Nagel (1993, p. *ix*) offers a summary to the different types of decision aiding software available based upon problem type and the decision making technique used.

1. *Decision tree software for making decisions under conditions of risk, such as whether to go on strike or accept a management offer. A decision tree is usually pictured as looking like a tree on its side with branches and sub-branches. The branches generally represent alternative possibilities that depend on the occurrence or nonoccurrence of probabilistic events.*
2. *Linear programming software for allocating money, time, people, or other scarce resources to activities, places, tasks, or other objects to which the*

resources are to be allocated. In terms of form rather than function, linear programming involves maximizing or minimizing an objective function or algebraic equation subject to constraints generally in for form of inequalities like greater than or less than.

3. *Statistical software for predicting how a future event is likely to occur, such as a trial, an election, or a weather occurrence, in the light of past events or expert opinions. Statistical software generally involves calculating averages or predictive equations in which decisions or other outcomes are related to factual inputs.*
4. *Spreadsheet-based software in which the alternatives tend to be in the rows, the criteria in the columns, relations in the cells, overall scores for each alternative in a column at the far right, and a capability for determining what it would take to bring a second-place or other-place alternative up to first place.*
5. *Rule-based software, which contains a set of rules for dealing with a narrow or broad field of decision making. The user gives the computer a set of facts, and the computer applies the rules to the facts in order to determine which alternative decision should be or is likely to be decided. Such software is sometimes referred to as artificial intelligence (AI) or expert systems, but the other forms of decision-aiding software also have characteristics associated with AI and expert systems.*
6. *Multicriteria decision-making (MCDM) software, which emphasizes multiple goals to be achieved, as contrasted to decision trees, linear programming, and statistical regression analysis, which emphasize a single objective function or a single dependent variable.*
7. *Decision-aiding software that focuses on a specific subject matter, as contrasted to the other software, which cuts across all subjects. Subject-specific software could relate to how to decide where to drill an oil well, how to deal with crisis situations in flying a plane, or any other specific decision-making situation.*
8. *Software that is useful for generating alternatives, goals, or relations but does not process those elements in order to draw a conclusion.*

D.J. Power (2000) offers yet another taxonomy for DSS software (Table 1.). His framework is based on the dimension of the dominant technology component or driver of the decision support system. He further categorizes based upon targeted users, the specific purpose of the system and the primary deployment technology. Power (2000) describes the characteristics of his five technology components in the following way:

> ***Communications-Driven & Group DSS*** *– This category includes communication, collaboration and decision support technologies. This category in Power's*

taxonomy is similar to the GDSS or groupware category used by other researchers. Software in this category supports electronic communication, scheduling, document sharing, and other group productivity and decision support enhancing activities. Group DSS, two-way interactive video, White Boards, Bulletin Boards and Email fall into this category.

Data-Driven DSS *– This software emphasizes access to and manipulation of large databases of structured data and especially a time-series of internal, and sometimes external, company data. Examples of this software include file drawer and management reporting systems, data warehousing and analysis systems, Executive Information Systems (EIS), Spatial Decision Support Systems and Business Intelligence Systems.*

Document-Driven DSS *- This software may also be referred to as a Knowledge Management System. A Document-Driven DSS integrates a variety of storage and processing technologies to provide complete document retrieval and analysis. Examples of documents that may be accessed include policies and procedures, product specifications, catalogs, and corporate historical documents. The Web provides large document databases including databases of hypertext documents, images, sounds and video.*

Knowledge-Driven DSS *– This software is sometimes referred to as Intelligent Decision Support (Dhar & Stein, 1997). It is a person-computer system with specialized problem-solving expertise. The "expertise" consists of knowledge about a particular domain, understanding of problems within that domain and "skill" at solving some of these problems. The software can suggest or recommend actions to managers. Data Mining is a related concept and it refers to a class of analytical applications that search for hidden patterns in a database.*

Model-Driven DSS *– This software emphasizes access to and manipulation of a model. Examples include systems that use accounting and financial models, representational models, and optimization models. Some systems allow complex analysis of data and may be classified as hybrid DSS systems providing modeling, data retrieval and data summarization functionality. Model-Driven DSS use data and parameters provided by decision-makers to aid them in analyzing a situation, but they are not usually data intensive and do not require large databases.*

Table 4.1. Power's DSS Taxonomy (reproduced from Powers, 2000)

Dominant DSS Component	***Target Users*:** Internal - External	***Purpose:*** General – Specific	***Deployment Technology***
Communications Communication-Driven DSS	Internal teams, now expanding to partners	Conduct a meeting or Help users collaborate	Web or Client/Server
Database Data-Driven DSS	Managers, staff, now suppliers	Query a Data Warehouse	Main Frame, Client/Server, Web
Document base Document-Driven DSS	the user group is expanding	Search Web pages or Find Documents	Web or Client/Server
Knowledge base Knowledge-Driven DSS	Internal users, now customers	Management Advice or Choose products	Client Server, Web, Stand-alone PC
Models Model-Driven DSS	Managers and staff, now customers	Crew Scheduling or Decision Analysis	Stand-alone PC or Client/Server or Web

Software that aids groups in decision making may consist of the above mentioned decision making types of software or a combination of them, but also has the additional requirements of overcoming the previously discussed difficulties groups encounter when making decisions. Brainstorming (Osborn, 1963) and nominal group technique (Delbecq, Van de Ven & Gustafson, 1975) are examples of techniques that have been developed to overcome these difficulties.

There are many current examples of GDSS. One example is software generically referred to as "meetingware." Meetingware software is software with multi-platform applications that turn a web browser into a virtual meeting room on the Internet or an organization's Intranet that provides a forum for raising issues, inputting data and opinions and deciding on courses of action. Examples of meetingware are Facilitate.com (Facilitate.com, Inc., 2001) and Council (Council, 2001).

GDSS software is often advertised as offering a structured environment for decision making and consensus building. Examples of software of this type are Team2000 by Expert Choice (Expert Choice, 2001), Decision/Capture (DecisionCapture, 2001), and ConsensusBuilder by Camas (Camas, 2001).

4.4. Computer-Aided Group Decision Making

CGDSAs are employed in an effort to improve decision making efficiency and solution quality. In order to understand whether or not they actually make this happen, their affects on the subtle and not so subtle dynamics of group decision making must be understood. The theory of a CGDSA builds on the theory of group decision making which says that noise and control variables affect solution quality in decision making and that noise and control variables can be divided into internal, external, process and problem variables. The theory of a CGDSA says that a CGDSA affects and potentially transforms process variables from noise variables to control variables and occasionally from control variables to noise variables.

4.4.1. Augmented Group Decision Making Theory and Model

Addition of the CGDSA into the previously discussed group decision making model (Figure 3.3.) illustrates how a CGDSA affects the group decision making process (Figure 4.2.). A computerized GDSA (CGDSA) usually contains a collection of controlled process variables. For example, a CGDSA may provide a formal methodology for problem solving, improve information availability and give guidance as to where efforts should be concentrated. The following model illustrates a CGDSA's ability to

affect and potentially transform process variables from noise variables to control variables and occasionally from control variables to noise variables.

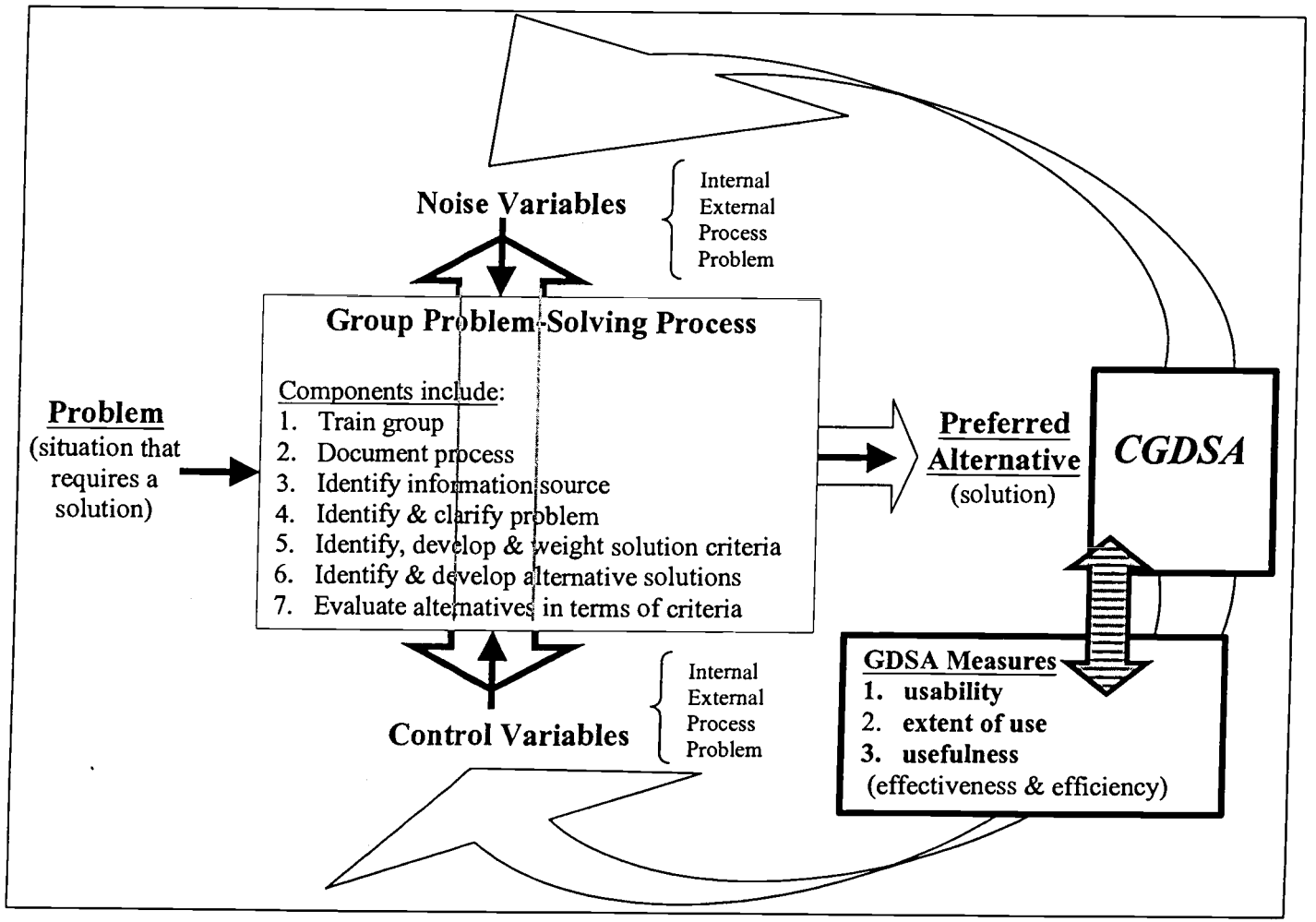

Figure 4.2. Computer-Aided Group Decision Making Model

4.4.2. CGDSA Variable Transformation

In addition to having an effect on the problem solving process, introduction of a CGDSA into the decision making process has the effect of potentially transforming process control variables into process noise variables and/or process noise variables into process control variables. This transformation, in turn, has the potential to affect the solution quality and may also affect an evaluation of a CGDSA. This transformation is illustrated in the presented model (Figure 4.2.) by the double-headed arrow between noise variables and control variables.

In most cases, the transformation of variables will involve the transformation of a noise variable to a control variable (illustrated by the double-headed arrow between noise variables and control variables in Figure 4.2.). For example, a CGDSA may provide a formal methodology for decision making which makes a previously uncontrolled variable (noise variable) into a controlled variable (control variable). Not all variables may be directly affected by a CGDSA, but rather may be indirectly affected. For example, authority figure support of the decision making group may improve when a CGDSA is used. In some cases, a CGDSA will not transform variables, for example, problem complexity. A CGDSA will have the greatest impact upon transforming process variables since it is the decision making process itself that is being aided by the CGDSA.

Increased control of variables will decrease variation in the system, however, the transformation of noise variables to control variables may not affect the solution quality in a positive manner. It is possible that this transformation would promote "over-control," which may have a negative impact upon solution quality. If the goal is to

improve solution quality, it may be advisable to resist the transformation of noise variables to control variables in some cases.

When evaluating the effects that a CGDSA has on decision making, it is important to distinguish between the effects from the CGDSA itself and the effects of the evaluation design. It is the CGDSA effects that are of interest.

4.4.3. CGDSA Measures

The aided group decision making model (Figure 4.2.) includes the measures of a CGDSA: usability; extant of use; and usefulness. When it is shown that use of the CGDSA affects other independent variables that have been previously shown to have an effect on solution quality, it can be concluded that the CGDSA had an effect on the solution quality as well. CGDSAs that change independent variables in a manner that has been shown to improve solution quality can be considered to be useful (for improving the effectiveness and/or efficiency of the decision making process).

In addition to being useful, a CGDSA must be usable and be used. The logic for these requirements is rather straightforward. A CGDSA cannot be useful if it cannot be used or is not used. The effectiveness of a CGDSA, therefore, must be based upon its usability, the extent of its use and its usefulness.

5. REQUIREMENTS FOR A GENERALIZED CGDSA EVALUATION METHODOLOGY

5.1. CGDSA Evaluation Methods & Approaches found in the Literature

Rohrmann and Schutz (1993) developed a generic summary of evaluation criteria for decision-aiding technologies (Table 5.1.) based upon the different perspectives of authors, designers, and users (Adelman, Rook & Lehner, 1985; Mahmood & Sniezek, 1989; Riedel, 1986; Riedel & Pitz, 1986; Rouse, 1984; Sage, 1981; Rohrmann, 1986; Zimolong & Rohrmann, 1988). Decision-analytic quality, attitudinal effects and general/indirect benefits deal with the content problem of GDSAs, while user/system interaction deals with the interaction problem (usability). "Not all criteria listed in the table (Table 5.1.) are relevant to every computerized decision support aid. Instead, a critical selection of pertinent aspects, reflecting its specific purpose, is indicated...the evaluation criteria are neither exhaustive nor independent, and objective measurements may often be difficult" (Rohrmann & Schutz, 1993, p, 12). Rohrmann and Schutz (1993, p. 8-12) summarize their explanations of the major categories with the following direct quotes.

Decision-Analytic Quality – A "good decision" is a somewhat questionable criterion. The criteria listed in the table (Figure 6) refer to the inherent characteristics of a DAS. The aid – the program and the rationale behind it – should be sound and correct in theoretical, logical, technical, and mathematical terms, and it should produce a valid representation of the user's intentions, knowledge, and preferences. The resulting evaluation/decision structure must reflect and clarify the cognitive problem space of the decision maker.

Attitudinal Effects – Only if the user has a positive attitude toward the DAS will she or he be ready to learn how to make the best use of the tool and to accept and apply the results.

General and Indirect Effects – Users satisfied with a decision aid often refer to the "insights" they gained (rather than to specific formal results). Accordingly, cognitive

changes associated with the decision analysis should be measured by psychometric means. Beyond analyzing and solving a particular decision problem, a DAS can increase general decision making competence (transfer learning).

User/System Interaction – While solving a decision task with a DAS, the decision maker has to "cooperate" with a computer program – instead of working just with paper and pencil. The central role of user-friendly computer systems has been recognized to be a major factor for their efficiency and acceptance (Monk, 1984; Streitz, 1986). "The challenge of developing an interactive decision-making system lies not so much in the design of algorithmic modules that form the basis of the system, but more in the creation of a good interface between the user and the decision-analytic system" (Wisudha, 1985, p. 246).

Successful interaction with the DAS requires the development and application of an adequate mental model. Further, the system should minimize the cognitive load by relieving the user's memory and facilitate the perception and processing of information. DAS usability is not just a software problem. If the instructions are hard to understand, if the various scaling tasks (e.g., weighting procedures) are difficult, or if the results are not sufficiently explained, a decision aid cannot be effective.

Finally, the characteristics of the user of the system have to be considered (Norman, 1984). Obviously, evaluation criteria are different for an experience professional decision analyst, a sophisticated computer owner, and an occasional DAS user.

Flexibility – Most DAS are conceptualized as context-free tools, which, in principle can deal with any particular decision problem. In reality, there are usually many restrictions, depending on the characteristics of the decision task (alternatives, attributes, data type, etc.) and of the decision makers (laypeople versus experts, single versus group, etc.). Thus "adaptive" DAS (Rouse, 1984) are needed, and flexibility becomes an important criterion.

Economy/Efficacy – Implementation of DAS produces costs in terms of money, time and personnel, however decision-making performance is improved by using a DAS. Therefore, overall costs should be reduced and profits increased.

Table 5.1. Evaluation Criteria for Decision Aiding Technologies (reproduced from Rohrmann & Schutz, 1993, p. 9)

Evaluation Aspect	Evaluation Competence			
Decision-Analytic Quality				
Theoretical/logical soundness			DT	
Ability to elicit goals and preferences	DM	DC	DT	
Utilization of information		DC	DT	
Ability to reduce judgmental biases			DT	
Instructiveness of sensitivity analyses	DM			
Correctness of computation			DT	DS
Reliability of model results			DT	DS
Congruence between problem/generated model	DM	DC		
Ex-post goodness of the decision	DM			
Attitudinal Effects				
Confidence in the approach	DM			
Acceptance of procedures	DM	DC		
Reduction of decisional stress	DM			
Satisfaction with results	DM	DC		
Frequency of application	DM	DC		
General and Indirect Benefits				
Problem clarification	DM			
Facilitation of communication	DM	DC		
Improvement of decision skills	DM	DC		
User/System Interaction				
Comprehensibility of tasks	DM	DC		
Simplicity of handling	DM			DS
Software-ergonomic norms	DM			DS
Quality/clarity of information display	DM			DS
Visualization and graphical features	DM			DS
Transparency of program steps	DM			
Controllability of program course	DM		DT	DS
Possibility of input changes				DS
Explanatory power	DM		DT	
Dependency of assistance	DM	DC	DT	DS
Quality of manual/handbook	DM		DT	
Flexibility				
Adaptability to tasks	DM	DC	DT	
Flexibility with input data				DS
Adaptability to user's competence		DC	DT	
Usability for group situations		DC		
Economy/Efficacy				
Time requirements	DM	DC	DT	

Table 5.1 (continued)

Need for personnel		DC		
Training necessity	DM	DC		
Monetary costs	DM			
Profit	DM			
Evaluation Competence Key DM = decision maker (end user); DC = decision counselor (analyst, mediator, etc.); DT – decision theorist (scientist, expert); DS = DAT software specialist				

Rohrmann and Schutz (1993) identify four main perspectives to consider when designing an evaluation protocol (Figure 5.1.). The four main perspectives are data collection, focus, information source and reference for comparisons. Data collection can occur by an analytical assessment by experts or an empirical study that collects data from users. Focus can take three different forms: content orientation which deals with the substantive quality of the technology and its components; outcome orientation which focuses on final results and consequences of applying the technology; and process orientation which surveys all stages of the intervention and the development of effects (Rohrmann & Schutz, 1993, p. 14).

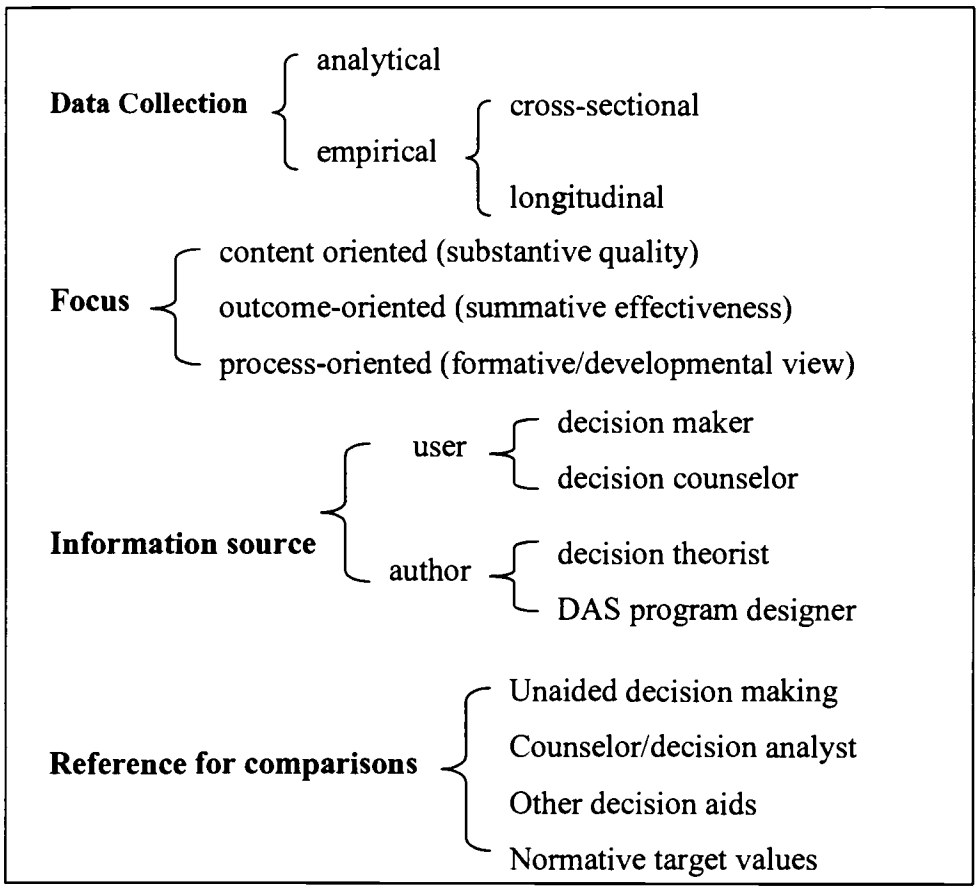

Figure 5.1. Types of DAS Evaluation Studies (reproduced from Rohrmann & Schutz, 1993, p. 14)

A taxonomy of components required in a CGDSA proposed by the developers of ConsensusBuilder, Ullman and D'Ambrosio, is described in their paper "Taxonomy for Classifying Engineering Decision Problems and Support Systems" (D'Ambrosio & Ullman, 1995) and is summarized in Figure 5.2. This taxonomy highlights components within the CGDSA rather than requirements of the overall CGDSA that were emphasized in Klein & Methlie's (1995) model and Sprague & Carlson's model (1982).

Structure - Decision Space

1. Problem Completeness - description of criteria and alternatives
2. Abstraction Level - alternatives and criteria are either refined (quantitative) or not refined (qualitative) or mixed
3. Determinism - deterministic (point valued variables) vs. distributed (distributed variables)

Structure - Preference Model

4. Objective Function - mechanism to measure alternatives vs. criteria - optimization, weighted preference, or judgment
5. Consistency - criteria importance and alternative evaluation - consistent (unified view) vs. inconsistent
6. Comparison Basis - absolute comparison of alternative to criteria or relative comparison to another alternative

Structure - Belief Model

7. Dimension - classification of decision problem information - none, one, or two
    a. knowledge - how much the evaluator knows about the alternative/criteria space
    b. confidence - how well the evaluator believes the alternative meets the criteria
8. Belief Completeness - complete vs. incomplete team evaluation of information (# teams performing each evaluation)

Focus

9. Problem Focus - product vs. process

Range

10. Range of Independence –
    Type I - Independent - no interaction; single issue
    Type II - Dependent - interaction; changing criteria
    Type III - Interdependent - sub-issues evolve

Support

11. Level of Support –
    Level 1 - Representation - issues/arguments/constraints/alternatives
    Level 2 - Outcome Determination - analysis tools & data manipulation
    Level 3 - Decision Analysis - distribution and application of utility/value to possible outcomes

Figure 5.2. Summary of Ullman & D'Ambrosio's Taxonomy of a Decision Support System (Ullman, David G. and Bruce D'Ambrosio. *Taxonomy for classifying engineering decision problems and support systems.* Artificial Intelligence for Engineering Design, Analysis and Manufacturing, (1995), 9, 427-438.

5.2. Previous CGDSA Evaluation Research

The research literature provides very few examples of laboratory studies on GDSAs from the user's perspective, but some of the work that has been done will be reviewed here.. A summary of six different studies cited by Rohrmann and Schutz (1993, p. 19-22) is provided. The summary format for each study includes subjects, task, experimental design, testing/measures, findings and conclusions.

5.2.1. Unaided Decision Making versus MAUD3 (Multi-Attribute Utility Decomposition (John, von Winterfeldt & Edwards, 1983)

Subjects: 35 undergraduate students divided into two groups

Task: Identify a decision problem of personal importance and generate four viable alternatives.

Experimental Design: (1 week time span between session 1 & 2)

Within-subject design to compare 1) individual preference order of alternatives, 2) correspondence of the aided preference ordering with subjects' intuitive (holistic) judgments, and 4) the subject's satisfaction with the process and their confidence in the results

	Session 1	Session 2
Group 1 (24 students)	MAUD3	human decision analyst
Group 2 (11 students)	human decision analyst	MAUD3

Testing/Measures:

Each volunteer was asked (before & after each session) to give holistic ratings of the choice alternatives, rank different vectors of alternative ratings, and to judge the usefulness of MAUD3 versus the human analyst.

Human analysts judged the attributes each volunteer generated with respect to completeness, logical as well as value independence, and overall quality of the attribute sets.

Findings:

1. high convergence for preference order of alternatives resulting from the MAUD3 and analyst session (r = 0.63)
2. high convergence for aided preference ordering with subjects' intuitive judgments (ranging from r = 0.50 to r = 0.88)
3. the number and quality of attributes generated was greater with the analyst, but MAUD3 attribute sets were judged to be more independent subjects' satisfaction with the analyst was higher than with MAUD3; subjects' confidence in the results was higher with MAUD3 than with the analyst

Conclusions:

- "the computer sessions compared quite favorably with the analyst sessions" (p. 317)
- "stand-alone decision aids are feasible" (p. 318)
- the study did not include a control group of unaided decision makers so no conclusions could be drawn about the principal benefit of systematic decision-aiding techniques

5.2.2. Content Analysis of MAUD (Humphreys and McFadden, 1980)

Subjects: four groups of subjects (3, 5, 6 & 8 in each group respectively) involved with decision-making problems in the arts and mass media

Task: Used MAUD to establish preferences among alternatives

Experimental Design: non-experimental

Testing/Measures: content analysis of interviews and group discussions to discover aspects of MAUD that aided decision makers; interviewed established preference orderings and participant's satisfaction with the process; later individual judgments and preferences were discussed in the respective groups

Findings: decision makers, whose intuitive preferences did not agree with MAUD-generated preferences, found MAUD most useful

Conclusions:

reduction of goal confusion and increased consciousness about the structure of value-wise importance of attribute dimensions were the most important effects of decision making with MAUD
no control group was used to compare aided with unaided decision making
small number of subjects made it difficult to assess the generalizability of the findings
the duration of positive effects over time was not investigated

5.2.3. Applicability & Usability of MAUD (Bronner & DeHoog, 1983)

Subjects: 40 subjects

Task: solve two decision problems in sessions run individually

Experimental Design: single factor, two level, post test only

Testing/Measures: behavior observation data, protocols of the subject-program interaction, and a questionnaire concerning ease of use, perceived usefulness, and suggestions for improvement of the program

Findings: most subjects judged the interaction with the computerized decision aids as "simple, clear and understandable" (p. 287) and found it particularly applicable to

decision problems that were neither too trivial nor too emotionally important (e.g., choosing a job or an education)

Conclusions:

Helping the decision maker clarify her or his decision problem was the major benefit.

- The question of whether the use of computerized decision aids actually increases decision quality was not addressed.

5.2.4. Trained Counselor versus *DAS versus Unaided Decision Making (Timmermans, Vlek, & Hendricks, 1989) *Note: DAS = computerized decision support aid

Subjects: three groups (supported by a trained counselor, supported by a computerized decision aid, & unsupported)

Task: solve a problem (problem type not indicated)

Experimental Design: single factor, three-level, post-test only

Testing/Measures:

objective measures: time needed to analyze the decision problem, number of attributes generated, convergence of intuitive preferences and preferences generated during the aided decision process

subjective measures: user satisfaction with both procedure and resulting choice, experienced difficulty of the procedure, and acceptance of the decision-analytic method

Findings:

objective: time needed was greater for counselor- and computer-supported decision making; more attributes were considered in counselor- and computer-supported decision making

subjective: subjects judged the decision-aiding procedures as especially useful for structuring and understanding the problem at hand; no significant differences were

found between the computer-supported and counselor-supported conditions; subjects in the supported conditions were less satisfied with the decision process; no differences were found between the three conditions and the final choice; when the decision problem was regarded as difficult, decision support was more effective (more often led to a change in the final preference) than when it was regarded as simple

Conclusions:

in general, the results of the study supported the claim of computerized decision support aid usefulness
the supported conditions led to a more thorough decision process
the use of a computerized decision support aid might be particularly useful for complex decision problems and under these conditions decision makers are willing to rely on computerized decision support aids

5.2.5. Effects of computerized decision support aid availability, computerized decision support aid training & high and low data Availability (Goslar, Green & Hughes, 1986)

Task: solve an ill-structured business decision problem with a financial analysis program (not based on the decision-analytic approach)

Experimental Design: three-factor, single-level, post-test only

Testing/Measures:

Objective: number of alternatives considered; amount of time needed for decision making; amount of data considered for decision making

Subjective: confidence in the decision; each subject's decision processing; and overall performance

Findings: no main effect was found on any of the dependent variables; significant interaction effects were found with regard to the number of alternatives considered

(subjects with computerized decision support aid training, computerized decision support aid availability or high amount of data available considered fewer alternatives)

Conclusions: neither computerized decision support aid availability or computerized decision support training enhances decision making performance

5.2.6. Computer aided decision making versus unaided decision making (Aldag & Power, 1986)

Subjects: individual students

Task: solve a problem using a computerized decision support aid

Experimental Design: between subjects design

Testing/Measures: judgment by independent raters; student's attitudes toward the computerized decision support aid; student's perceptions of their decision making and performance

Findings: computerized decision support aid users were not rated to be superior to non-computerized decision support aid users; overall attitudes toward the computerized decision support aid were favorable

Conclusions:

Limited support for the hypothesis that users of a computerized decision support aid will "exhibit more confidence in, and satisfaction with, their decision processes and recommendations" (p. 576) than non-computerized decision support aid users Computerized decision support aids "seem to have a high face validity and may result in positive user affect and enhanced confidence. To this date, however, claims of improved decision quality must be taken primarily on faith" (p. 586).

5.3. CGDSA Evaluation Methodology

5.3.1. Introduction

All evaluation work involves collecting and sifting through data, making judgments about the validity of the information and the inferences derived from it. The generic goal of most evaluations is to provide "useful feedback" to a variety of audiences and that "feedback" is perceived as "useful" if it aids in decision-making. Given this logic, the evaluation method proposed for measuring group decision support aids will be considered "useful" or effective if it aids in decision-making, i.e. helpful in answering whether or not there is benefit to using that group decision support aid for improved decision quality.

Evaluation is defined as "the systematic assessment of the worth or merit of some object." (Trochim) The term "object" could refer to a program, policy, technology, person, need, activity, or in the case of this research, a group decision support aid (GDSA).

Three questions can be explored for decision aiding systems: "whether they are used (e.g., for what purposes, how often), whether they are useful (i.e., an effective tool), and whether they are usable under realistic conditions – or to put it in another way, usability determines to what extent the potential usefulness of a decision support aid can be exhausted" (Rohrmann & Schutz, 1993). To be useful, a decision support aid must be helpful in improving the solution quality of the decision maker's problem and be usable by the decision maker. Therefore, two problems must be addressed in evaluating decision support aids (Streitz, 1986):

1. The content problem, dealing with the decision problem at hand to which a particular analytic technique is applied.
2. The interaction problem, resulting from the fact that the decision maker(s) makes use of an interactive computer program.

Identifying relevant and measurable evaluative criteria forms the basis for an effective GDSA evaluation. Effectiveness (Bunge, 1967) is defined as the degree to which an initial (unsatisfactory or not sufficiently satisfying) situation is changed toward a desired state, as defined by the (normative) goal for applying the technology.

Several methodologies for the evaluation of CGDSAs have been proposed in the literature, but they have not been model-based. The proposed general methodology for the evaluation of a computerized CGDSA introduced in this research (Table 5.2.) is based upon the previously presented Group Decision Making Model (Figure 3.3.) and the Computer-Aided Group Decision Making Model (Figure 4.2.). The evaluation methodology maps directly to the Computer-Aided Group Decision Making Model (Figure 4.2) for measures of the solution quality of a test problem.

When a CGDSA is to be evaluated, an appropriate test problem is selected then all of the different items in the CGDSA evaluation methodology are considered for applicability. The CGDSA evaluation methodology follows the guiding principles of design of experimentation by providing the evaluator with an exhaustive list of independent variables to consider for measuring CGDSA usefulness. By controlling or measuring the independent variables, it is possible to demonstrate whether these variables are causal factors for improved or decreased solution quality.

In addition to measuring CGDSA usefulness, the CGDSA evaluation methodology addresses software usability issues and practical use considerations. Extent

of use is not considered by the CGDSA evaluation methodology since this is measured by the actual use of the CGDSA in the field.

References (Table 5.2.) are provided for many of the measures to validate the theoretical basis for the proposed support group decision making model and the proposed evaluation methodology that is based on this model. Suggestions for evaluation techniques for the various variables is also given, i.e., survey, observation, or expert assessment.

CGDSA usefulness is assessed by comparing the quality of a test problem using the CGDSA to the quality of a test problem without the use of the CGDSA. Standard design of experiment techniques are used to make these comparisons. Various options for the measure of solution quality are presented in section 5.3.2.

CGDSA usability can be assessed in terms of the items listed in the CGDSA evaluation methodology without the need for any comparisons. Practical considerations are added to the CGDSA evaluation methodology as suggestions to make the evaluation itself usable.

Table 5.2. Ideal Generalized CGDSA (from the user's perspective) Evaluation Methodology

suggested techniques for evaluation: (S = survey, O = observation, E = expert assessment)		S	O	E	References
The evaluation should *consider, control or measure the independent variables (internal, external, process & problem). *consider = leave out of the evaluation, if justified					
CGDSA USEFULNESS					
	Internal Variables – group member associated parameters				
1i	Variation in domain experience within the group	X			Bucciarelli, 1991
2i	Variation in education within the group	X			Boiney - 1998
3i	Authority level mix within the group	X	X		Kelly – 1997; Sosik - 1997

Table 5.2 (continued)

4i	Group size		X		Zarnoth - 1997
5i	Team dynamics training and/or experience	X			
6i	Prior history of working with group members	X			
7i	Diversity mix (gender, race, age, values)	X			Hollenbeck - 1998
8i	Personality Mix		X		Arora – 1999; Naude – 1997; Volkema – 1998; Zarnoth - 1997
9i	Individual & Group Biases		X		Carroll & Johnson, 1990; Einhorn, 1980; Fong, 2000; Harris, 1997; Huerer, 1999; Plous, 1993; Poulton, 1989; Sanders, 1993; Laughlin & Ellis, 1986; Cohen, March, and Olsen, 1972; Janis, 1982
10i	Dominance of one or more group members		X		Arora – 1999; Dooley - 1999
11i	Degree of consensus reached by the group	X	X		
12i	Level of individual problem understanding	X	X		
13i	Ability of the group to break the problem into components	X	X		
	External Variables – influences imposed upon group members				
1e	Authority figure support	X	X		LePine - 1997
2e	Perceived importance by authority figures	X	X		Dominick – 1997; Nygren - 1997
3e	Time constraints		X		Kelly - 1997
4e	Authority figure expectations	X	X		
5e	Resource constraints – money, experts…		X		Winquist - 1998
6e	Historical decision-making approaches used by organization	X			
	Process Variables – variables associated with the problem-solving process				
1p	Formal methodology (problem clarification, criteria identification, alternative generation)		X		
2p	Information availability		X		Winquist - 1998
3p	Information consistency		X		
4p	Perceived value of information	X			
5p	Information complexity	X	X		
6p	Decision making process documentation		X		

Table 5.2 (continued)

7p	Preference determination method reliability			X	
8p	Methodology/problem type alignment			X	
9p	Guidance of where to concentrate efforts		X		
10p	Time to generate a solution		X		Ward, 1995
11p	Time spent researching the problem		X		Dylla, 1991
12p	Number of alternatives considered & time spent generating them		X		Ullman, 1997
13p	Time spent assessing the alternatives		X		
14p	Time spent on criteria development		X		
15p	number of criteria considered		X		
	Problem Variables – variables associated with the test problem & its alternatives				
1b	Problem type (alignment with the CGDSA)		X		Rittel & Webber, 1973; Keen, 1978
2b	Domain neutrality	X	X		
3b	Information requirements		X		
4b	Complexity		X		
5b	Prevalence of value-based issues		X		
6b	Degree to which criteria are met by the preferred alternative		X		
7b	Was the correct problem solved?		X		
8b	Perceived solution quality by a panel of experts		X		Graham, 1997; LePine, 1997
9b	comparison of solution quality to the unsupported decision making process or other GDSAs				
	CGDSA USABILITY				
1u	Perceived usefulness of the tool	X			Horn, 1996
2u	Confidence in the approach	X			
3u	Requirement for training & training effectiveness		X	X	
4u	Ease of use	X			
5u	Help screens		X		
6u	Access to procedural guidance		X		
7u	Computer screen characteristics: clarity of information, helpfulness of screen component, ease of editing, clarity of relationship to other screen components, aesthetic appeal, intuitive appeal of the information, use of color, number or size coding	X			

Table 5.2 (continued)

EVALUATION METHOD PRACTICAL USE CONSIDERATIONS						
1c	Length of time required to complete an evaluation should be short.			X		
2c	Number of individuals required to complete the evaluation should be few			X		
3c	Should be able to observe the overall decision making process			X		
4c	Evaluation test problem should be similar to real problems for which the software will be used					

5.3.2. CGDSA Usefulness

A decision support aid is useful in solving the decision maker's problem if using it leads to quality problem solution. The quality of the problem solution can be measured by the degree to which the criteria were met, and the perceived solution quality by a panel of "experts." It was pointed out earlier, however that "experts" are not necessarily better decision makers that novices (Carroll & Johnson, 1990). If the problem does not have a verifiable "correct" solution, other means must be used to assess the quality of the solution.

If independent variables have previously been shown to have an affect on solution quality, it is possible to show the relationship (correlation) between those independent variables and newly introduced independent variables. For example, if the number of alternatives generated has been shown to be related to improved solution quality and the use of a particular GDSA results in more alternatives being generated than without the use of that GDSA, it follows that solution quality is also related to the use of the GDSA.

In addition to selecting measures of problem solution quality, it is important to consider variables that may affect problem solution quality in addition to use of a GDSA. The following examples of variables that are related to or affect the quality of problem solutions are found in the research literature.

5.3.2.1. Group Size

The effect of team size on group performance has not been fully examined. Research by Zarnoth and Sniezek (1997) has indicated that increasing group size will have the effect of decreasing overconfidence of the group's decision (Zarnoth & Sniezek, 1997).

5.3.2.2. Time Constraints

Time constraints will be imposed on the design groups as a practical necessity. It is unreasonable to ask even compensated subjects to devote unlimited time to research purposes. Relatively little experimentation has been done with unlimited time frames. Kelly (1997) et al. discuss the effects of time limits on the performance of small group, decision making teams and suggests that the presence of a time limit will focus the resources of the team members on the task at hand more efficiently than an unlimited time frame (Kelly et al.1997).

Smith reports that short group meetings are intentionally pursued at the Project Design Center of NASA's Jet Propulsion Labs in Pasadena, California where group advancement is only allowed when all members have completed their assignments (Smith, 1998). The decrease in design cycle times reported indicates that structured time

limits have proved beneficial. Group focus and concentration is desirable for the sake of experimental efficiency, as more time will be spent on design task.

Dylla's research permitted unlimited time frames, but was only collecting data from nine subjects working individually (Dylla, 1989). From a logistical standpoint, using groups makes unlimited time frames impractical due to scheduling problems.

5.3.2.3. Knowledge Domain Neutrality

Everyone has a certain pre-existing knowledge of the world as a result their individual education and experiences. This internal database contains information gathered from memories of processes, things seen and heard, and projects previously created (Sauter, 1999). By definition this domain of knowledge is specific to individuals and is internal to them. The reverse of this is public domain knowledge. Public domain knowledge constitutes the information directed to the group as a whole in the form of group instruction and problem statements and is considered the external domain.

Winquist and Larson (1989) suggest that internal knowledge of group members is shared less frequently than public knowledge (Winquist & Larson, 1998). The theory presented is that the decision making process is a dynamic process and the recall trigger of specific internal memory is less likely to occur if the memory is not widely held. It is impossible to measure internal knowledge because it is impossible to examine all the memories of the team members.

5.3.2.4. Problem Completeness

Problem completeness is the measure of the amount of information that is given to the test group regarding the particulars of the problem. Completeness is related to domain knowledge in that the design project may be set up as an incomplete problem, only to have the required information be supplied by the internal knowledge of one or more of the team members. This can be avoided by determining a wholly neutral (foreign) problem so that the only knowledge available is that supplied by the researchers (Bucciarelli, 1991). This would be an example of a complete problem, everything that can be known about it is given to the group at the beginning.

5.3.2.5. Number of Criteria Considered

Dylla (1991) in an experiment consisting of 6 mechanical engineers individually designing a simple mounting system found a statistically significant correlation between the number of criteria considered and the quality of the product.

5.3.2.6. Time on Criteria Development

Dylla (1991) found that there was a correlation between the time spent on generating the criteria and the quality of the solution. He showed that the more time spent on gathering information and working to understand the goals and limitations on the problem, the better the solution.

5.3.2.7. Number of Alternatives Considered

There is no experimental proof that the number of alternatives considered is correlated to product quality. However, there is extensive anecdotal evidence that "If you develop one idea, it will probably be a poor idea; if you generate twenty ideas, you might have one good idea" (Ullman 97, PG 121). In addition, methods like brainstorming, 6-3-5 and brainwriting were all developed to stimulate the generation of multiple ideas.

5.3.2.8. Time Taken to Reach a Decision

Generally, the less time to choose one alternative the better, but there are design methodologies that encourage retaining 2-3 alternatives as long as possible. (Ward, 95).

5.3.2.9. Personality Heterogeneity in the Group

A study using a Myers-Briggs Type Indicator performed by Roger Volkema and Ronald Gorman (1998) found significant interaction between group composition and problem formulation, suggesting that a multi-temperament (heterogeneous) composition can moderate the effect of problem formulation on performance.

5.3.3. CGDSA Usability

In addition to being useful, a CGDSA must be usable. The logic for this requirement is rather straightforward. A CGDSA cannot be useful if it is not usable.

There are generally three types of usability evaluation methods (Horn, 1996): testing, inspection, and inquiry. In the testing approach, representative users work on typical tasks using the system (or the prototype) and the evaluators use the results to see

how the user-interface supports the users to do their tasks. In the inspection approach, usability specialists—and sometimes software developers, users and other professionals—examine usability-related aspects of a user interface. In the inquiry approach, usability evaluators obtain information about users' likes, dislikes, needs, and understanding of the system by talking to them, observing them using the system in real work (not for the purpose of usability testing), or letting them answer questions verbally or in written form.

5.3.4. Evaluation Method Practical Considerations

Practical considerations are included in the CGDSA Evaluation Methodology because the methodology must be "usable" or it will not be used in the same way that software that is not usable will not be used. User's of the methodology may have specific needs that they must address in order to perform a CGDSA evaluation that are not included in this generalized methodology.

6. APPLICATION OF THE GENERALIZED CGDSA EVALUATION METHODOLOGY

6.1. Introduction

Validation of the integrity of a model rests in part on comparing model behavior to time series data collected in the "real world." When a model is structurally complete and simulates properly, calibration of the model can proceed to fit the model to this observed data. The goal of validation is to produce a model that represents true system behavior close enough for the model to be used as a substitute for the physical system and to increase to an accetable level of credibility of the model. The Group Decision Making Model and the Computer-Aided Group Decision Making Model presented in this research were externally validated through citations from the literature.

Validation of the integrity of a model rests in part on comparing model behavior to data collected in the "real world" over time. When a model is structurally complete and simulates properly, calibration of the model can proceed to fit the model to this observed data. The goal of validation is to produce a model that represents true system behavior close enough for the model to be used as a substitute for the physical system and to increase to an accetable level of credibility of the model.

The thesis in this research is that the proposed general methodology for the evaluation of a CGDSA from the user's viewpoint represents the "ideal" evaluation methodology. This "ideal" methodology can be used as a comparison standard for actual evaluation methodologies. As was pointed out in the literature review, although many group decision support aids exist, there has been very little done in the way of evaluating

them. As additional computerized decision support aids are evaluated from the user's viewpoint, these evaluations can be compared to the "ideal" methodology proposed in this research. As with all models, this model will be upheld or modified, based on its ability to explain "real world" data.

As a start to validate this model, an evaluation of a computerized decision support aid was performed. The evaluation methodology used for this evaluation was compared to the "ideal" methodology proposed in this research. In addition, several GDSA evaluations reported in the literature were also compared to the "ideal" methodology proposed in this research. These comparison analyses were used to "fine tune" the supported group decision making model and the general methodology for the evaluation of a CGDSA from the user's viewpoint proposed in this research.

6.2. Specific Evaluation of a CGDSA

6.2.1. Selection of a CGDSA to evaluate

ConsensusBuilder, a CGDSA, was selected for evaluation since it funded this research and it is representative of CGDSAs. In general, CGDSAs allow group members to input alternatives (potential problem solutions), attributes of those alternatives with criteria (measures of acceptable attribute limits), and a preferential weighting or ranking of those criteria. The software then uses an algorithm to analyze these inputs and generate information about the group-preferred alternative and suggestions for further work. ConsensusBuilder met these requirements and had the additional capability of allowing users to add a knowledge level to their preference inputs. The mathematical

models behind the software may be different for other software packages, but the experience of the user is essentially equivalent.

ConsensusBuilder is based on a Bayesian decision model. The developers of ConsensusBuilder, Ullman and D'Ambrosio (1998) propose a Consensus Model of decision making. In this model, four classes of information (the issue, criteria, alternatives and evaluation) are used in the decision making activities of argumentation, negotiation and agreement. Additional information on the software as well as papers discussing the technical basis of the software can be found at the website http://www.consensusbuilder.com.

6.2.2. Test Problem Selection

It was important to select a test problem that was not too easily solved since research has shown that CGDSAs are claimed to be most effective for complex problems. The complexity, however, cannot be so great that a group cannot solve the problem in a reasonable amount of time. In order to control the size of the test problem, the scope of the problem was narrowed by the amount of information available to the test subjects.

Testing occurred in a laboratory setting, however there was an attempt to select a problem that resembles a problem that might actually be encountered in the business world. The problem (Appendix A) posed to the test subjects was to select a vendor for an electroplating solution for a printed circuit board shop, given four alternatives (hypothetical vendors). Providing a predetermined number of alternatives limited one of the measures of solution quality, but this was necessary given the constraints of

laboratory testing. The test subjects were supplied information on printed circuit board fabrication (Appendix C,D, & E), the electroplating process (Appendix F & G) , some of the criteria (requirements for a satisfactory solution), definitions of terms used in printed circuit board plating (Appendix H), information on brightener systems (Appendix I) and hypothetical testimonials (subjective information – Appendix J).

6.2.3. CGDSA Training

As previously discussed, it has been shown that GDSA training can affect the user's perception of the GDSA as well as the ability to use the GDSA for problem solving. A training program was developed for ConsensusBuilder use (Appendix B). The training program explained some of the modeling that formed the basis for the analysis that was performed by the software. Instruction in how to operate the software was provided and users were given an opportunity to solve a simple problem using the software.

6.2.4. Evaluation Methods

6.2.4.1. Subjects & Group Sizes

Subjects for this study were OSU faculty, undergraduate and graduate students. Subjects were recruited by advertisement in the mechanical engineering and industrial engineering departments (Appendix Q). An incentive was paid to the volunteers for their participation. It was necessary to obtain approval from the Institutional Review Board for the Protection of Human Subjects (IRB) prior to testing (Appendix R).

A group size of three was selected as a matter of practicality (being able to recruit enough volunteers) even though this small group size limits some of the conclusions that may be drawn from this research. A pre-exercise survey (Appendix K) asking about previous training in decision making was used and volunteers with any previous training were not assigned to the control group.

6.2.4.2. Experimental Model

A one factor (CGDSA use), two-level (ConsensusBuilder & control group – unsupported), between group (and a quasi within group), post-testing only model was used. Three repetitions were performed to test repeatability. The test group (group using ConsensusBuilder) attempted to solve the problem without the use of ConsensusBuilder first, then immediately followed this with use of the software to solve the problem. The purpose was to have some within group comparison of using and not using the software. The learning effect was an issue for the within group comparison, hence the referral to a "quasi" within in group model. A two-hour time frame was used to solve the problem. The time frame was broken down in the following manner:

Test Group
1 - 30 min.: review information individually
30 - 45 min.: arrive at a group decision without the use of CB
45 - 75 min.: arrive at a group decision using CB
75 - 120 min.: arrive at a 2nd group decision using CB

Control Group
1 - 30 min.: review information individually 30 - 45 min.: arrive at a group decision 75 - 90 min.: arrive at a group decision

6.2.4.3. Evaluation Techniques and Measures

In consideration to Rohrmann and Holger's (1993) four perspectives: data collection was analytical, focus was outcome oriented, the information source was the user-decision maker, and the reference for comparisons was unaided decision making. Evaluation methods included behavior observation via the use of videotapes, questionnaires, and Meyers Briggs type instruments.

There were two main types of data for this research: objective and subjective. The objective measures were obtained through observation of video tapes. All of the problem solving sessions were video taped and the tapes were analyzed for the time spent clarifying the problem, number of criteria considered, time spent developing criteria and the amount of data/information considered collectively by the group. Due to the constraints of the experiment it did not make sense to analyze the number of alternatives considered (a set number of alternatives was presented to each group) or the time necessary to reach a decision (the time given to reach a decision was predetermined by the experimental design).

Subjective measures were measures of usability. Usability was determined by using the inquiry approach discussed previously (Horn, 1996) with questionnaires that inquired about users' likes, dislikes, and understanding of the system (Appendix O & P).

6.2.4.4. Videotaping – Independent Variables

The purpose for videotaping was twofold: a record was provided that was reviewed over and over for the assessment of behavior so the observer did not need to

assimilate all of the information from multiple perspectives in one viewing; and this allowed the researcher to be in a different room during the bulk of the problem solving session. It is possible that if the researcher was present, participants would look to the researcher for cues of satisfaction or dissatisfaction and this would have affected the participant's problem solving behavior. Several video tapes were made simultaneously in order to view the problem solving process from several perspectives: what is happening on the computer screen for the test group, the information that is being utilized, and the person to person interactions in the group. The groups were filmed in a university filming studio. Cameras were prevalent throughout the room and the subjects were not told which cameras were actually running during the exercise so it is likely that they did not present a distraction to the subjects.

6.2.4.5. Pre-Exercise Background Survey

The main purpose of the pre-exercise questionnaire (Appendix K) was to gather some basic information about the participants. The pre-exercise questionnaire was used to help assure that participants with prior decision making training were not assigned to the control groups. This was done to eliminate another variable from the control groups. If individuals in some the control groups had had prior training in decision making, this could potentially have affected their problem solving behavior, which in turn, could have affected the differences or likenesses observed between the test groups and the control groups.

6.2.4.6. Post-Exercise Decision Making Process Survey

The purpose of the post-exercise questionnaire (Appendix L) was to assess the problem solving process from the user's perspective. Issues of available information, disagreements, effort expended to make decisions, individual participation, time pressures, problem solving approaches, agreement with the group's decision, change in the decision over time, and whether the test situation was perceived as being similar to situations that may be encountered in the workplace were contained in the questionnaire.

6.2.4.7. Meyers Briggs Inventories

Two different inventories (change tendencies and problem solving behavior – Appendices M & N) were used to assess the heterogeneity of the different groups (Robbins & Finley, 1996 and Keirsey & Bates, 1978) . This information was not used to assemble groups, but was rather looked at after the problem solving sessions as an analysis tool. This information was used to explain the possible reasons for group biases that were seen.

6.2.4.8. Usability Surveys

Usability questionnaires (Appendices O & P) were used with the test groups as a way to assess the usability of ConsensusBuilder. User perceptions were assessed both after the initial training session in the use of ConsensusBuilder and after the completion of the problem solving session. The reason for questionnaires at these two different times

was to see if additional use of ConsensusBuilder, implying increased learning, had an affect on the user's perceptions of the software usability.

Participants were asked to make assessments of the software screen components in terms of clarity of information, helpfulness, ease of editing, clarity of the relationship of the different screen to one another, aesthetic appeal, intuitive appeal of the information, usefulness of color, size and number coding and suggestions for improvements to the different screen components. Participants were also be asked for their assessment of the software training session, changes they would suggest for the software effectiveness, likes and dislikes about using the software, and the advantages or disadvantages the software made on their decision making process.

After the problem solving session was over, the participants were asked whether their initial impressions of the software had changed, if the software helped their group's ability to solve the problem, and if the software affected the group's ability to reach consensus.

6.3. Assessment of Specific Evaluations in terms of the Generalized CGDSA Evaluation Methodology

The ConsensusBuilder evaluation, as well as six other CGDSA evaluations found in the literature, was assessed in terms of the generalized methodology for CGDSA evaluation presented in this research. In particular, the process variables that were transformed and the other variables and considerations that were addressed were shown. The greater the number of variables and considerations addressed, the more thorough the evaluation.

7. CGDSA EVALUATION RESULTS & ANALYSIS

7.1. Introduction

This research involves two levels of evaluation. First, an evaluation of a CGDSA, ConsensusBuilder was performed as a way to demonstrate some of the components in the generalized CGDSA evaluation methodology. The primary focus of this research, however, is on the second level of evaluation which is to assess the ConsensusBuilder evaluation as well as several MAUT evaluations found in the literatures in terms of the generalized CGDSA.

7.2. ConsensusBuilder Evaluation Results Summary & Analysis

The first part of the ConsensusBuilder evaluation was to test its usability and this was accomplished by comparing the decision making process and solution quality for groups using ConsensusBuilder to groups not using any sort of CGDSA. The second part of this evaluation involved usability assessment of ConsensusBuilder. A summary of participant background characteristics, change personality and problem solving behavior type is presented prior to presenting the experimentation results.

7.2.1. Background Information

Background information on the subjects is contained in Appendix S. Information included year in school, program of study, native language, work experience, and existence of training in formal decision making, problem solving or printed circuit board fabrication.

7.2.2. Change Personality & Problem Solving Behavior

A summary of the change personality survey and problem solving behavior instrument results from the subjects is contained in Appendix T and Appendix U. Subjects filled out these surveys prior to performing the decision making task.

7.2.3. ConsensusBuilder Usefulness

A summary of the ConsensusBuilder usefulness results from the observed participant's behavior (independent variables) is contained in the following tables (Table 7.1.). The video tape was divided into two minute increments and the activity that was observed was noted. If the activity only occurred for a fraction of the two minute interval, it was still counted as occurring for the entire interval. An additional thirty minutes was given to the test group because of the need to enter data into the ConsensusBuilder program. For analysis purposes, the time used to enter data that was actually observed was subtracted from the total time. One-way ANOVA was performed on the observed behavioral data. The independent variables: time spent clarifying the problem, time spent developing criteria, time spent analyzing the alternatives, time to solve the problem, and the number of criteria used were compared for the test groups and the control groups using ANOVA for a significance level of 0.5. Raw video-tape data can be found in Appendix AA.

Table 7.1. Video Tape Data Summary

	Time Clarifying Problem (minutes)	Time Developing Criteria (minutes)	Time Analyzing Alternatives (minutes)	Time Entering Data (minutes)	Total Time (minutes)	# criteria
Control 1	20	24	36	0	60	3
Control 2	2	16	30	0	34	5
Control 3	2	8	30	0	32	5
Test 1	4	14	28	32	90	5
Test 2	6	16	20	52	88	6
Test 3	10	4	40	32	86	5
	% Time Clarifying Problem (minutes)	% Time Developing Criteria (minutes)	% Time Analyzing Alternatives (minutes)	Time spent solving problem (minutes)		# criteria
Control 1	33.3	40.0	60.0	60		3
Control 2	5.9	47.0	88.2	34		5
Control 3	6.2	25.0	93.8	32		5
Test 1	6.9	24.1	48.3	58		5
Test 2	16.7	44.4	55.6	36		6
Test 3	18.5	7.4	74.1	54		5

Table 7.2. Descriptive Statistics and ANOVA Summary of Videotape Data

TIME TO CLARIFY PROBLEM				
GROUP	Mean	N	Std. Deviation	Median
CONTROL	15.1333	3	15.7335	6.2000
TEST	14.0333	3	6.2429	16.7000
Total	14.5833	6	10.7224	11.8000

ANOVA Table

		Sum of Squares	df	Mean Square	F	Sig.
CLARIFY * GROUP	Between Groups	1.815	1	1.815	.013	.916
	Within Groups	573.033	4	143.258		
	Total	574.848	5			

$F_{crit.} = {}_{0.05}F_{1,4} = 7.71$

$F_{calc.} < F_{crit.}$ Fail to reject H_o, No difference exists

Sig. > 0.05, Fail to reject H_o, No difference exists

TIME TO DEVELOP CRITERIA				
GROUP	Mean	N	Std. Deviation	Median
CONTROL	37.3333	3	11.2398	40.0000

TEST	25.3000	3	18.5292	24.1000
Total	31.3167	6	15.2087	32.5000

ANOVA Table

		Sum of Squares	df	Mean Square	F	Sig.
DEVELOP * GROUP	Between Groups	217.202	1	217.202	.925	.391
	Within Groups	939.327	4	234.832		
	Total	1156.528	5			

$F_{crit.} = {}_{0.05}F_{1,4} = 7.71$

$F_{calc.} < F_{crit.}$ Fail to reject H_o, No difference exists

Sig. > 0.05, Fail to reject H_o, No difference exists

TIME TO ANALYZE ALTERNATIVES

GROUP	Mean	N	Std. Deviation	Median
CONTROL	80.6667	3	18.1156	88.2000
TEST	59.3333	3	13.2990	55.6000
Total	70.0000	6	18.3997	67.0500

ANOVA Table

		Sum of Squares	df	Mean Square	F	Sig.
ANALYZE * GROUP	Between Groups	682.667	1	682.667	2.703	.175
	Within Groups	1010.073	4	252.518		
	Total	1692.740	5			

$F_{crit.} = {}_{0.05}F_{1,4} = 7.71$

$F_{calc.} < F_{crit.}$ Fail to reject H_o, No difference exists

Sig. > 0.05, Fail to reject H_o, No difference exists

TIME TO SOLVE PROBLEM

GROUP	Mean	N	Std. Deviation	Median
CONTROL	42.0000	3	15.6205	34.0000
TEST	49.3333	3	11.7189	54.0000
Total	45.6667	6	12.9872	45.0000

ANOVA Table

		Sum of Squares	df	Mean Square	F	Sig.
TIME * GROUP	Between Groups	80.667	1	80.667	.423	.551
	Within Groups	762.667	4	190.667		
	Total	843.333	5			

$F_{crit.} = {}_{0.05}F_{1,4} = 7.71$
$F_{calc.} < F_{crit.}$ Fail to reject H_o, No difference exists
Sig. > 0.05, Fail to reject H_o, No difference exists

NUMBER OF CRITERIA USED

GROUP	Mean	N	Std. Deviation	Median
CONTROL	4.3333	3	1.1547	5.0000
TEST	5.3333	3	.5774	5.0000
Total	4.8333	6	.9832	5.0000

ANOVA Table

		Sum of Squares	df	Mean Square
CRITERIA * GROUP	Between Groups	1.500	1	1.500
	Within Groups	3.333	4	.833
	Total	4.833	5	

$F_{crit.} = {}_{0.05}F_{1,4} = 7.71$
$F_{calc.} < F_{crit.}$ Fail to reject H_o, No difference exists
Sig. > 0.05, Fail to reject H_o, No difference exists

7.2.4. Decision Making Process Survey

Statistical analysis of the Likert scale data from the questionnaires was limited. The Likert scale data is ordinal data so it cannot be assumed that the category intervals are of equal size. This prevents the use of hypothesis testing. Verbal cues were added to the Likert scale response questions to reduce variation in how different participants made their ratings. The results of the decision making process survey are contained in Appendix V. Scale responses are summarized in histograms.

7.2.5. Post-Instruction Usability Survey

A large portion of the data provided by the questionnaires were opinions based on the individual perceptions of the participants. Content analysis was used to categorize

participant feedback into summary findings. Even though statistical analysis could not be performed on this data, the data did provide valuable insight into how the software was valued and could be improved from the user's perspective. Post-instruction usability results are contained in Appendix W.

7.2.6. Post-Exercise Usability Survey

The participants were asked questions about the usability of ConsensusBuilder again after they had completed the decision making task so see if additional time spent with the software would have any effect on their initial opinions. Post-exercise usabiity results are contained in Appendix X.

7.2.7 Assessment of the ConsensusBuilder Evaluation and Six CGDSA Evaluations found in the literature to the General Methodology for the Evaluation of CGDSAs

Appendix Y contains the assessment of the ConsensusBuilder evaluation and CGDSA six evaluations found in the literature to the general methodology for the evaluation of CGDSAs presented in this research.

8. CGDSA EVALUATION DISCUSSION OF FINDINGS

8.1. ConsensusBuilder Evaluation Results

8.1.1. Usefulness

The overall perception of all three test groups regarding the usefulness of ConsensusBuilder was positive. Objective measure of usefulness, however, involved measuring variables that have previously been shown to correlate to improved solution quality. The variables measured in this research were time clarifying the problem, time developing criteria, time analyzing alternatives and the number of criteria used to make the decision. ANOVA results revealed that there was no difference in these measures between the test group and the control group. In addition, there was no significant difference between the group's responses on the decision making process survey (Table 7.2.) and all of the group's final decisions were the same as their preliminary decisions. This suggests that the use of ConsensusBuilder did not improve the solution quality or in other words it was not useful for the decision making exercises in this research.

It can be argued, that the lack of differences between the control group and the test group are due to something completely unrelated to the use of ConsensusBuilder. This finding, however, did not support Timmermans, Vlek, & Hendrick's (1989) findings that decision aids are useful. The findings in this research study were more in alignment with Aldag and Poser's (1986) conclusions that computerized decision support aids "seem to have a high face validity and may result in positive user effect and enhanced confidence. To date, however, claims of improved decision quality must be taken primarily on faith" (p. 586).

8.1.2. Usability

The overall perception of all three test groups regarding the usability of ConsensusBuilder was positive. There are limitations in analysis of the survey data since responses were either based on some sort of Likert scale or written prose. It is likely that the subjects tended to rate things high rather than low since they were students with the knowledge that the software development had been overseen by a professor at the university where the research was being conducted. In addition, one of the subjects in Test Group 1 had previously done doctoral research on this software. Given a probable bias of the subjects to rate the software higher than lower, ratings of 3 or lower on a 5 point scale by 50% of the subjects may be an indication of area for software improvement. Since the 50% value is arbitrarily selected it may be useful to look at lower percentages as well.

Review of the histograms for assessment of the different ConsensusBuilder screens suggested that improvements may be needed in the following ConsensusBuilder screen components. The following matrix (Table 8.1.) shows which attributes for each of the ConsensusBuilder screen components had a rating of the mid-point of the Likert scale or lower by four out of the nine subject (44%).

Subject's written comments tended to emphasize confusion associated with the Satisfaction & Probability of Being Best screen. Several subjects suggested that the two types of information in this screen be separated into two different screens. Subjects, in general, perceived the tool as being useful, but thought it was still in need of some improvements. Low ratings on the subject's trust in probability values on the satisfaction

screen may be addressed by either offering additional information on the algorithms that the software is based upon in training or as an added feature in the software itself.

Table 8.1. ConsensusBuilder Screen Rating Results

	Belief map	Number Line	Alternatives	Criteria	Criteria Weighting	Members	Satisfaction	Sensitivity	What to do next	Management Evaluation
Clarity of Information		X					X	X		
Helpfulness										
Ease of Editing										
Clarity of Relationship to other Screens	X						X	X		
Aesthetic Appeal	X							X	X	X
Intuitive Appeal of Information							X			
Use of Size Coding										
Use of Number Coding										
Trust in Probability Values							X			

8.1.3. Ability to Transform Process Variables

During the course of the research it was recognized that the ability to transform process variables came from the experimental constraints as well as the software itself. Appendix Z shows the transformation of variables that occurred due to the ConsensusBuilder study and six other studies described in the literature. It is obvious that the ConsensusBuilder study was more in-depth than the literature studies (Appendix

Y). It is possible that some transformations actually occurred in the literature studies that are not shown in this table (Appendix Z) due to both the fact that not all of the information about the study was available and the focus of the ConsensusBuilder study was different than the focus for the literature studies. The ConsensusBuilder study was designed to be based upon the Generalized CGDSA Evaluation Methodology (Table 5.2.), while the literature studies were not based upon this model.

Transformations of noise variables are listed in Table 8.2. Transformations from noise variables to measured noise variables were:

- Degree on consensus reached by the group
- Number of criteria considered
- Number of alternatives considered & time spent generating them
- Degree to which criteria are met by the preferred alternative

While the software does not necessarily control these variables, it provides a method for monitoring or measuring them. Since it has been shown that these variables positively correlate to solution quality, the decision making group can use these measures as an indication of the preferred alternative quality.

The transformations from noise variables to control variables directly related to the use of ConsensusBuilder software (Table 8.2.) were:

- Formal methodology
- Decision making process documentation
- Requirement for training & training effectiveness
- Guidance on where to concentrate efforts
- Was the correct problem solved?
- Help screens (did not exist)
- Access to procedural guidance

These findings suggest that ConsensusBuilder helped the subjects with the decision making process itself with a focus on the problem at hand. These findings are in

alignment with Bronner and DeHoog's (1983) findings that the major benefit of the CGDSA (MAUD) was that it helped the decision maker clarify the decision problem and Timmermans, Vlek and Hendricks' (1989) findings that a CGDSA leads to a more thorough decision process.

Table 8.2. Variable Transformations in the ConsensusBuilder Evaluation

Transformations due to the experimental constraints (Noise to Measured Noise)	
• Variation in domain experience within the group • Team dynamics training and/or experience • Diversity mix • Personality mix • Individual & group biases • Perceived value of information • Time spent assessing the alternatives • Time spent on criteria development • Ease of use • Computer screen characteristics	• Dominance of one or more group member • Level of individual problem solving • Ability of the group to break the problem into Components • Historical decision making approaches used by the organization • Time to generate a solution • Perceived solution quality by a panel of experts • Perceived usefulness of the tool • Confidence in the approach
Transformations due to the experimental constraints (Noise to Control)	
• Variation in education within the group • Authority level mix within the group • Group size • Time constraints • Information availability • Information consistency • Problem type • Problem complexity • Comparison of solution quality to the unsupported decision making process or other CGDSAs • Should be able to observe the overall decision making process	• Authority figure support • Perceived importance by authority figures • Authority figure expectations • Resource constraints • Information complexity • Methodology/problem type alignment • Domain neutrality • Information requirements • Prevalence of value-based issues • Length of time required to complete an evaluation should be short • Number of individuals required to complete the evaluation should be few • Evaluation test problem should be similar to real problems for which the software will be used
Transformations due to or related to the use of the CGDSA (Noise to Measured Noise)	
• Degree on consensus reached by the group • Number of criteria considered	• Number of alternatives considered & time spent generating them • Degree to which criteria are met by the preferred alternative
Transformations due to or related to the use of the CGDSA (Noise to Control)	
• Formal methodology • Decision making process documentation • Requirement for training & training	• Guidance on where to concentrate efforts • Was the correct problem solved? • Help screens

Table 8.2 (continued)

• effectiveness	• Access to procedural guidance
Variables Unaffected	
• Prior history of working with group members	• Preference determination – method reliability

8.2. Comparison of the ConsensusBuilder Evaluation and MAUT Evaluations found in the Literature to the Generalized CGDSA Evaluation Methodology

The usefulness and usability sections of table 7.9 summarizes the usability variables that were addressed by both the ConsensusBuilder evaluation and the six studies referenced from the literature. The ConsensusBuilder evaluation addressed all of the usability variables, all but two of the usefulness variables (internal, external, process and problem variables), and all of the practical considerations from the Ideal Generalized CGDSA Evaluation Methodology (Table 5.2.), while the studies referenced from the literature only addressed a fraction of these variables. This is likely due to the fact that the ConsensusBuilder evaluation was based upon this methodology, while the literature studies were not.

The fact that the ConsensusBuilder evaluation was able to address all of the variables from the Ideal Generalized CGDSA Evaluation Methodology (Table 5.2.) and provide meaningful usability information demonstrates that the methodology was useful. Since this methodology was based upon the Group Decision Making Model (Figure 3.1.) and the Computer-Aided Group Decision Making Model (Figure 4.2.), it follows that these models were supported by the ConsensusBuilder evaluation and the evaluations referenced from the literature. In other words, the ConsensusBuilder evaluation and the

evaluations referenced from the literature have validated the Group Decision Making Model (Figure 3.1.), the Computer-Aided Group Decision Making Model (Figure 4.2.), and the Ideal Generalized CGDSA Evaluation Methodology (Table 5.2.).

During the course of this research it was discovered that it was possible to change a noise variable from an unmeasured variable to a measured variable (Appendix Z). This suggests that the CGDSA Model (Figure 4.2.) should be modified to reflect these observations. A modified model is shown in Figure 8.1. which adds the feature of the ability of noise variables to be transformed into measured noise variables.

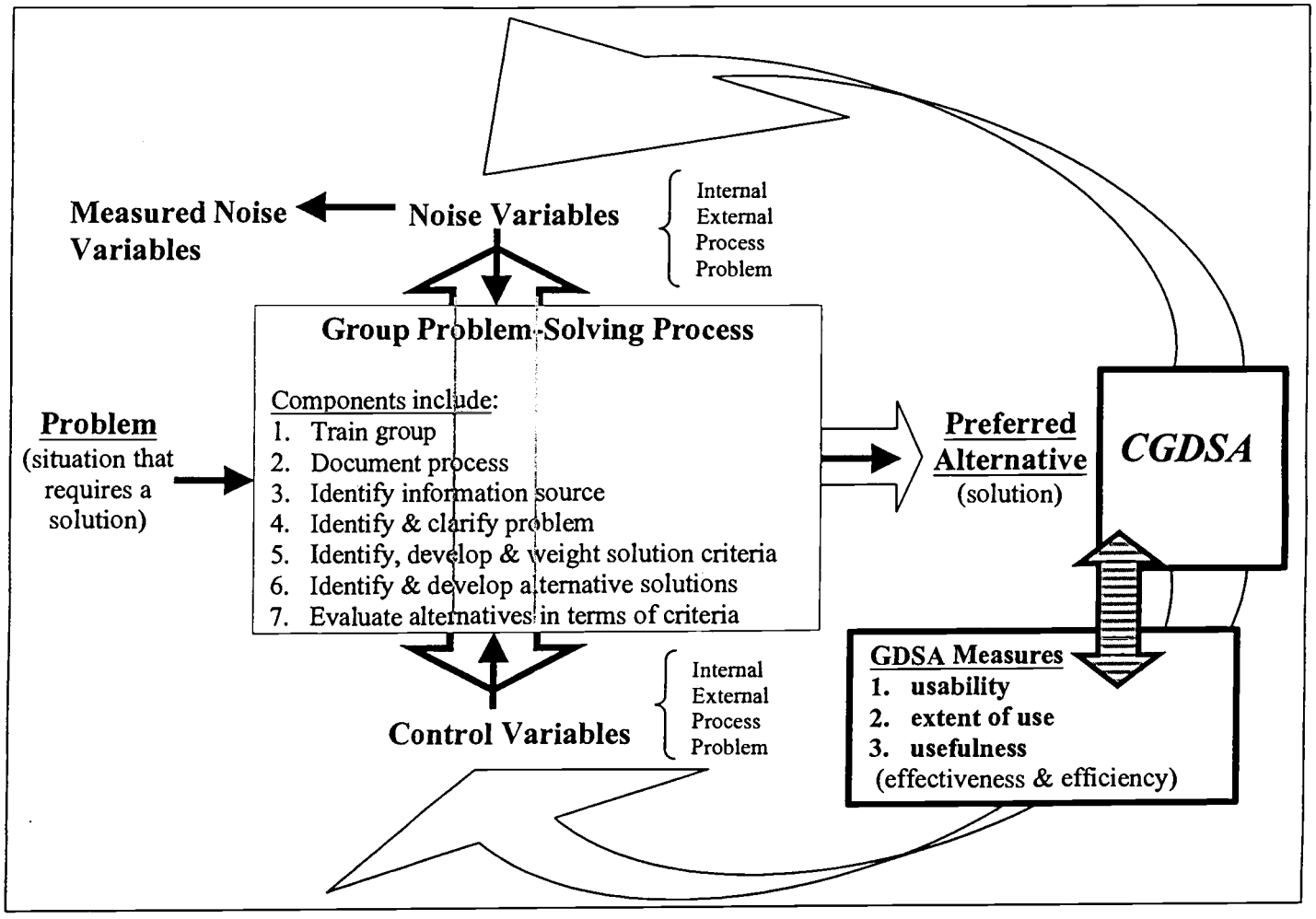

Figure 8.1. Modified Computer-Aided Group Decision Making Model

8.3. Implications of Findings

Evaluation is critical for both vendors and users of CGDSAs. The findings in this research suggest that it is possible to evaluate the ever growing number of CGDSAs entering the marketplace with a model based understanding of the group decision process and the associated computer-aided group decision process. Additionally, findings that the computer-aided group decision making process is very complex supports the need for a rationale, model-based evaluation approach.

This study, like the literature referenced studies, did not find the evaluated CGDSA (ConsensusBuilder) to be helpful for improving decision quality. This is bothersome, since the goal of a CGDSA is to improve the quality of decisions. This suggests that either CGDSAs need to be improved to meet their intended goal of improving decision quality or we have not yet found a way to capture or measure the beneficial impact they have on the decision making process.

Although this research did not refute any of the literature referenced studies, it did highlight additional evaluation considerations. There is need for additional work to understand the effectiveness of group decision making aids, since a lot of work has been done to try and understand group decision making, but little work has been done to evaluate the increasing number of aids for this activity.

9. CONCLUSIONS

9.1. Significant Contributions & Findings

The significant contribution of this research was the development of a Group Decision Making Model (Figure 3.1.), a Computer-Aided Group Decision Making Model (Figure 4.2.), and a Ideal Generalized CGDSA Evaluation Methodology from the User's Perspective (Table 5.2.). These models and the developed methodology can be used to guide future research on both the group decision making process and CGDSAs.

The ConsensusBuilder evaluation was not the focus of this research, but was rather used to illustrate the efficacy of the Group Decision Making Model (Figure 3.1.), Computer-Aided Group Decision Making Model (Figure 4.2.), and Ideal Generalized CGDSA Evaluation Methodology from the User's Perspective (Table 5.2.). The major CGDSA evaluation finding was that the software was generally usable, but did not contribute to improved solution quality as compared to a group that did not use the software and this finding was in alignment with the findings in studies in the referenced literature. The value of the ConsensusBuilder evaluation for this research, however, was that it was possible to perform a thorough evaluation of ConsensusBuilder, a CGDSA, using the CGDSA Evaluation Methodology developed in this research.

9.2. Limitations of the Research

The statistical significance of the analyses performed in this research were limited for a number of reasons. The small sample sizes necessitated by financial and time constraints negatively impacted *conclusion* validity (that a relationship exists between two variables).

A pre-exercise survey was used to assure that participants with decision making training were not assigned to the control group, which meant that participants were not randomly assigned to the test and control groups. This lack of randomness caused a lack of *internal* validity (establishment of cause and effect relationships). The lack of internal validity precludes *construct* validity (the treatment was the cause of the results and the results were correctly measured) and *external* validity (the ability to generalize the findings to other groups in other settings and at other times).

Given the lack of statistical significance, the best that can be hoped for was to demonstrate that there is a possible association between the treatment (use of ConsensusBuilder) and the effect (improved decision quality).

The observed positive or negative outcomes associated with the use of a CGDSA may actually be related to variables other than the features of the CGDSA. Such factors may be, for example, the knowledge of the decision maker, the result of training effectiveness, individual or group biases, or situational circumstances that have nothing to with the CGDSA. Observations of variables other than the CGDSA that may have influence the results were noted but not controlled.

In addition to the limitations that affect the statistical significance of this research, there is one major limitation of laboratory research. Even if it is possible to develop an evaluation method for CGDSA usefulness and usability, it is not possible to assess whether or not the CGDSA will actually be used in organizations. However, it could be argued that use is more a function of organizational managerial support than anything else so it is not all that important to assess us.

This research was also limited by the fact that only one specific CGDSA was evaluated. It would be useful to conduct research on a number of CDGDAs simultaneously in order to speak to the usefulness of CGDSAs in general.

9.3. Recommendations for Future Research

Recommendations for future research include additional studies based upon the models and evaluation methodology developed in this research. These studies could be used to both verify and/or modify the models and methodology developed here.

Research with actual users of CGDSAs in a non-laboratory setting would be useful to either support or refute the findings of laboratory studies. Studies after long term use of a CGDSA rather than initial introduction and use of the CGDSA would serve to remove the tentativeness of initial study or laboratory study findings.

Research that compares a CGDSA to non-computer-aided group decision making using the same algorithms and techniques available within the CGDSA could be used to highlight the advantages or disadvantages of using a CGDSA.

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APPENDICES

APPENDIX A Test Problem

Your team has been assigned the following responsibilities: make a recommendation to management about the vendor to select for the copper plating chemistry. You have five 500 gallon plating tanks available for plating which will accommodate using any of the commercially available copper plating chemistries. Four possibilities for copper plating chemistry exist: Bernie's Copper Plating Chemistry , Madison Global Plating Chemistries, Inc., PCB Chemistry Solutions, Inc., and Universal Plating Solutions, Inc. You do not have to select chemistry for either pre- or post-plating.

The boards you will be plating are outer layers only. The thickest boards (panels) are 60 mils thick and the smallest drilled holes are 12 mils in diameter. There is a requirement to plate ½ ounce copper on ½ ounce clad laminate. The copper thickness in the holes must not be less than ¼ ounce. The smallest lines and spaces on the board surfaces are 4 mils and 4 mils.

The plating operation runs for 3 shifts, 5 days a week. Two panels can be run in a tank at one time. Maintenance requires 4 hours per week on each shift for plating line maintenance. The remaining time can be used for plating. Current customer demand is for 1500 panels/week with an estimated ramp to 1800 panels/week over the next 3 – 5 years.

Management has suggested that you take the following things into consideration when making your recommendations, ***in addition to*** other considerations you may have:

- quality
- cost
- technical support
- vendor's reputation
- delivery

A

You have been provided some written materials in addition to vendor brochures to help you make your decision:

A – Test Problem (this page)
B – Fabrication of Inner Layers: illustrates how an inner layer is made (your task does **not** involve making inner layers)
C – Multi Layer Fabrication 1: illustrates how a multilayer board is made ("Copper Electroplating" directly relates to your task)
D – Multi Layer Fabrication 2: illustrates continuation of multilayer board fabrication
E – Copper Electroplating – explains the electroplating process
F – Pattern Plating – explains copper plating of multilayer board outer layers
G – Printed Circuit Board Plating Terminology – terms associated with copper plating on printed circuit boards
H – Organic Additives – explains the purpose of organic additives
I – Testimonials – Opinions regarding the various vendors by members of your organization as well as engineers from other organizations.

Please follow the schedule below:
1 - 30 min.: review information *individually*
30 - 45 min.: arrive at a group decision ***without the use of CB***
45 - 75 min.: arrive at a group decision ***using CB***
105 - 120 min.: arrive at a group decision ***using CB***

Thank you.

APPENDIX B Training Handout

ConsensusBuilder

a group decision support aid

User Training

Power Point Slide Presentation on ConsensusBuilder with example problems. Copies of all slides were given to the subjects.

Exercise – Your Choice!

1. Problem Statement:

Identify the problem, a general solution and the customer for the solution.

Problem: _____

General Solution: _____

Customer of Solution: _____

2. List your team members.

3. List the criteria (desired features) to measure the alternatives and the criteria measures (objective ways to rate the "goodness" of a criteria).

4. Weight the criteria for each team member.

5. Alternative development. Add known alternatives to the problem statement. If alternatives are not known, go to step 3 to develop criteria for use in research for existing alternatives and/or development of new alternatives.

Problem Action Statement with Alternatives:
Select product/service/system/procedure **for** customer **from** alternatives.

Alternatives (potential problem solutions):

---

6. Create a belief map. Each group member will individually rank each alternative against each criterion in terms of **knowledge** (x-axis) and **confidence** (y-axis):

knowledge (self-assessment of uncertainty of information used in evaluation)

and ***confidence*** (a measure of the likelihood the alternative meets the criteria's desired target).

7. Evaluation – Consensus Metric

8. Evaluation – Satisfaction & Probability of Being Best

Satisfaction is the belief that an alternative meets its targets; it is a combination of knowledge and confidence

Probability of being best indicates the chance of each alternative being the "best" for a given viewpoint (criteria weighting), using all of the data from the belief map.

9. Evaluation – Sensitivity Analysis

- Sensitivity analysis forms the basis for what to do next.
- Sensitivities show which criteria the alternatives are sensitive to.
- Sensitivities are listed in the order of their likelihood of changing satisfaction.
- Sensitivities are different for each member, since they are based upon each member's criteria weighting.

10. Evaluation – What to do next results.

The ***what to do next report*** is based upon the sensitivity data for ALL members.
•***Increase team knowledge*** is recommended when criteria/alternative combinations have a low knowledge level and if changed once more knowledge is obtained may cause the highest satisfaction alternative to fall.
•***Refine criterion*** is recommended when there is no significant difference between the alternatives for a given criterion.
•***Develop better and more differentiated alternatives*** is recommended when it appears that increased team knowledge & refined criteria will not help differentiate the alternatives.

11. Evaluation – Evaluation Management.

Evaluation Management depends upon a member's selected weighted criteria. A choice to include, discount or exclude the belief map data for different members can be made. The inclusion, discount or exclusion of belief map data affects the observed satisfaction, probability of being best and sensitivity analysis results.

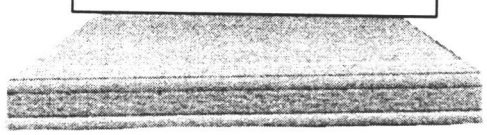
12. Gather additional information on the problem both individually and as a group. Discuss and share findings. Return to steps 3 & 6 on a continual basis (daily, weekly, monthly,...) to update the problem assumptions (criteria and alternatives). Follow step 8 to re-evaluate individual and group ranking of the problem solution. Continue this process until a robust decision can be made.

APPENDIX C Fabrication of Inner Layers Handout

Fabrication of Inner Layers

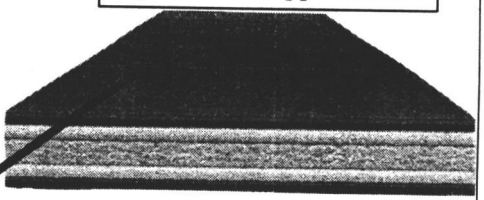
A multilayer printed circuit board is made of layers of metal circuitry that are separated from one another by a dielectric material. This dielectric material is known as laminate. Clad laminate refers to a layer of laminate that has a coating of copper metal on each side of the dielectric. Inner layers are the layers of circuitry that are found between laminates.

copper clad laminate



Inner fabrication begins with clad laminate – a layer of dielectric material with a layer of copper on each side.

photoresist application



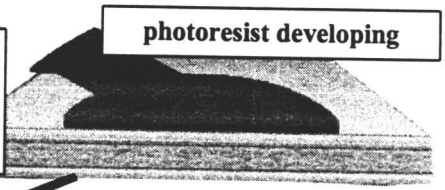
Photoresist is a light sensitive polymer that acts as a mask to prevent either etching or plating on the material that is being masked.

photoresist

Photoresist is imaged with a circuit pattern using collimated UV light. The polymer in areas that are exposed to the light is transformed so that it becomes soluble in caustic solution.

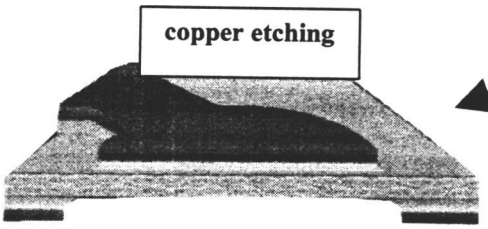
B

photoresist developing



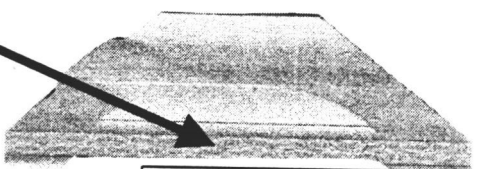
Developing is the process where the exposed photoresist is immersed in a developing (caustic) solution. The areas that were exposed to the UV light are soluble in the solution and removed by it, leaving the unexposed polymer as a mask.

copper etching



The clad laminate is immersed in a copper etching solution. The copper that is not masked or protected by the photoresist is etched away. The remaining copper is in the shape of the desired circuit.

The photoresist is removed from the surface of the copper to leave the resultant copper circuit on the surface of the laminate. The inner layer is now complete.



photoresist removal

Go to Multilayer Fabrication 1

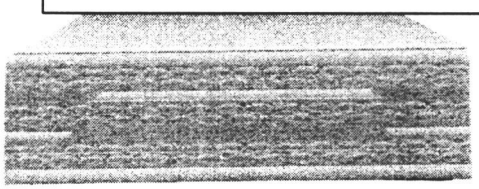
APPENDIX D Multilayer Fabrication 1 Handout

Multi-layer Fabrication - 1

Several inner layers are laminated together to produce multiplayer circuit boards. Outer layers are the layers of circuitry on the outer most sides of the multilayer circuit board.

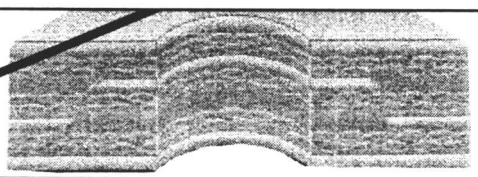
lamination

Multiple inner layers are laminated together to form a multilayer - layers of circuit patterns.



drilling

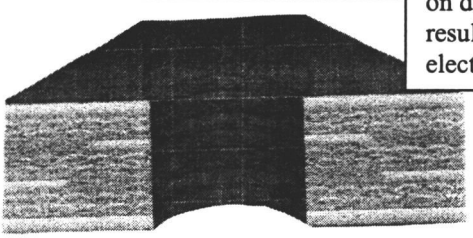
Holes are drilled in the multilayers in order to make connections between the different layers. These holes are referred to as "through-holes."



C

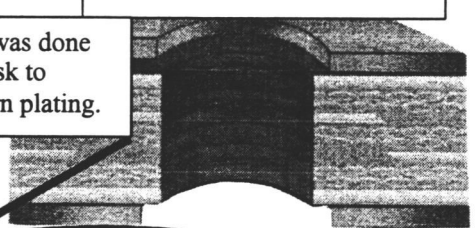
electroless copper

Electroless copper is a method for depositing very "thin" metal on dielectric material without the use an electric current. The resultant metal is very thin and is used to conduct current for electroplating which deposits a much thicker layer of metal.



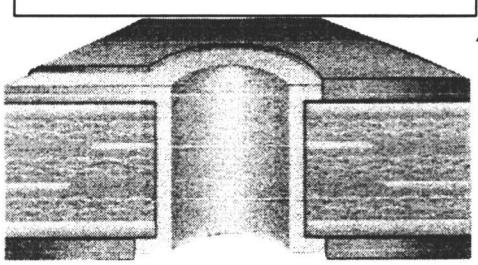
photoresist patterning

Photoresist is patterned in the same way as was done for inner layers. Photoresist is used as a mask to prevent plating from occurring during pattern plating.



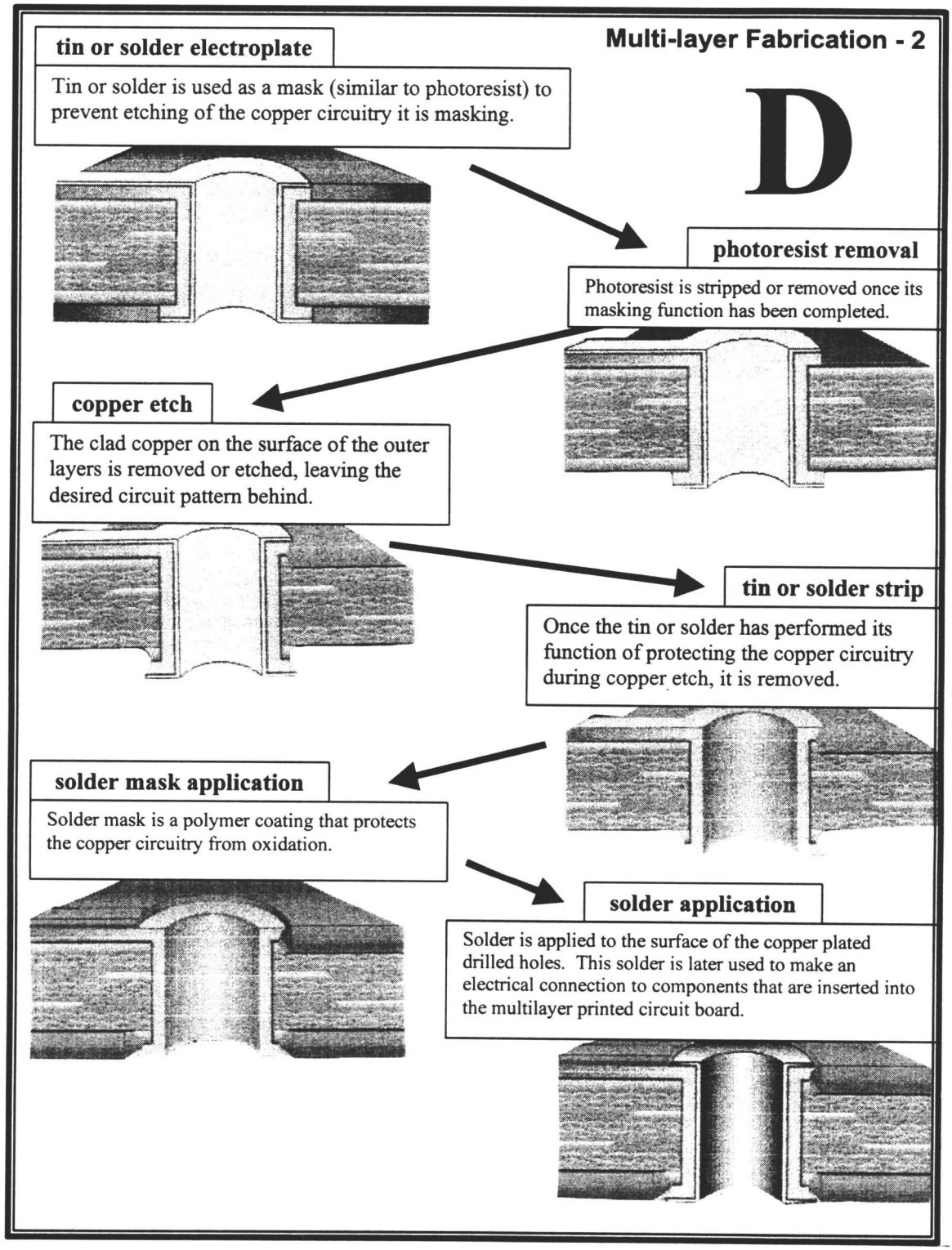
This is your problem!!!

copper electroplating



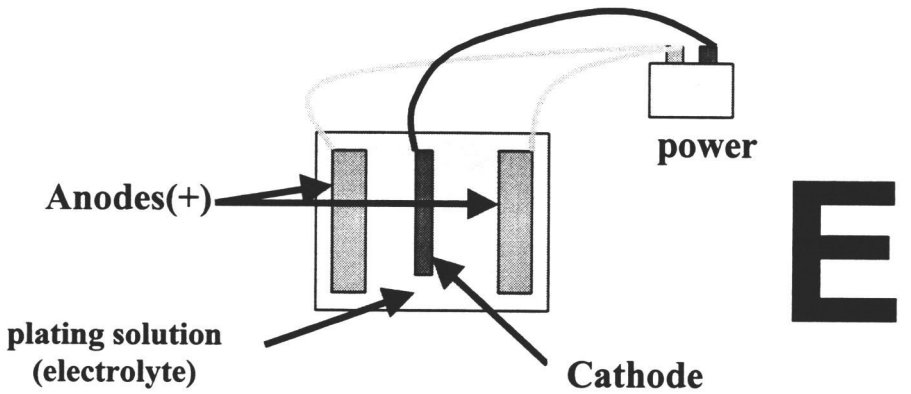
Copper electroplating uses current and a plating bath (electrolyte solution) to deposit a thick layer of metal on the surfaces of the multilayer board (on the electroless copper over the clad copper) as well as on the surface of the holes (on the electroless copper) that were drilled through the circuit board. This metal serves to electrically connect the different layers of the circuit board to one another.

APPENDIX E Multilayer Fabrication 2



APPENDIX F Copper Electroplating Handout

Copper Electroplating (electrodeposition)



Once the through-holes (holes drilled through the entire circuit board) have been coated with electroless copper, the multilayer (inner layers laminated together) board is ready for acid copper electroplating (short for "electrolytic plating"). Putting a uniform, reliable sheath of copper plate on the insides of every hole turns out to be quite straight forward. Thanks to decades of work by the major electrochemical suppliers, the various chemical systems are well understood. A plating solution can be mixed using readily available materials.

An acid copper electroplating solution (electrolyte solution, electrolyte, plating solution, chemistry) is a mixture of water, sulfuric acid, copper sulfate, and a trace of hydrochloric acid. To this is added a number of organic constituents that serve to regulate and distribute the delivery of copper to the surface being plated. The two basic organic additives are commonly referred to as the *"brightener/leveler"* and the *"carrier"*.

A basic electroplating cell consists of a tank full of electroplating solution with arrays of copper anode bars arranged along two opposite sides. These bars are referred to as the anodes, and are connected to the positive terminal of a current source. Situated halfway between these anode "banks" is the copperclad laminate (substrate) that is to be plated. It is often referred to as the cathode. (above fig.)

In the simplest terms, copper deposition occurs when an electrical potential is established between the anodes and the cathode. The resulting electrical field initiates migration of copper ions from the anodes to the electrically conductive surface of the cathode where the ionic charge is neutralized as the metal ions plate out of solution.

At the anode (in a properly maintained bath), sufficient copper erodes into the electroplating solution, to exactly make up for the deposited material, maintaining a constant concentration of dissolved copper. There is a tendency for electrical charges to build up on the nearest high spot, thereby creating a higher electrical potential. This area of increased potential attracts more copper than the surrounding areas which in turn makes the high spot even higher. If this process were allowed to continue unchecked, the resulting plated surface would resemble a random jumble of copper spears instead of the smooth, bright surface needed for reliable electrical circuit formation. Inhibiting and controlling this nonlinear behavior is done by the organic additives. This situation is especially critical at the rims of the through-holes. Here the copper concentration is sufficiently high and, in the absence of some mediating mechanism, plating (electrodeposition) would completely close off many of the smaller diameter holes.

APPENDIX G Pattern Plating (multilayer plating process)

Pattern plating, as the name implies, is done by masking off most of the clad copper laminate surface with photoresist and plating only the exposed traces and pads of the circuit pattern.

Pattern plating copperclad laminate (substrate) proceeds as follows:

1. Calculate the total plating time.

Consider an acid copper plating bath that deposits 0.0011" (1.10 mils or 28 microns or 0.81 oz – copper thickness can be designated as either a thickness or a weight) of high ductility copper in 1 hr at 20 ASF(Amps per Square Foot). Plating up "one ounce" of copper (i.e. plating 1 oz. of copper onto square foot of board) is equivalent to plating a thickness of 0.0013" (1.3 mils or 34 microns).

Example: **If you are starting with "half ounce" copperclad (a clad {copper coated} surface is used to begin with for the purpose of adhesion between the copper and the laminate) and want to plate up to a finished thickness of "one ounce", you will need to add .65 mils. The total plating time at 20 ASF will be: [0.65 mils / (1.1 mils/hr.) x 60 min./hr. = 35.5 minutes = T**

2. Calculate the required plating current.

Convert the total area of the pattern being plated into square feet (remember both sides of the copper clad laminate!) and multiply the result by 20. To normalize the plating field, it is often beneficial to add an exposed ¾" boundary around the board to increase to total plating area and suppress the formation of high potential areas at the edges of the pattern. These are referred to as "robber bars" or "thieving bars" since they "steal" some of the electric field from the circuit pattern.

***Example:* If you are plating a double-sided board with a total circuit area equal to 25 sqin. (robber bars included) you will need: [25/144] x 20 = 3.5 Amps = C**

3. Dip the patterned board (board is coated with photoresist in a circuit pattern) into a 10% solution of sulfuric acid to make sure that no residual developing solution (from the previous photoresist developing step) remains on the board surface or in the through-holes and to minimize the introduction of contaminants into the copper plating tank.
4. Attach the cathode clip to the board, making certain that both copper surfaces (front and back of the board) have good electrical contact to the *negative* terminal of the plating power supply.
5. Turn the power supply on.

Note: The power supply should be adjusted so that, at its lowest setting, it establishes an electrical potential of about 0.25 Vdc when the board is first lowered into the bath. This will help prevent the formation of a low adhesion electroless copper layer that might lead to trace peeling and cracking during soldering.

6. Lower the board into the plating tank halfway between the two anode banks until the top edge is at least 1" below the surface of the electrolyte.
7. Swish the board gently back and forth to drive any trapped air bubbles out of the through holes.
8. Turn on the air compressor and adjust the air flow until a uniform blanket of agitation roils the top of the bath on both sides of the board. You only need about 2 CFM (Cubic Feet per Minute) of air flow per square foot of bath surface.
9. Slowly ramp up the current (take about 20 sec.) to the value C calculated above.

over →

10. Plate the board for the total time (T).
11. Remove the board from the bath and thoroughly rinse in the rinse tank to remove most of the electrolyte. Rinse the board under running tap water to remove the rest.
12. Blow dry.

The plated board is now ready for <u>further processing</u>.

APPENDIX H Printed Circuit Board Terminology Handout

Printed Circuit Board Plating Terminology G

ACTIVATING: A treatment that renders nonconductive material receptive to electroless deposition. Nonpreferred synonyms: Seeding, Catalyzing and Sensitizing.
ANNULAR RING: The conductive foil and plating surrounding a hole.
ASPECT RATIO: The ratio of the circuit board thickness to the smallest hole diameter.
B-STAGE MATERIAL: Sheet material impregnated with a resin, cured to an intermediate stage (B-stage resins). Prepreg is the preferred term.
BARREL: The cylinder formed by plating through a drilled hole.
BASE LAMINATE: The substrate material upon which the conductive pattern could be formed. The base material may be rigid or flexible.
BLOW HOLE: A void caused by out gassing.
BRIDGING, ELECTRICAL: The formation of a conductive path between two insulated conductors such as adjacent foil traces on a circuit board.
CENTER-TO-CENTER SPACING: The nominal distance between the centers of adjacent features or traces on any layer of a printed circuit board.
CIRCUMFERENTIAL SEPARATION: The crack in the plating extending around the entire circumference of a plated-through hole.
CLAD OR CLADDING: A relatively thin layer or sheet of metal foil which is bonded to a laminate core to form the base material for printed circuits.
CLEARANCE HOLE: A hole in the conductive pattern, larger than, but concentric with, a hole in the printed board base material.
COMPONENT HOLE: A hole used for the attachment and electrical connection of component terminations, including pins and wires, to the printed circuit board.
COMPONENT SIDE: That side of the printed circuit board on which most of the components will be mounted.
CONDUCTIVE PATTERN: The configuration of design of the conductive material on the base laminate. Includes conductors, lands, and through connections.
CONDUCTOR SPACING: The distance between adjacent edges, (not centerline to centerline), of conductors on a single layer of a printed board.
CONDUCTOR BASE WIDTH: The conductor width at the plane of the surface of the base material. See also: Conductor width.
CONDUCTOR-TO HOLE-SPACING: The distance between the edge of a conductor and the edge of a supported or unsupported hole.
CONDUCTOR WIDTH: The observable width of the pertinent conductor at any point chosen at random on the printed circuit board.
CONTAMINANT: An impurity or foreign substance whose presence on printed wiring assemblies could electrolytically, chemically, or galvanically corrode the system.
COPPER FOIL: A cathode-quality electrolytic copper used as a conductor for printed circuits. It is made in a number of weights (thicknesses): the traditional weights are 1 and 2 ounces per square foot (0.0014" and 0.0028" thick).
CORE MATERIAL: The fully cured inner-layer segments, with circuiting on one or both sides, that form the multilayer circuit.
COSMETIC DEFECT: A defect, such as a slight change in its usual color, that does not affect functionality of the circuit board.
CURRENT-CARRYING CAPACITY: The maximum current which can be carried continuously, under specified conditions, by a conductor without causing degradation of electrical or mechanical properties of the printed circuit board.
DEFECT: Any deviation from the normally accepted characteristics of a product or component. See also: Major Defect and Minor Defect.
DIELECTRIC: An insulating medium which occupies the region between two conductors.

DIELECTRIC STRENGTH: The voltage that an insulating material can withstand before breakdown occurs, usually expressed as a voltage gradient (such as volts per mil.).
DIMENSIONAL STABILITY: A measure of dimensional change caused by factors such as temperature, humidity, chemical treatment, age, or stress; usually expressed as units/unit.
DRY-FILM RESISTS: Coating material in the form of laminated photosensitive sheets specifically designed for use in the manufacture of printed circuit boards and chemically machined parts. They are resistant to various electroplating and etching processes.
ELECTROLESS DEPOSITION: The deposition of conductive material from an autocatalytic reduction of a metal ion on certain catalytic surfaces.
ELECTROLESS PLATING: The controlled autocatalytic reduction of a metal ion on certain catalytic surfaces.
ELECTROPLATING: The electro-deposition of a metal coating on a conductive object. The object to be plated is placed in an electrolyte and connected to one terminal of a d-c voltage source. The metal to be deposited is similarly immersed and connected to the other terminal. Ions of the metal provide transfer to metal as they make up the current flow between the electrodes.
FOIL: A thin sheet of metal, usually copper or aluminum, used as the conductor for printed circuits. The tinnier the foil, the lower the required etch time. Thinner foils also permit finer definition and spacing. See: Copper Foil.
HOLE DENSITY: The quantity of holes in a printed circuit board per unit area.
HOLE PULL STRENGTH: The force, in pounds, necessary to rupture a plated-through hole or its surface terminal pads when loaded or pulled in the direction of the axis of the hole. The pull is usually applied to a wire soldered in the hole, and the rate of pull is given in inches per minute.
HOLE VOID: The void in the metallic deposit of a plated-through hole exposing the base material.
INTERNAL LAYER: A conductive pattern which is contained entirely within a multilayer printed board.
IPC: (Institute for Interconnection and Packaging Electronic Circuits). A leading printed wiring industry association that develops and distributes standards, as well as other information of value to printed wiring designers, users, suppliers, and fabricators.
INTERSTITIAL VIA HOLE: A plated-through hole connecting two or more conductor layers of a multilayer printed board but not extending fully through all of the layers of base material comprising the board.
LAMINATE: A product made by bonding together two or more layers of metal.
LAMINATION: The process of preparing a laminate; also, any layer in a laminate.
LAND: A portion of a conductive pattern usually, but not exclusively, used for the connection and/or attachment of components. Also called Pad, Boss, Terminal area, Blivet, Tab, Spot, or Donut.
LANDLESS HOLE: A plated-through hole without a land(s).
LAYER-TO-LAYER SPACING: The thickness of dielectric material between adjacent layers of conductive circuitry in a multilayer printed circuit board.
MAJOR DEFECT: A defect that could result in failure or significantly reduce the usability of the part for its intended purpose.
MASK: A materiel applied to enable selective etching, plating, or the application of solder to a printed circuit board.
MAXIMUM, PLATED-THROUGH HOLE SIZE: A hole size equal to the specified hole size before plating, plus the manufacturing tolerance, less twice the minimum plating thickness.
MICROSECTIONING: The preparation of a specimen for the microscopic examination of the material to be examined, usually by cutting out a cross-section, followed by encapsulation, polishing, etching, staining, etc..
MIL: One-thousandth (0.001) of an inch.
MIL SPEC.: standards and specifications for boards built for military applications
MINIMUM ANNULAR RING: The minimum metal width, at the narrowest point, between the circumference of the hole and the outer circumference of the land. This measurement is made to the drilled hole on internal layers of multilayer printed circuit boards and to the edge of the plating on outside layers of multilayer boards and double-sided boards.
MINIMUM ELECTRICAL SPACING: The minimum allowable distance between adjacent conductors at any given voltage or altitude, that is sufficient to prevent dielectric breakdown, corona or both.

MINIMUM PLATED-THROUGH HOLE SIZE: A hole size equal to the specified hole size before plating, less the manufacturing tolerance, less twice the minimum plating thickness.
MINOR DEFECT: A defect which is not likely to reduce the usability of the unit for its intended purpose. It may be a departure from established standards having no significant bearing on the effective use or operation of the unit.
MULTILAYER PRINTED CIRCUIT BOARDS: Printed circuit boards consisting of three or more conducting circuit planes separated by insulating material and bonded together with internal and external connections to each level of the circuitry as required.
NEGATIVE: An artwork master or production master in which the intended conductive pattern is transparent to light, and the areas to be free from conductive material are opaque.
NONFUNCTIONAL LAND: A land on internal or external layers, not connected to the conductive pattern on its layer.
OVERHANG: Increase in printed circuit conductor width caused by plating build-up or by undercutting during etching.
PAD: The portion of the conductive pattern on printed circuits designated for the mounting or attachment of components. See: Land
PADS ONLY: A multilayer construction with all circuit traces on inner layers and component terminal area only on one surface of board. This adds two layers, but may avoid the need for subsequent solder resist, and usually inner layers are easier to form which may lead to higher overall yields.
PANEL: The base material containing one or more circuit patterns that passes successively through the production sequence and from which printed circuit boards are extracted. See: Backplanes and Panels.
PANEL PLATING: The plating of the entire surface of a panel (including holes).
PATTERN: The configuration of conductive and nonconductive materials on a panel or printed board. Also the circuit configuration on related tools, drawings and masters.
PATTERN PLATTING: Selective plating of a conductive pattern.
PEEL STRENGTH: The force per unit width required to peel the conductor or foil from the base material.
PINHOLE: A minute hole through a layer or pattern.
PIT: A depression in the conductive layer that does not penetrate entirely through it.
PLATED-THROUGH HOLE: A hole with the deposition of metal (usually copper) on its sides to provide electrical connections between conductive patterns at the levels of a printed circuit board.
PLATING, ELECTROLESS: A method of metal deposition employing a chemical reducing agent present in the processing solution. The process is further characterized by the catalytic nature of the surface which enables the metal to be plated to any thickness.
PLATING, ELECTROLYTIC: A method of metal deposition employing the work or cathode; the anode; the electrolyte, a solution containing dissolved salts of the metal to be plated; and a source of direct current. See: Electroplating.
PLATING RESISTS: Materials which, when deposited on conductive areas, prevent the plating of the covered areas. Resists are available both as screened-on materials and dry-film photopolymer resists.
PLATING VOID: The absence of a plating metal from a specified plating area.
POSITIVE: An artwork master or production master in which the intended conductive pattern is opaque to light, and the areas intended to be free from conductive material are transparent.
PRINTED WIRING LAYOUT: A sketch that depicts, the printed wiring substrate, the physical size and location of electronic and mechanical components, and the routing of conductors that interconnect the electronic parts in sufficient detail to allow preparation of documentation and artwork.
PTH (PLATED-THROUGH HOLE): Refers to the technology that uses the plated- printed wiring patterns, or portions thereof, with respect to desired locations on the opposite side of the board.
RESIST: Coating material used to mask or to protect selected areas of a pattern from the action of an etchant, solder, or plating. See: Dry-Film Resists, Plating Resists, and Solder Resists.
REVERSE IMAGE: The resist pattern on a printed circuit board enabling the exposure of conductive areas for subsequent plating.
SCHEMATIC DIAGRAM: A drawing which shows, by means of graphic symbols, the electrical connections, components, and functions of an electronic circuit.
SOLDER LEVELING: The process of dipping printed circuit boards into hot liquids, or exposing them to liquid waves to achieve fusion.

SMC (SURFACE MOUNTED COMPONENT): Component with terminations designed for mounting flush to printed wiring board.
SOLDER ABILITY TESTING: The evaluation of a metal to determine its ability to be wetted by solder. Such evaluations include: the edge dip solderability test; the meniscus test; and the globule test.
SUBSTRATE: A material, on whose surface an adhesive substance is spread for bonding or coating.
THIEF: An auxiliary cathode placed to divert current to itself from portions of the work which would otherwise receive too high a current density.
THIN FOIL: A metal sheet less than 0.0007 inches (1/2 oz) thick.
THROUGH CONNECTION: An electrical connection between conductive patterns on opposite sides of an insulating base; e.g., plated-through hole or clinched jumper wire.
THROUGH-HOLE TECHNOLOGY: Traditional printed wiring fabrication where components are mounted in holes that pierce the board.
UV (ULTRAVIOLET) CURING: Polymerizing, hardening, or cross linking a low molecular weight resinous material in a wet coating or ink, using ultraviolet light as an energy source.
UNDERWRITERS' LABORATORY SYMBOL (UL): A logotype authorized for placement on a product which has been recognized/accepted by Underwriters Laboratories, Inc.
VIA HOLE: A plated-through hole used as a through connection, but in which there is no intention to insert a component lead or other reinforcing material.
VOID: The absence of substance in a localized region.
WETTING: The information of a relatively uniform, smooth, unbroken and adherent film for solder to a base material.
WICKING: Migration of copper salts into the glass fibers of the insulating material.

APPENDIX I Organic Additives Handout

Organic additives

In a well controlled plating bath, the **carrier** supports the formation of a black skin on the anode material which serves to regulate the diffusion of copper ions into the electrolyte. The material is also attracted to, but *not co-deposited* on the cathode (work piece) forming a layer (film layer) in close proximity to the surface that controls the rate of copper grain growth.

The **brightener** works within the film layer to control copper deposition on a microscopic level.

It tends to be attracted to points of high electro-potential, temporarily packing the area and forcing copper to deposit elsewhere. As soon as the deposit levels, the local point of high potential disappears and the brightener drifts away. (i.e. brighteners inhibit the normal tendency of the plating bath to preferentially plate areas of high potential which would inevitably result in rough, dull plating). By continuously moving with the highest potential, brightener/levelers prevent the formation of large copper crystals, giving the highest possible packing density of small crystals, which results in a smooth, glossy, highly ductile copper deposition.

The action of the **carrier** can be likened to the function of a doorman at a theater who regulates the flow of people into a theater but doesn't really care where they go once inside. The brightener is like the ushers who politely lead each person to a vacant seat until the theater is uniformly filled.

H

APPENDIX J Testimonials Handout

Testimonials

Process Engineering Manager –
It's important that we consider quality of the product as well as the vendor's ability to provide technical support. We're short handed on engineers as it is so we don't need a bunch of technical issues with this plating bath. I've use both Universal and Global before, but had some issues with both of them. Universal produces a pretty nice copper deposit, but once we had a pitting problem with the copper and it took us a week to get any kind of response from them for support. I'm still not sure if the pitting problem had anything to do with the copper bath itself or was the result of some other problems we were having. The thing I liked about the Global bath was the ability to plate at really high current densities – this drastically decreased our through-put times. I seem to remember some issues with pricing though. I wasn't directly involved, but purchasing was having a really difficult time.

Production Manager –
Obviously my biggest concern is that we avoid technical problems at all costs. I can't get the production out when the line is down. Our engineering staff is plenty big enough to deal with any of the technical difficulties that might come up. The last plant I worked at used Bernie's copper and I recall a few delivery glitches. I remember them because the copper line was down for several days at a time waiting for a chemistry delivery – what a pain! I don't know much about the technical end of things – we just make 'em and ship 'em.

Purchasing Manager –
As far as I'm concerned, chemistry is chemistry. The bottom line is what everything costs. It seems like we have enough technical geniuses running around to handle the technical side of things. I remember a situation where we used PCB Chemistry as a vendor and it took forever to get the line up and running. The expense was high because we went through four different start-up baths due to some kind of contamination problem before the bath was working right.

Marketing Manager –
Two of our biggest competitors use Bernie's and PCB Chemistry's copper baths. They're pretty successful so I think we should look at these vendors as serious possibilities. Copper is one of the main materials in a board so this decision is pretty important. I certainly don't want to have to go to our customers and whine about some type of plating problem we're having.

Plant Manager –
I don't really care which brand of chemistry we use. Just pick one that works and doesn't cost us an arm and a leg. I will be really upset if I start hearing that the line is down because of technical or delivery problems. I also don't want purchasing breathing down my neck with complaints about cost. It's time for this engineering team to earn their pay and pick the best copper plating chemistry vendor.

Engineer from Company A –
We just switched from Bernie's copper bath to PCB's bath. Start-up was no problem at all. We've been using the bath for about four months now. I don't think PCB's bath is any better technically than Bernie's bath. Our plating manager is new and I think he wanted to switch since he's used the PCB bath before and had good luck with it.

Engineer from Company B –
We've used the Universal copper bath since I've been with the company and I've been here for seven years. We've been through the plating problems that everyone seems to have – pitting, uneven plate,..., but the Universal guys have always helped us get through the problems. All we have to do is get on the phone and they'll send someone out to help us out. A couple of years ago we had a problem that went on for about three weeks and the Universal guys were at our plant almost around the clock until the problem was resolved. It turns out that there was some kind of problem with one of their lots of product – but it was fixed and we haven't had a problem since.

Engineer from Company C –
We've used Global copper plating solution for about three years. It's advertised as a high speed plating bath, but I wouldn't recommend using it at the highest current density. When we did that we had really uneven, wavy plating. We even had burnt plating once in a while. The bath worked just fine at 20 ASF. I think the pricing of this product is a little high, but the technical support is really good.

Engineer from Company D -
We use Bernie's plating bath. We used to use PCB's bath, but we switched because we were having some delivery problems with their product. Technically the PCB bath was a very good product. We had some initial problems getting the line up and running with Bernie's bath. I don't think their technical support people are all that knowledgeable. We have a pretty strong engineering group here though, so we didn't really have to rely on the vendor for help.

APPENDIX K Pre-Exercise Questionnaire

Pre Exercise Survey

Date:

Name:

e-mail address:

phone number:

Year in School:

Program of Study:

Native Language:

Describe any previous (formal) training you've had in:

decision making:

printed circuit board fabrication or electroplating:

problem solving:

teamwork:

List any technical (work) experience you've had:

What is your past work experience (include ALL experience)?

APPENDIX L Post-Exercise Questionnaire

Post Exercise Survey (Test & Control Groups)

1. What information did you find to be useful? Select all that apply.

- ☐ Plating information
- ☐ Vendor information
- ☐ Testimonials from plating solution customers
- ☐ Testimonials from other engineers
- ☐ Testimonials from management
- ☐ Printed circuit board fabrication information
- ☐ Other: (describe)

2. How do you think additional information would affect your recommendations?

3. Did team members identify the solution criteria (requirements) of the test problem in this exercise? Select one response.

- ☐ 1 – None: No, not at all – we never did identify the solution criteria
- ☐ 2 – Very little: To some degree, but there was a lot of confusion
- ☐ 3 – Some: We identified some of the solution criteria, but also missed some
- ☐ 4 – Most of it: For the most part, we were able to identify the solution criteria
- ☐ 5 – All of it: Yes, the solution criteria were fully understood

4. Was there any disagreement within your team? Select one response.

- ☐ 1 – None: No, we never had any disagreements at all – we agreed on everything.
- ☐ 2 – Very little: We would initially disagree on some issues, but after discussion would come to an agreement.
- ☐ 3 – Some: We agreed on some issues, but disagreed on others.
- ☐ 4 – A lot: We disagreed on many issues.
- ☐ 5 – Everything had disagreement: We disagreed on virtually everything.

5. Do you think reaching consensus is important? Select the most appropriate response.

- ☐ 1 – Not important at all: Lack of consensus didn't affect our ability to solve the problem OR we had consensus on everything and I don't think it helped us solve the problem.
- ☐ 2 – Very little: Lack of consensus slowed us down, but did not adversely affect our ability to complete the task.
- ☐ 3 – Somewhat important: We thought it was important to continue to investigate questions where we lacked consensus until we had consensus.
- ☐ 4 – Important: Lack of consensus negatively affected our team and adversely affected our ability to complete the task even though we ultimately did complete the task.
- ☐ 5 – Extremely important: Disagreements prevented us from completing the task. Our decisions were based upon an averaging of team member's views which didn't really represent individual views within the team.

6. How did your team reach consensus? Select all that apply.

33. No effort: We didn't. We just gave our individual opinions and let the majority rule.
34. Discussion: We discussed ideas until we had a shared understanding and consensus.
35. Additional Data: We sought additional information when it was clear that we were in disagreement and the additional information usually led the group to consensus.
36. Dominance of one person: We tended to listen to one person in our group and agreed with his/her opinions.
37. Naturally: We all agreed on everything from the beginning and as we went along.

7. Did all team members contribute to developing your proposed solution (alternative) equally? Select the most appropriate response.

☐ 1 – No, one or two people made all of the suggestions on problem modeling and evaluation.
☐ 2 – Everyone contributed to some degree, but one or two people tended to dominate the suggestion/idea part of the process.
☐ 3 – Everyone contributed suggestions and ideas equally.

8. Did time pressure affect the selected alternative? Select the most appropriate response.

☐ 1 – None: We had more than enough time to complete the exercise.
☐ 2 – A little: We had just enough time to complete the exercise. We would have liked a little more time, but it wasn't absolutely necessary.
☐ 3 – Some: We did feel rushed, but our recommendations would not have changed with more time.
☐ 4 – A lot: We did feel rushed, and it's possible that our recommendations would have changed with more time.
☐ 5 – Extreme impact: We did not have enough time to thoroughly evaluate everything needed to make an informed recommendation. It is highly likely that additional time would have caused us to make different recommendations.

9. Describe the approach your team took to solve this problem. Select all that apply.

☐ We didn't use any particular approach. We just gave recommendations at the required time intervals.
☐ First we read all of the materials, discussed the options and then voted on our recommendations.
☐ We discussed the problem first and then read material as we had questions.
☐ We read the materials as needed, listed the solution criteria, brainstormed possible alternatives and discussed which alternatives best met the solution criteria.
☐ Other: (describe)

10. Indicate whether the following factors aided, hindered or had no effect on your group's ability to arrive at a selected alternative?

	Aided	Hindered	No Effect	Didn't Do
Discussion of the issues with one another.				
Measurement of consensus within our group.				
Access to objective information.				
Access to subjective information.				
Comparison of solution criteria to possible alternatives.				
Time pressure to make a recommendation.				
A clear understanding of what was required.				

Agreement within the group.				
Similar background of group members.				
The use of a decision support aid.				
Dominance of one group member.				
Diversity within the group.				
The time constraints.				
Understanding the exercise requirements.				
Understanding the technology of the problem.				
Interpretation of various testimonials.				
Dealing with incomplete information.				
Dealing with other group members.				
Trying to reach consensus in the group.				
Trying to prioritize the importance of different solution criteria.				
Not knowing how to approach the problem.				
Comparison of the alternatives.				

12. Did you personally agree with your group's selected alternative? Select all that apply.

- ☐ 1 – Absolutely: I agreed with my group's selected alternative and it agreed with my personal opinion.
- ☐ 2 – For the most part: I agreed with my group's selected alternative even though it was different than my personal opinion.
- ☐ 3 – A little: I did not agree with my group's selected alternative. The selected alternative reflected my personal opinion, but I don't think it really reflected everyone else's opinion.
- ☐ 4 – Very little: I did not agree with my group's proposed solution. The proposed solution did not reflect my personal opinion.
- ☐ 5 – Not at all: I did not agree with my group's proposed solution because we did not really explore the alternatives adequately.

13. Did your proposed solution change over time? Select all that apply.

- ☐ No, our selected alternative was the same as our initial choice.
- ☐ Yes, as we read more information our selected alternative changed.
- ☐ Yes, as we discussed the issues with one another our selected alternative changed.

14. Do you think this exercise is similar to situations you might encounter in industry or business? Select all that apply.

- ☐ Yes, I've seen similar situations in the workplace.
- ☐ Yes, I have no work experience, but I think this exercise would be similar to situations found in the workplace.
- ☐ No, I have work experience and I've never seen anything similar to this exercise in the workplace.
- ☐ No, I have no work experience, but I doubt this exercise would be similar to situations found in the workplace.

APPENDIX M Change Personality Instrument

Change Personality

Reactive ⟷ **Proactive**

1. **FLEXIBILITY** How able are you to change your behavior at will?

1	2	3	4	5	6	7
Unable & unwilling			Able & willing, if the cause is attractive			Couldn't stop if I tried

2. **RECEPTIVITY** How open are you to new ideas?

1	2	3	4	5	6	7
I know what I like, and that's all I want to know!			I enjoy stepping outside the box and hearing a fresh viewpoint.			I live for new ideas. My Problem is following through

3. **STATUS** How able are you to change right now?

1	2	3	4	5	6	7
Too stressed out in my life as a whole to give a work idea its due.			Looking for an opportunity to try something new in my job.			I'm ready to go, no matter what the idea

4. **DISTRESS** How might you describe your current level of negative stress?

1	2	3	4	5	6	7
I'm maxed out. My confidence is low & my attention span is for the birds. Kill me.			Copacetic. Things are going well for me at home, and I feel I can handle a new challenge.			Feeling no stress whatsoever gears may be stripped.

5. **PATIENCE** How patient are you in the face of change? How comfortable are you with delayed gratification?

1	2	3	4	5	6	7
I like results ASAP. I can't go forward unless my results are assured.			I am willing to wait for results if I have reason to think they will be coming.			I can wait forever.

6. **LOCUS OF CONTROL** Do you focus on yourself or outside yourself?

1	2	3	4	5	6	7
I can only be concerned right now about me and my survival.			I feel I have found a good balance between taking care of myself and offering my contributions to others.			I am not important. All that matters is the success of the group.

7. **MIND SPACE** What is your natural time orientation?

1	2	3	4	5	6	7
Right now, today I can't think of long term ramifications or the Big Picture			I am comfortable with long term but understand that goals are achieved in increments			I don't even think about time, Whatever happens, will happen

8. **DIVERSITY** How do you feel about different-ness - "other-ness" of other people's ideas?

1	2	3	4	5	6	7
I have trouble subscribing to an idea I know I could never have come up with.			I welcome ideas from people who are different from me.			Unless an idea comes from outside my immediate circle, I'm not interested in it

8 - 10	14 - 30	31-55	52 - 56
METAMORON (Analytical)	**METAPHOBE** (Amiable)	**METAPHILE** (Driver)	**METAMANIAC** (Expressive)
Its no coincidence Bob Crachit worked for Ebenezer Scrooge.	You can change well with the right combination of Push, then Pull.	The change-making ideal. Ideal candidate for a Pull program.	Way too much of a good Organizational equivalent of idiot savant.

APPENDIX N Problem Solving Behavior Instrument

Circle either "a" or "b" whichever, on first reading, best describes you.

1. At a party do you
a. interact with many, including strangers
b. interact with a few, known to you

2. Are you more
a. realistic and speculative
b. speculative than realistic

3. Is it worse to
a. have your "head in the clouds"
b. be "in a rut"

4. Are you more impressed by
a. principles
b. emotions

5. Are you more drawn toward
a. convincing
b. touching

6. Do you prefer to work
a. rather carefully
b. just "whenever"

7. Do you tend to choose
a. rather carefully
b. somewhat impulsively

8. At parties do you
a. stay late, with increasing energy
b. leave early, with decreased energy

9. Are you more attracted to
a. sensible people
b. imaginative people

10. Are you more interested in
a. what is actual
b. what is possible

11. In judging others are you more swayed by
a. laws than circumstances
b. circumstances than laws

12. In approaching others is your inclination to be somewhat
a. objective
b. personal

13. Are you more
a. punctual
b. leisurely

14. Does it bother you more having things
a. incomplete
b. completed

15. In your social groups do you
a. keep abreast of other's happenings
b. get behind on the news

16. In doing ordinary things are you more likely to
a. do it the usual way
b. do it your way

17. Writers should
a. "say what they mean and mean what they say"
b. express things more by use of analogy

18. Which appeals to you more
a. consistency of thought
b. harmonious human relations

19. Are you more comfortable in making
a. logical judgments
b. value judgments

20. Do you want things
a. settled and decided
b. unsettled and undecided

21. Would you say you are more
a. serious and determined
b. easy going

22. In phoning do you
a. rarely question that it will all be said
b. rehearse what you'll say

23. Facts
a. "speak for themselves"
b. illustrate principles

24. Are visionaries
a. somewhat annoying
b. rather fascinating

25. Are you more often
a. a cool-headed person
b. a warm-hearted person

26. Is it worse to be
a. unjust
b. merciless

27. Should one usually let events occur
a. by careful selection and choice
b. randomly and by chance

28. Do you feel better about
a. having purchased
b. having the option to buy

29. In company do you
a. initiate conversation
b. wait to be approached

30. Common sense is
a. rarely questionable
b. frequently questionable

31. Children often do not
a. make themselves useful enough
b. exercise their fantasy enough

32. In making decisions do you feel more comfortable with
a. standards
b. feelings

33. Are you more
a. firm than gentle
b. gentle than firm

34. Which is more admirable:
a. a. the ability to organize and be methodical
b. the ability to adapt and make do

35. Do you put more value on the
a. definite
b. open-minded

36. Does new and non-routine interaction with others
a. stimulate and energize you
b. tax your reserves

37. Are you more frequently
a. a practical sort of person
b. a fanciful sort of person

38. Are you more likely to
a. see how others are useful
b. see how others see

39. Which is more satisfying:
a. to discuss an issue thoroughly
b. to arrive at agreement on an issue

40. Which rules you more:
a. your head
b. your heart

41. Are you more comfortable with work that is
a. contracted
b. done on a casual basis

42. Do you tend to look for
a. the orderly
b. whatever turns up

43. Do you prefer
a. many friends with brief contact
b. a few friends with more lengthy contact

44. Do you go more by
a. facts
b. principles

45. Are you more interested in
a. production and distribution
b. design and research

46. Which is more of a compliment:
a. "there is a very logical person"
b. "there is a very sentimental person"

47. Do you value in yourself more that you are
a. unwavering
b. devoted

48. Do you more often prefer the
a. final and unalterable statement
b. tentative and preliminary statement

49. Are you more comfortable
a. after a decision
b. before a decision

50. Do you
a. speak easily and at length with strangers
b. find little to say to strangers

51. Are you more likely to trust your
a. experience
b. hunch

52. Do you feel
a. more practical than ingenious
b. more ingenious than practical

53. Which person is more to be complimented:
a. clear reason
b. strong feeling

54. Are you inclined more to be
a. fair minded
b. sympathetic

55. Is it preferable mostly to
a. make sure things are arranged
b. just let things happen

56. In relationships should most things be
a. re-negotiable
b. random and circumstantial

57. When the phone rings do you
a. hasten to get to it first
b. hope someone else will answer

58. Do you prize more in yourself
a. a strong sense of reality
b. a vivid imagination

59. Are you drawn more to
a. fundamentals
b. overtones

60. Which seems the greater error:
a. to be too passionate
b. to be objective

61. Do you see yourself as basically
a. hard-headed
b. soft-hearted

62. Which situation appeals to you more:
a. the structured and scheduled
b. the unstructured and unscheduled

63. Are you a person that is more
a. routinized than whimsical
b. whimsical than routinized

64. Are you more inclined to be
a. easy to approach
b. somewhat reserved

65. In writings do you prefer
a. the more literal
b. the more figurative

66. Is it harder for you to
a. identify with others
b. utilize others

67. Which do you wish more for yourself:
a. clarity of reason
b. strength of compassion

68. Which is the greater fault:
a. being indiscriminate
b. being critical

69. Do you prefer the
a. planned event
b. unplanned event

70. Do you tend to be more
a. deliberate than spontaneous
b. spontaneous than deliberate

Disclaimer: Note that these results are not reliable indicators of any aspect of your personality, intelligence or other cognitive function. The instructor in this course is not trained in the use of this material and it is given only as an exercise to help make you aware of problem-solving differences.

Enter the results in the table below marking whether your response was a or b.

	a	b		a	b		a	b		a	b		a	b		a	b		a	b
1			2			3			4			5			6			7		
8			9			10			11			12			13			14		
15			16			17			18			19			20			21		
22			23			24			25			26			27			28		
29			30			31			32			33			34			35		
36			37			38			39			40			41			42		
43			44			45			46			47			48			49		
50			51			52			53			54			55			56		
57			58			59			60			61			62			63		
64			65			66			67			68			69			70		
						+						+						+		
						=						=						=		

E	I	S	N	T	F	J	P

How to score the problem solving inventory:

1. Add up the columns to get the raw score. The EI score should total 10 and the others total 20.

Example: E: 6 S: 5 T: 15 J: 13
I: 4 N: 15 F: 5 P: 7

2. Divide the EI raw scores by 10 to get the fraction in each type. Enter the values in the spaces below. Do the same with each of the other measures by dividing by 20.

E_____ S_____ T_____ J_____

I_____ N_____ F_____ P_____

The high scores in each pair give your preference. Circle the letter with the highest score. If the scores are between .6/.4 and .4/.6 then you do not have a strong tendency either way. You will probably show some characteristics of both extremes.

Example: E: .6 S: .25 T: .75 J: .65
I: .4 N: .75 F: .25 P: .35

3. The primary personality type is that circled in step 2. It can be circled on the table that follows. If you do not have a strong tendency in one or more dimension, then don't circle anything until after the next step.

Example: Strongtly **N** (possibilities), **T** (objective) and **J** (decisive), but only ***weakly*** **E** (extrovert) so primary is: **ENTJ** or **INTJ**.

4. Most people are not one of sixteen personality types, but show some tendencies in a number of types. To get this information, calculate the percentage tendency for each of the sixteen by multiplying the four scores times each other and 100.

Example: The tendency toward ENTJ (the strongest tendency in the example) is:

.6 x .75 x .75 x .65 x 100 = 22%

The tendency toward ISFJ is:

.4 x .25 x .25 x .65 x 100 = 1.6%

Percentages less than 5% imply that there is little tendency for this type. Enter your percentages in the diagram that follows. The total of all the types is 100%. The diagram is a complete map of an individual's problem solving preference.

In general

25% ≤ very strong preference
15% ≤ strong preference < 25%
5% ≤ some preference < 15%
weak preference < 5%

		Information Managed					
		Facts Sensors (**S**)		Possibilities Intuitive (**N**)			
Problem Closure	Planner Judger (**J**)	**ISTJ** Organizer	**ISFJ** Server	**INFJ** Inspirer	**INTJ** Thinker	Introvert (**I**)	**Energy Source**
	Flexible Perceiver (**P**)	**ISTP** Artisan	**ISFP** Artist	**INFP** Idealist	**INTP** Conceptualist		
		ESTP Entrepreneur	**ESFP** Entertainer	**ENFP** Manager	**ENTP** Creator	Extrovert(**E**)	
	Planner Judger (**J**)	**ESTJ** Administrator	**ESFJ** Friend	**ENFJ** Persuader	**ENTJ** Leader		
		Objective Thinker (**T**)	Subjective Feeler (**F**)		Objective Thinker (**T**)		
		Decision Objectivity					

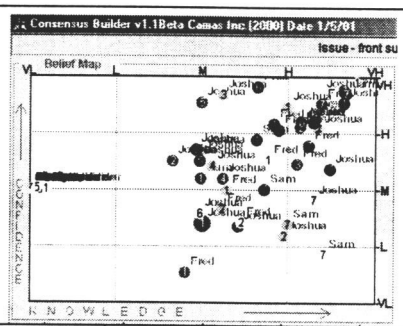
	Information Managed					
	Facts Sensors (S)		Possibilities Intuitive (N)			
	ISTJ Organizer Practical, orderly, matter-of-fact, logical, realistic, and dependable general 6% engineers 10% CEOs 32%	**ISFJ** Server Quiet, friendly, responsible, work devotedly to meet obligation, accurate, & painstaking general 6% engineers 6% CEOs 0.5%	**INFJ** Inspirer Principled, succeed by perseverance, originality and desire to do whatever is needed. general 1% engineers 5% CEOs 0.2%	**INTJ** Thinker Skeptical, critical, independent, determined, and good scientists. general 1% engineers 14% CEOs 16%	Introvert (I)	Energy Source
	ISTP Artisan Cool onlookers, reserved and analytical of life. general 5% engineers 2% CEOs 2.5%	**ISFP** Artist Retiring, quietly friendly, sensitive, kind and modest general 5% engineers 2% CEOs 0.1%	**INFP** Idealist Quest oriented, little concern for possessions, enthusiastic and loyal. general 1% engineers 5% CEOs 0.4%	**INTP** Conceptualist Quiet, problem solver and idea oriented. general 1% engineers 9% CEOs 1.3%		
	ESTP Entrepreneur Good at on-the-spot problem solving, conservative, best with real things. general 13% engineers 3% CEOs 1%	**ESFP** Entertainer Outgoing, easygoing, friendly, likes to make things happen. general 15% engineers 1% CEOs 1%	**ENFP** Manager Enthusiastic, high-spirited, imaginative and improvise well. general 5% engineers 6% CEOs 0.8%	**ENTP** Creator Quick, ingenious, good at many things, alert and outspoken. general 5% engineers 7% CEOs 5.3%	Extrovert(E)	
	ESTJ Administrator Practical, realistic, natural head for business or mechanics, like to organize, general 13% engineers 9% CEOs 28%	**ESFJ** Friend Warm-hearted, talkative, popular, conscientious, committee members and want to make a difference. general 13% engineers 3% CEOs 0.9%	**ENFJ** Persuader Responsive and responsible, group leader, sociable, popular and sympathetic. general 5% engineers 6% CEOs 0.7%	**ENTJ** Leader Hearty, frank, decisive, leaders in activities, possibly overconfident, good at public speaking. general 5% engineers 13% CEOs 9.4%		
	Objective Thinker (T)	Subjective Feeler (F)		Objective Thinker (T)		
	Decision Objectivity					

APPENDIX O Post Instruction Usability Questionnaire

Consensus Builder Usability (post instruction)

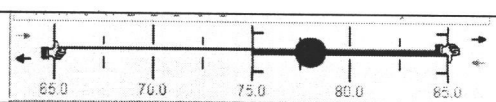
1. Rate the following *ConsensusBuilder* screen components in terms of effectiveness and list ways in which this screen component could be improved:

Belief Map Screen



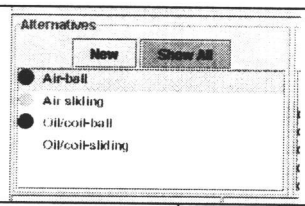
	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						
Use of number coding						
Use of size coding						
How would you improve this screen component?						

Belief Map Number Line



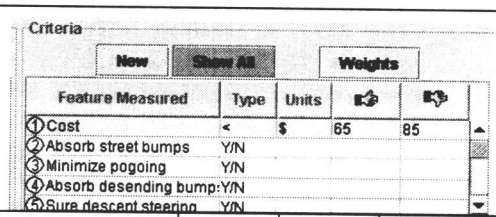
	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						
How would you improve this screen component?						

Alternatives Screen



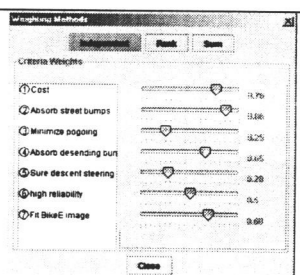
	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						
How would you improve this screen component?						

Criteria Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
How would you improve this screen component?						

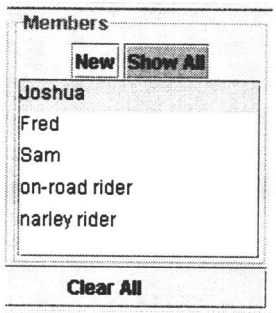
Criteria Weighting Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						

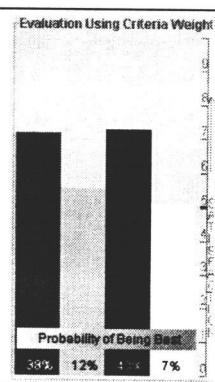
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
How would you improve this screen component?						

Members Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
How would you improve this screen component?						

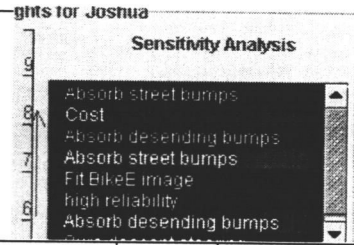
Satisfaction & Probability of Being Best Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						
Trust in probability values						

How would you improve this screen component?

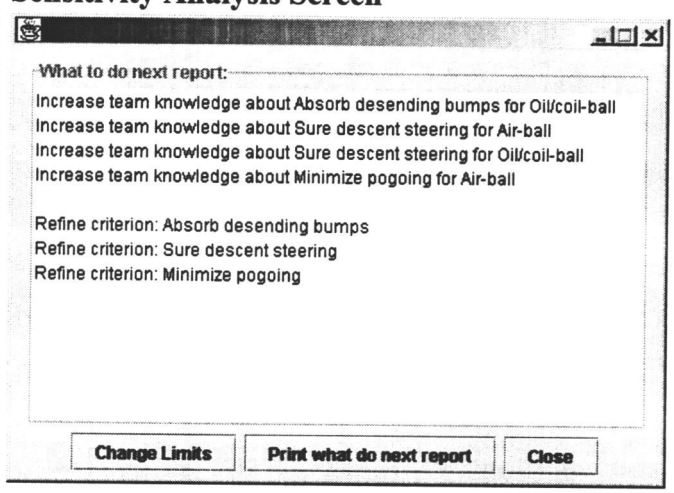
Sensitivity Analysis Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						

How would you improve this screen component?

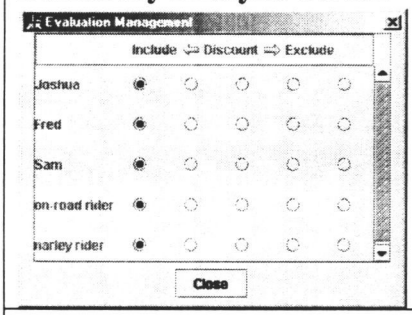
Sensitivity Analysis Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						

How would you improve this screen component?

Sensitivity Analysis Screen



	1 (low)	2	3	4	5 (high)	N/A
Clarity of information						
Helpfulness of this screen component						
Ease of editing						
Clarity of the relationship to other screens within *ConsensusBuilder*						
Aesthetic appeal						
Intuitive appeal of the information						
Use of color coding						
How would you improve this screen component?						

2. What portions of the instruction in the use of Consensus Builder were useful?

3. What did you like/dislike about the instruction in the use of Consensus Builder and why?

4. What changes, if any, would you make to Consensus Builder to improve the effectiveness of the tool?

5. What advantages or disadvantages exist for using Consensus Builder in the decision-making process?

6. What did you like about using Consensus Builder?

7. What didn't you like about using Consensus Builder?

APPENDIX P Post-Exercise Usability Questionnaire

Consensus Builder Usability (post exercise)

1. Now that you've had a chance to use Consensus Builder, did your impression of the tool change? Yes/No If so, how?

2. Did the use of Consensus affect your team's ability to develop your proposed solution? Yes/No Please describe.

3. Did the use of Consensus Builder affect your team's ability to arrive at consensus? Yes/No Please describe.

4. Do you think your impression of Consensus Builder would change as you used the tool more?

   Yes/No Please describe.

5. Would you use Consensus Builder as a group decision-making aid if it was available to you? Yes/No Why or why not?

6. What changes, if any, would you make to Consensus Builder to make it a more effective tool?

APPENDIX Q Subject Recruitment Advertisement

Earn $50 – Volunteers Needed

Volunteers are needed for one session which is for two evenings (3 hours each evening – Tue & Thur) for a graduate research project during Spring term. Session 1 is May 1 & 3; Session 2 is May 8 & 10; Session 3 is May 15 & 17; location is Kidder 104. The experiment involves solving a problem with or without the use of the decision support aid, ConsensusBuilder. The task to be solved will be to make a selection from a number of alternatives for a hypothetical situation given information about each option.

Volunteers will also be asked to fill out Meyers Briggs style surveys, surveys asking about impressions of the software (if in the study group), surveys about the processes the team used to solve the problem, and an informed consent form. The sessions will be videotaped.

For your participation, you will be paid $50 cash. You must be available both evenings. Payment will be pro-rated for failure to finish the project. You must have excellent English skills as we will be recording your team effort to solve a problem.

A second set of volunteers are needed for the control group, which meets only once. Payment will be $25 for this group.

Please respond to Cindy A. McNown Perry (camcnown@home.com or 503-361-0289) if you are interested, and include the evenings that you are available.

APPENDIX R Institutional Review Board Approval

OREGON STATE
UNIVERSITY

Report of Review by the Institutional Review Board for the Protection of Human Subjects

October 13, 2001

TO: David G Ullman
Mechanical Engineering

COPY: Laura Lincoln

RE: ConsensusBuilder

The referenced project was reviewed under the guidelines of Oregon State University's institutional review board (IRB), the Committee for the Protection of Human Subjects, and the U.S. Department of Health and Human Services. The IRB has **approved** your application.* The approval of this application expires upon the completion of the project or one year from the approval date, whichever is sooner. The informed consent form obtained from each subject should be retained in program/project's files for three years beyond the end date of the project.

Any proposed change to the protocol or informed consent form that is not included in the approved application must be submitted to the IRB for review and must be approved by the committee before it can be implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB.

[This approval is with the understanding that the general release form has been withdrawn and will not be administered, as per our phone conversation today.]

_____ Date: _____

Anthony Wilcox, Chair
Committee for the Protection of Human Subjects
Langton 214
anthony.wilcox@orst.edu; 737-6799

APPENDIX S Subject Background Information

Year in School								
Key: C = control group, T = test group, 1st number indicates 1st, 2nd or 3rd group, 2nd number indicates 1st, 2nd or 3rd subject								
C11	C12	C13	C21	C22	C23	C31	C32	C33
soph	soph	soph	grad	grad	pre-grad	fresh	senior	junior
T11	T12	T13	T21	T22	T23	T31	T32	T33
senior	soph	PhD graduate	PhD grad	senior	junior	grad	Masters graduate	fresh
Program of Study								
C11	C12	C13	C21	C22	C23	C31	C32	C33
Ind/Mfg Eng	Civil Eng	Ind/Mfg Eng	Ind Eng	Ind Eng	English – 2nd lang	Comp Science	Ind/Mfg Eng	Comp. Eng
T11	T12	T13	T21	T22	T23	T31	T32	T33
Sport Science	Elec. Eng	Mech Eng	Ind Eng	Ind Eng	Eng	Inf. Systems	Adult Edu.	Eng
Native Language								
C11	C12	C13	C21	C22	C23	C31	C32	C33
English	English	English	Chinese	Chinese	Chinese	Arimaic	English	Korean
T11	T12	T13	T21	T22	T23	T31	T32	T33
English	English	English	Thai	Syrian	English	Tamil	English	English
Formal Decision Making Training								
C11	C12	C13	C21	C22	C23	C31	C32	C33
none	none	none	none	none	none	none	none	none
T11	T12	T13	T21	T22	T23	T31	T32	T33
none	some	extensive	none	none	none	some	none	some
Printed Circuit Board Fabrication or Electroplating Experience								
C11	C12	C13	C21	C22	C23	C31	C32	C33
none	none	none	none	none	none	none	none	none
T11	T12	T13	T21	T22	T23	T31	T32	T33
none	some	none	none	none	none	none	none	none
Teamwork Training								
C11	C12	C13	C21	C22	C23	C31	C32	C33
some	some	none	none	some	none	some	some	none
T11	T12	T13	T21	T22	T23	T31	T32	T33
none	some	some	some	some	none	none	some	some
Formal Problem Solving Training								
C11	various engineering courses							
C12	engineering orientation classes							
C13	none							
C21	linear programming, stochastic modeling							
C22	design of experiments, linear programming, stochastic modeling							
C23	none							

C31	none
C32	none
C33	none
T11	algebra, calculus
T12	information management
T13	engineer for 20+ years
T21	design of experiments, linear programming, stochastic modeling, statistics
T22	none
T23	none
T31	none
T32	none
T33	leadership camp
	Work Experience
C11	volleyball referee, administrative
C12	not listed
C13	lumber grader, mfg. supervisor
C21	none
C22	construction site supervisor, hospital salesperson
C23	none
C31	restaurant manager
C32	roofing, oil leak detection
C33	night club DJ, assembly line laborer
T11	none
T12	census enumerator, manufacturing assembly
T13	engineering manager, design engineer, professor
T21	professor, cannery production improvement
T22	consulting firm manager, technical marketing, grocery store dept. manager
T23	receptionist, lifeguard, administrative, restaurant hostess
T31	graduate teaching assistant, software testing, shift coordinator
T32	English/French teacher, academic advisor, clerical worker
T33	title company employee, automotive parts packaging, paper carrier

APPENDIX T Subject Change Personality Instrument Results

Key: C = control group, T = test group, 1st number indicates 1st, 2nd or 3rd group, 2nd number indicates 1st, 2nd or 3rd subject

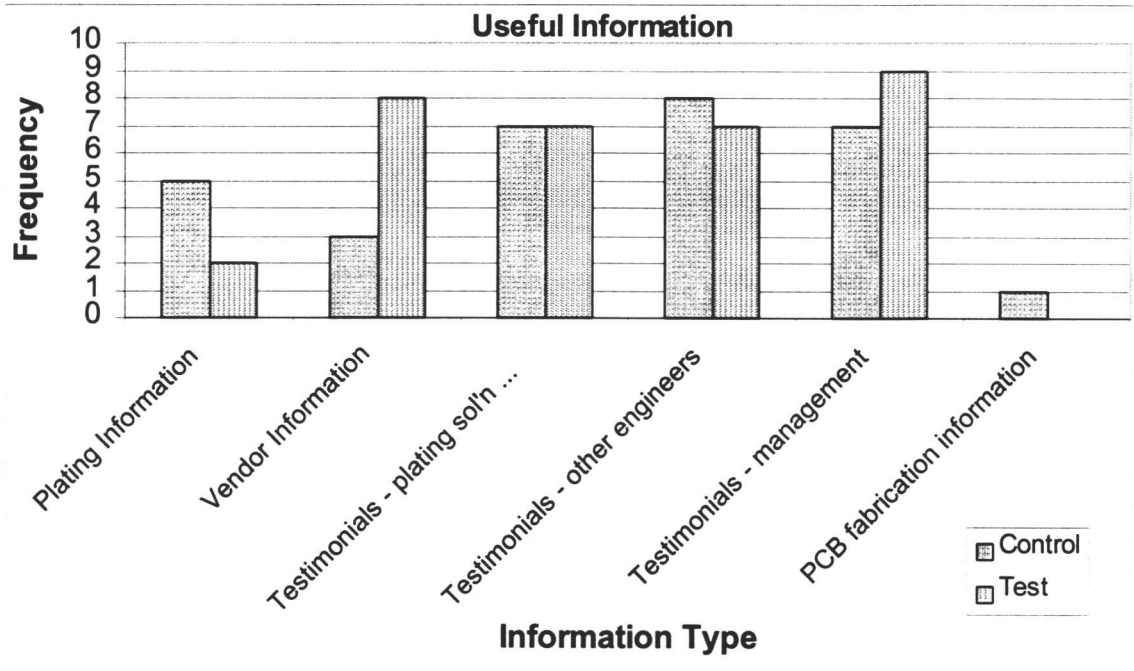
METAMORON (Analytical) Its no coincidence Bob Crachit worked for Ebenezer Scrooge.	**METAPHOBE** (Amiable) You can change well with the right combination of Push, then Pull	**METAPHILE** (Driver) The change-making ideal. Ideal candidate for a Pull program.	**METAMANIAC** (Expressive) Way too much of a good Organizational equivalent of idiot savant
C11	C12		C13
metaphile	metaphobe		metaphile
C21	C22		C23
metaphile	metaphile		metaphile
C31	C32		C33
metaphile	metaphile		metaphile
T11	T12		T13
metaphile	metaphile		metaphile
T21	T22		T23
metaphile	metaphile		metaphobe
T31	T32		T33
metaphile	metaphile		metaphile

APPENDIX U Subject Problem Solving Behavior Instrument Results

Key: C = control group, T = test group, 1st number indicates 1st, 2nd or 3rd group, 2nd number indicates 1st, 2nd or 3rd subject		
C11	C12	C13
ESTJ (25.5%)	ISTJ (19.1%)	ESTJ (33.1%)
C21	C22	C23
ENFP (31.3%)	ENFJ (18.5%)	ESFP (17.3%)
C31	C32	C33
ENTJ or INTJ (11.7%)	ENFP (33.1%)	INFP (22.0%)
T11	T12	T13
ISFJ (34.6%)	ESFJ (12.4%)	ISTJ (28.2%)
T21	T22	T23
ESTJ (20.5%)	ESFP (13.6%)	ISTJ (23.8%)
T31	T32	T33
ESTJ (28.4%)	ENFJ or INFJ (16.9%)	ENFJ (17.6%)

APPENDIX V Decision Making Process Survey Results

1. What information did you find to be useful? Select all that apply.



2. How do you think additional information would affect your recommendations?

If we knew more about how much coating was used so that we could find more data/calculations to back up our theories as to efficiency and cost. C11

We would have liked to have known how long the solution was useful for/how much/month we would need to buy. We made a lot of assumptions and any information to change those would have changed our direction. C12

Identify specific parameters of our requirements could change recommendations. C13

The cost and delivery information. C21

The initial make-up cost of Global company. Do Global and Universal have good delivery? C22

No. C23

It really helps a lot to go for details for data collection. C31

The more testimonials, the better we could place each company on our ranking system. C32

Any other additional information could've helped if it was the knowledge and experience of each of the company's quality assurance teams. C33

If we knew more about how much coating was used so that we could find more data/calculations to back up our theories as to efficiency and cost. C11

We would have liked to have known how long the solution was useful for/how much/month we would need to buy. We made a lot of assumptions and any information to change those would have changed our direction. C12

Identify specific parameters of our requirements could change recommendations. C13

The cost and delivery information. C21

The initial make-up cost of Global company. Do Global and Universal have good delivery? C22

No. C23

It really helps a lot to go for details for data collection. C31

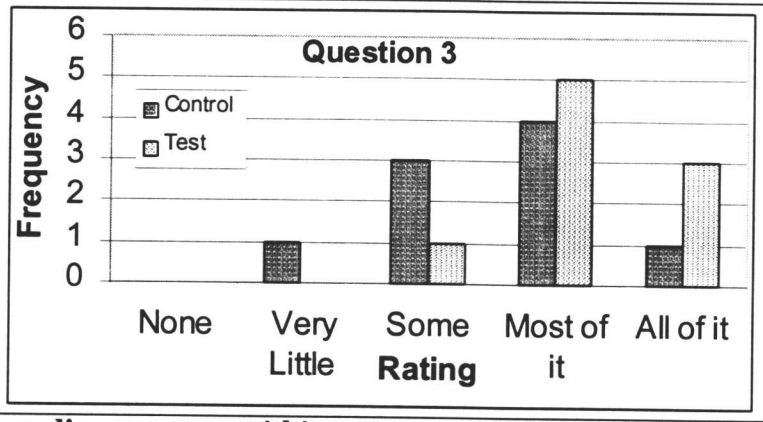
The more testimonials, the better we could place each company on our ranking system. C32

Any other additional information could've helped if it was the knowledge and experience of each of the company's quality assurance teams. C33

If we were given all the prices as well, I think that we would be able to give a more confident recommendation. T33

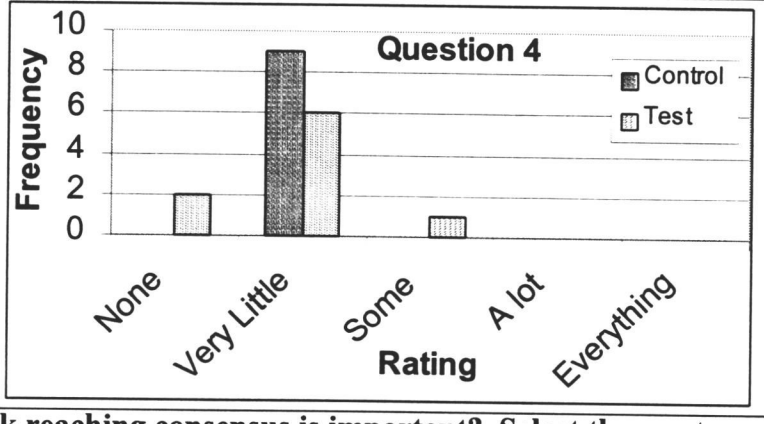
3. Did team members identify the solution criteria (requirements) of the test problem in this exercise? Select one response.

1 – None: No, not at all – we never did identify the solution criteria
2 – Very little: To some degree, but there was a lot of confusion
3 – Some: We identified some of the solution criteria, but also missed some
4 – Most of it: For the most part, we were able to identify the solution criteria
5 – All of it: Yes, the solution criteria were fully understood



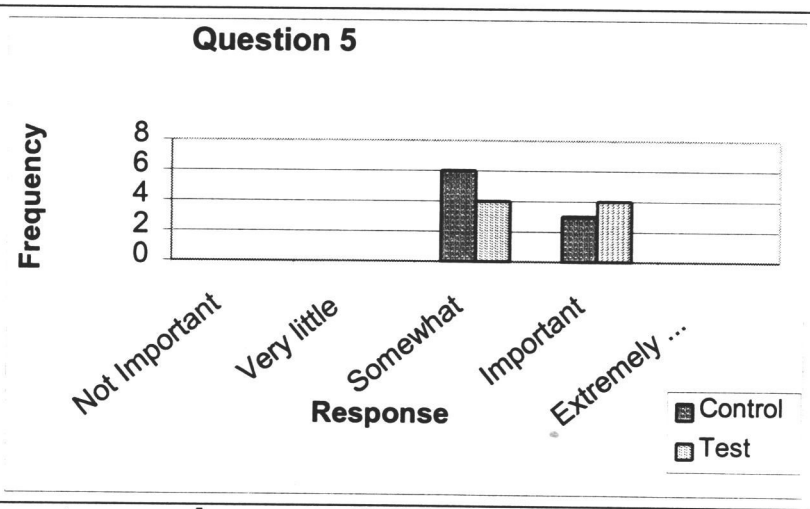
4. Was there any disagreement within your team? Select one response.

1 – None: No, we never had any disagreements at all – we agreed on everything.
2 – Very little: We would initially disagree on some issues, but after discussion would come to an agreement
3 – Some: We agreed on some issues, but disagreed on others.
4 – A lot: We disagreed on many issues.
5 – Everything had disagreement: We disagreed on virtually everything.



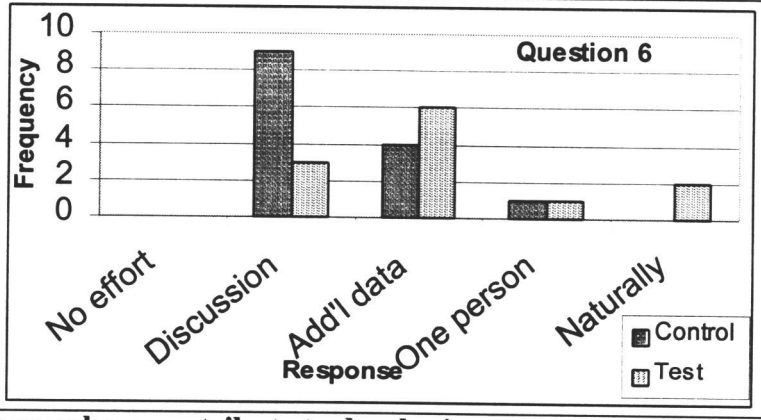
5. Do you think reaching consensus is important? Select the most appropriate response?

1 – Not important at all: Lack of consensus didn't affect our ability to solve the problem OR we had consensus on everything and I don't think it helped us solve the problem.
2 – Very little: Lack of consensus slowed us down, but did not adversely affect our ability to complete the task.
3 – Somewhat important: We thought it was important to continue to investigate questions where we lacked consensus until we had consensus.
4 – Important: Lack of consensus negatively affected our team and adversely affected our ability to complete the task even though we ultimately did complete the task.
5 – Extremely important: Disagreements prevented us from completing the task. Our decisions were based upon an averaging of team member's views which didn't really represent individual views within the team.



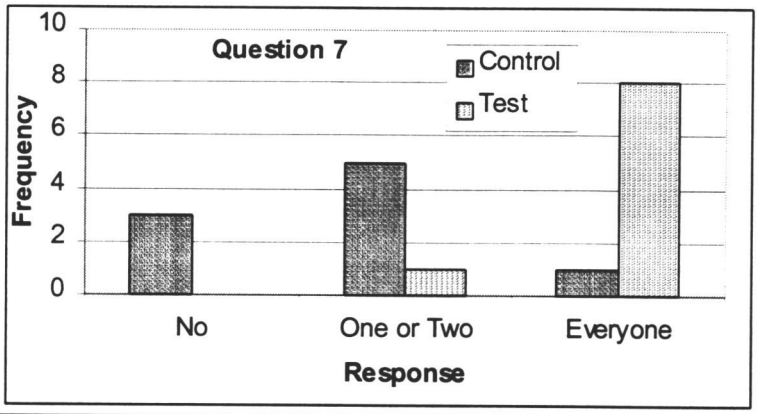
6. How did your team reach consensus? Select all that apply.

1 - No effort: We didn't. We just gave our individual opinions and let the majority rule.
2 - Discussion: We discussed ideas until we had a shared understanding and consensus.
3 - Additional Data: We sought additional information when it was clear that we were in disagreement and the additional information usually led the group to consensus.
4 - Dominance of one person: We tended to listen to one person in our group and agreed with his/her opinions.
5 - Naturally: We all agreed on everything from the beginning and as we went along.



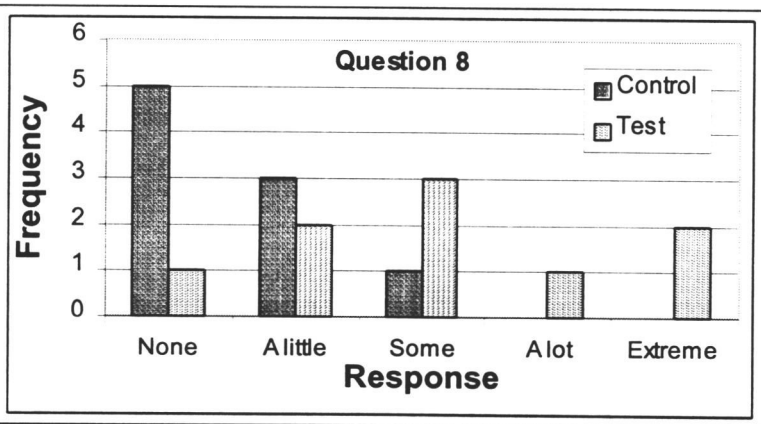
7. Did all team members contribute to developing your proposed solution (alternative) equally? Select the most appropriate response.

1 – No, one or two people made all of the suggestions on problem modeling and evaluation.
2 – Everyone contributed to some degree, but one or two people tended to dominate the suggestion/idea part of the process.
3 – Everyone contributed suggestions and ideas equally.



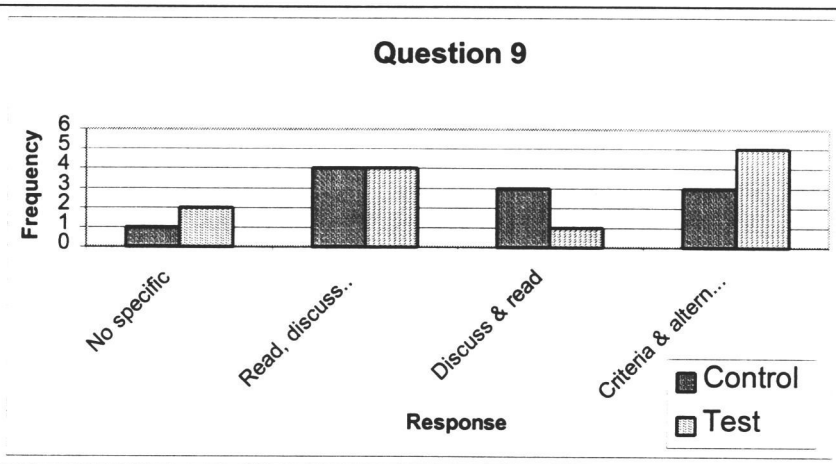
8. Did time pressure affect the selected alternative? Select the most appropriate response.

1 – None: We had more than enough time to complete the exercise.
2 – A little: We had just enough time to complete the exercise. We would have liked a little more time, but it wasn't absolutely necessary.
3 – Some: We did feel rushed, but our recommendations would not have changed with more time.
4 – A lot: We did feel rushed, and it's possible that our recommendations would have changed with more time.
5 – Extreme impact: We did not have enough time to thoroughly evaluate everything needed to make an informed recommendation. It is highly likely that additional time would have caused us to make different recommendations.

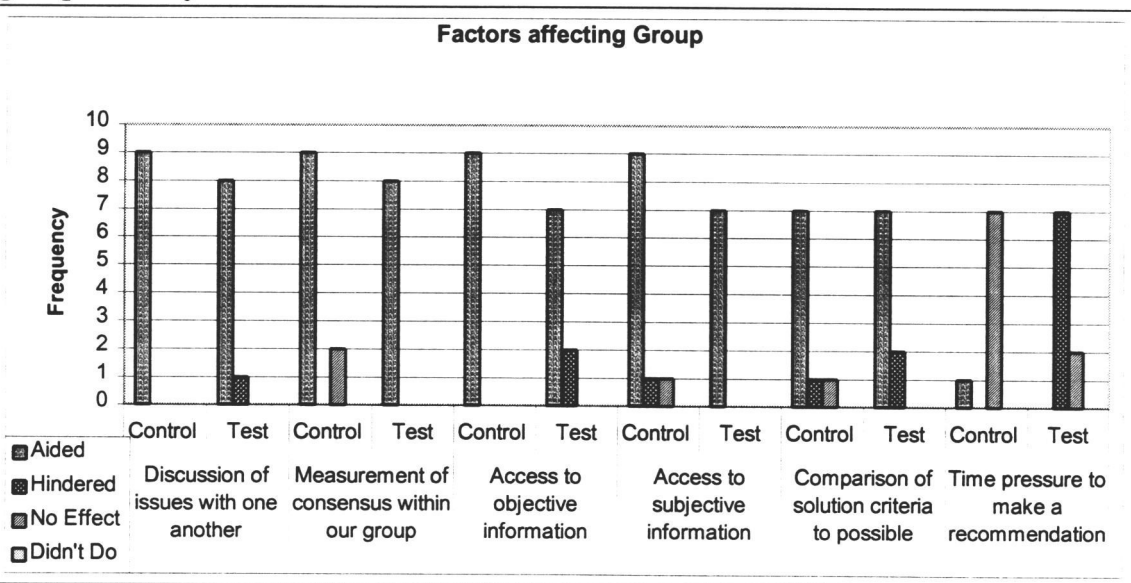


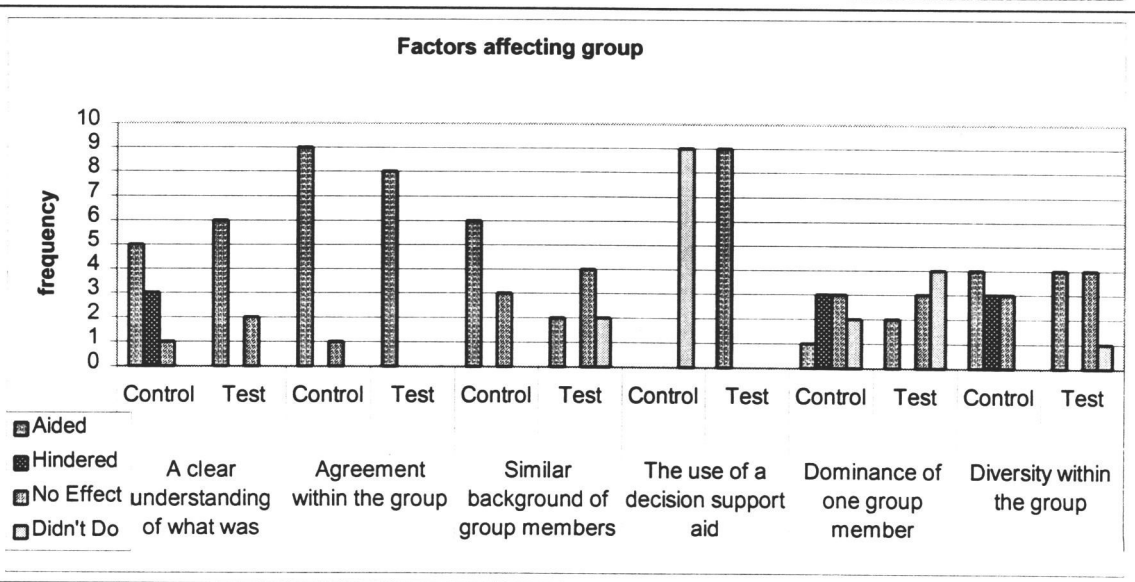
9. Describe the approach your team took to solve this problem. Select all that apply.

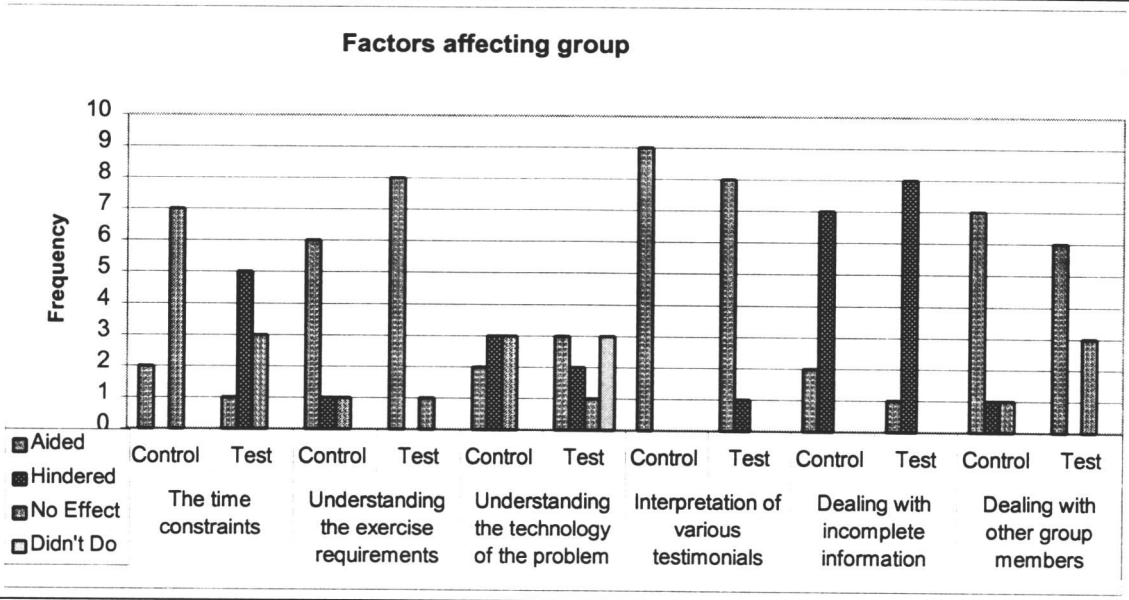
1 - We didn't use any particular approach. We just gave recommendations at the required time intervals.
2 - First we read all of the materials, discussed the options and then voted on our recommendations.
3 - We discussed the problem first and then read material as we had questions.
4 - We read the materials as needed, listed the solution criteria, brainstormed possible alternatives and discussed which alternatives best met the solution criteria.

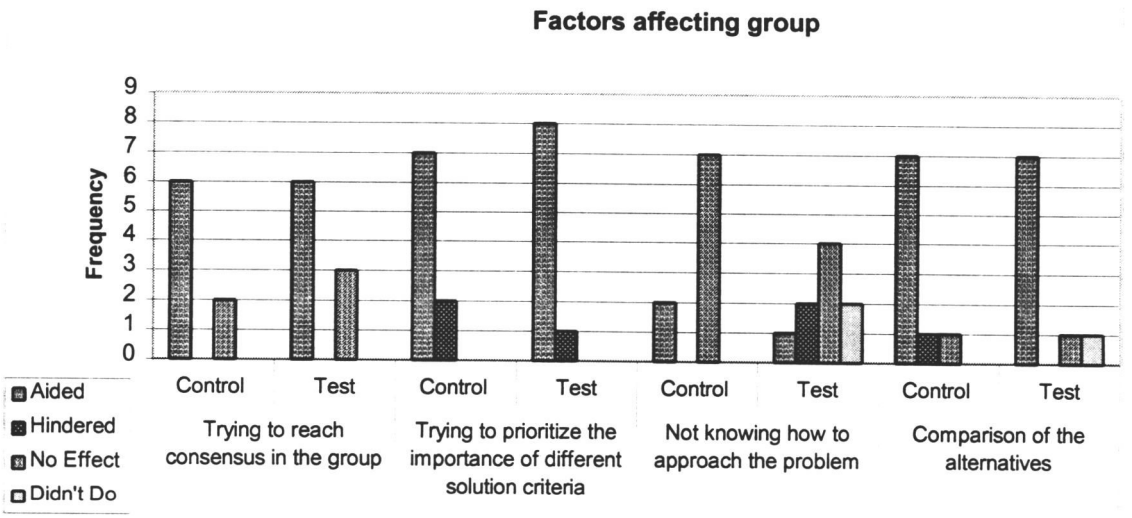


10. Indicate whether the following factors aided, hindered or had no effect on your group's ability to arrive at a selected alternative?

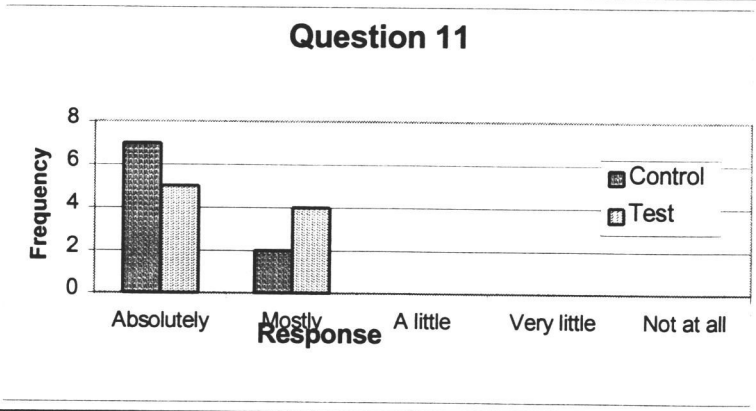




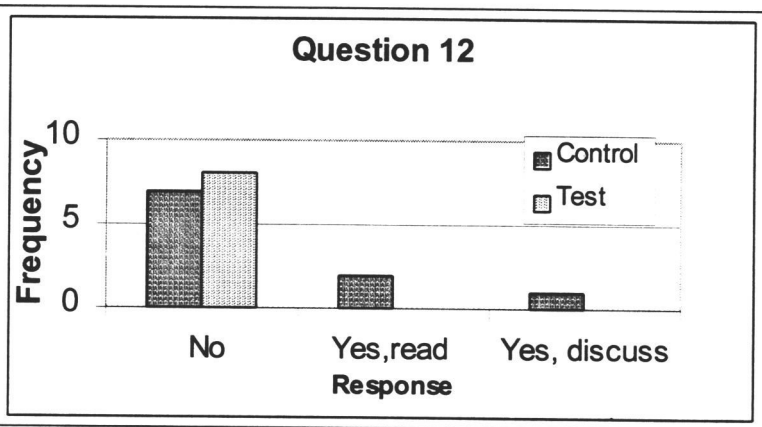




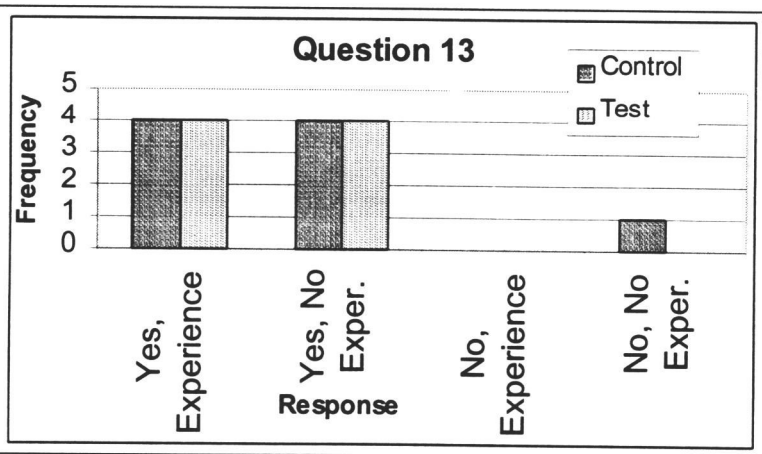
11. Did you personally agree with your group's selected alternative? Select all that apply.



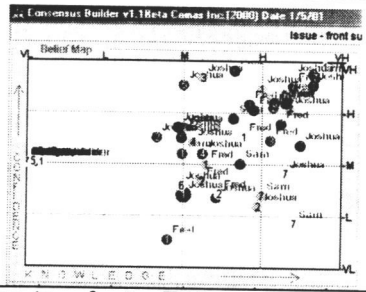
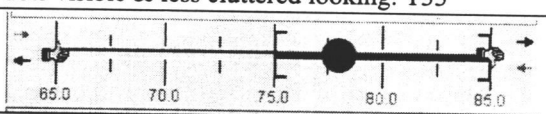
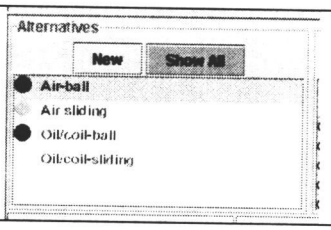
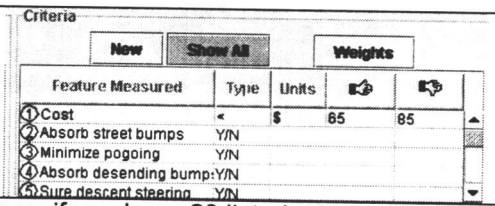
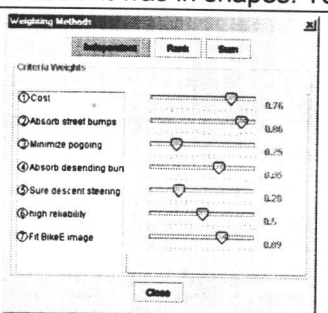
12. Did your proposed solution change over time? Select all that apply

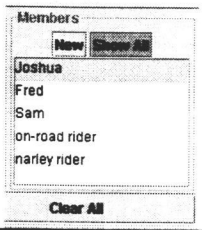
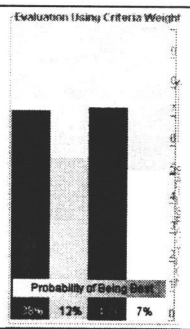
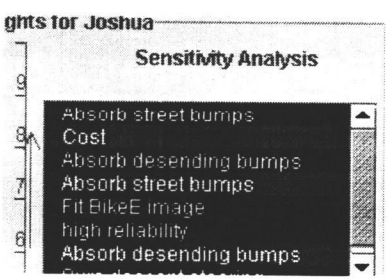


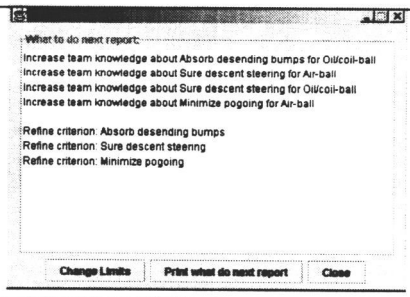
13. Do you think this exercise is similar to situations you might encounter in industry or business? Select all that apply.



APPENDIX W ConsensusBuilder Post Instruction Usability Survey Results

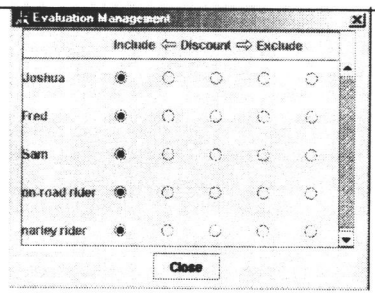
1. Rate the following *ConsensusBuilder* screen components in terms of effectiveness and list ways in which this screen component could be improved:
Belief Map Screen 
I would have a legend next to the screen to refer to. T11 Use symbol coding rather than number coding. Vertical should present the value of each criteria; delighted value, disgusted value. T21 I honestly couldn't think of how to improve it. T23 I would find a way to make most of the dots visible & less cluttered looking. T33
Belief Map Number Line 
Put a help button by it for clarity for people who don't understand how to use it. T11 This screen seems to be very clear. T33
Alternatives Screen 
This screen is fine. T33
Criteria Screen 
Maybe alternate background colors so if you have 20 listed criteria, the they would be easier to look at. T11 Instead of using #s it might be easier to read if it was in shapes. T33
Criteria Weighting Screen 
Rank did not work, I would make it work. T11 When "rank" option is selected, be able to change criteria values. T12

Remove the numbers from the right side to avoid confusion. T23 This screen seems easy to use. T33
Members Screen 
There is not much that you could do to improve this screen. T33
Satisfaction & Probability of Being Best Screen 
I would put a "frequently asked questions box " next to it that had a list of good questions. T11 Keep satisfaction and probability values separate. It's confusing to have satisfaction and probability on the same screen. T12 Show the satisfaction value at the top of each alternative. Add label alternative for each bar. T21 I wouldn't place the satisfaction & the probability of being best in the same area. I would make the satisfaction label larger on the side. T23 Put % values into another screen. T32 Change the places of the satisfaction & chances of being best. They don't mix well together – need to be separate. T33
Sensitivity Analysis Screen 
Change the color of the label to white. T21 Label better along the left side. T23 The screen is good and shows where help is needed to make a better choice. T33



What to do Next Screen

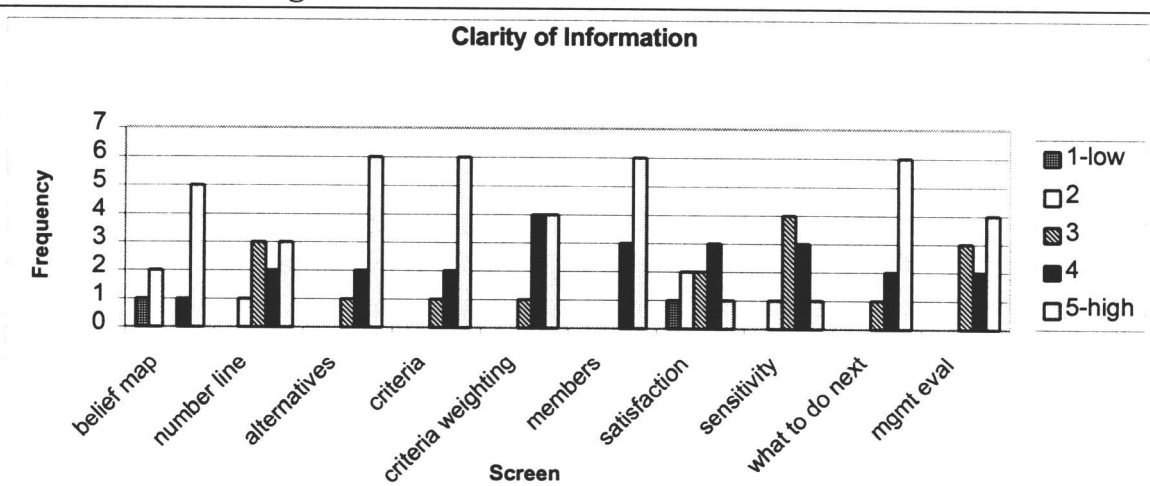
Have things listed in order of most importance that need to be done next. T11
Screen is good. T33

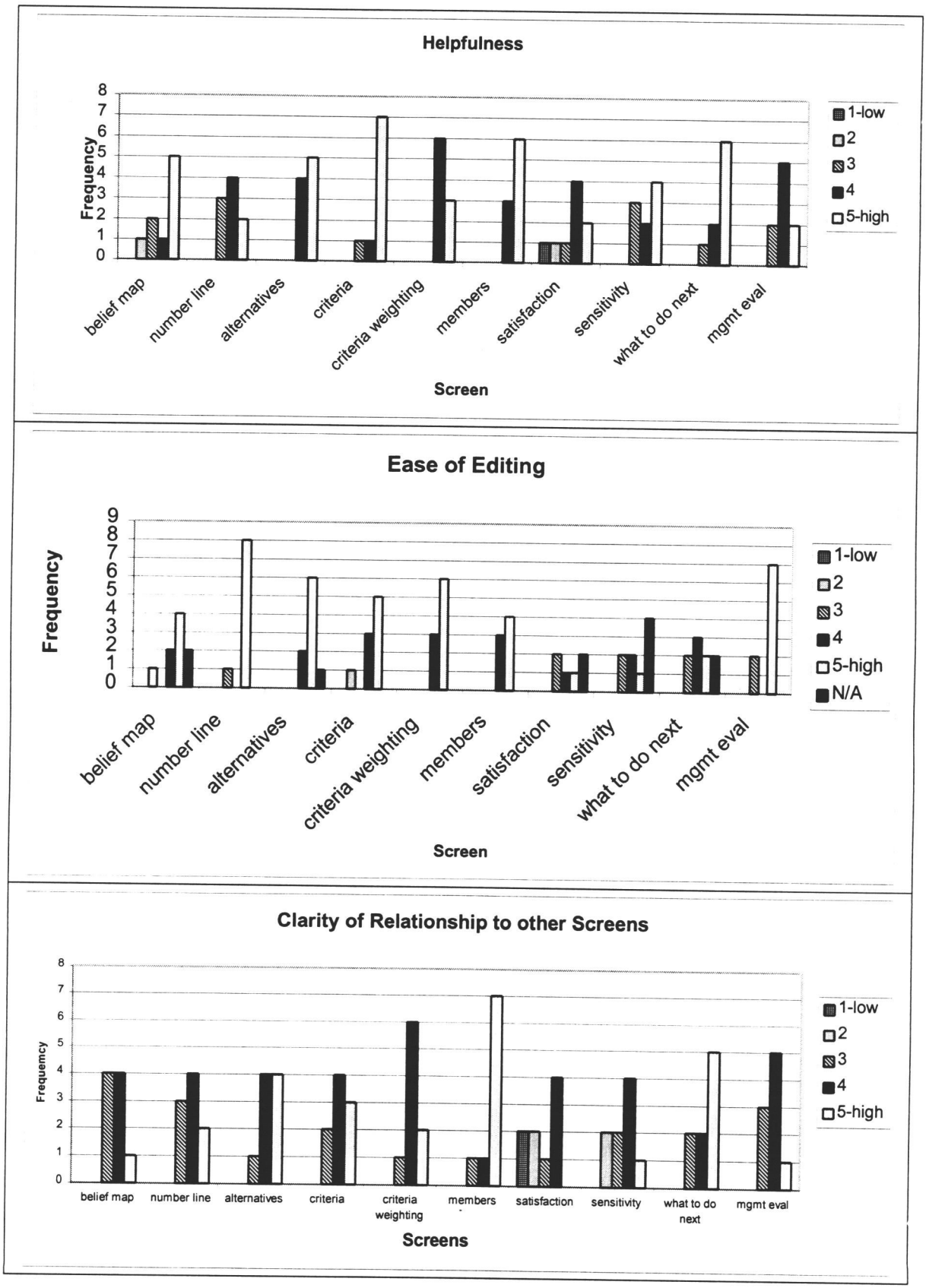


Evaluation Management Screen

Give value, weight or % for discount. T21
Label gradient from: include – discount – exclude. T23
Not really needing improvement. T33

Effectiveness Rankings:




Helpfulness
Frequency
0
1
2
3
4
5
6
7
8
belief map
number line
alternatives
criteria
criteria weighting
members
satisfaction
sensitivity
what to do next
mgmt eval
Screen
1-low
2
3
4
5-high
Ease of Editing
Frequency
0
1
2
3
4
5
6
7
8
9
belief map
number line
alternatives
criteria
criteria weighting
members
satisfaction
sensitivity
what to do next
mgmt eval
Screen
1-low
2
3
4
5-high
N/A
Clarity of Relationship to other Screens
Frequemcy
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4
5
6
7
8
belief map
number line
alternatives
criteria
criteria weighting
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satisfaction
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Screens
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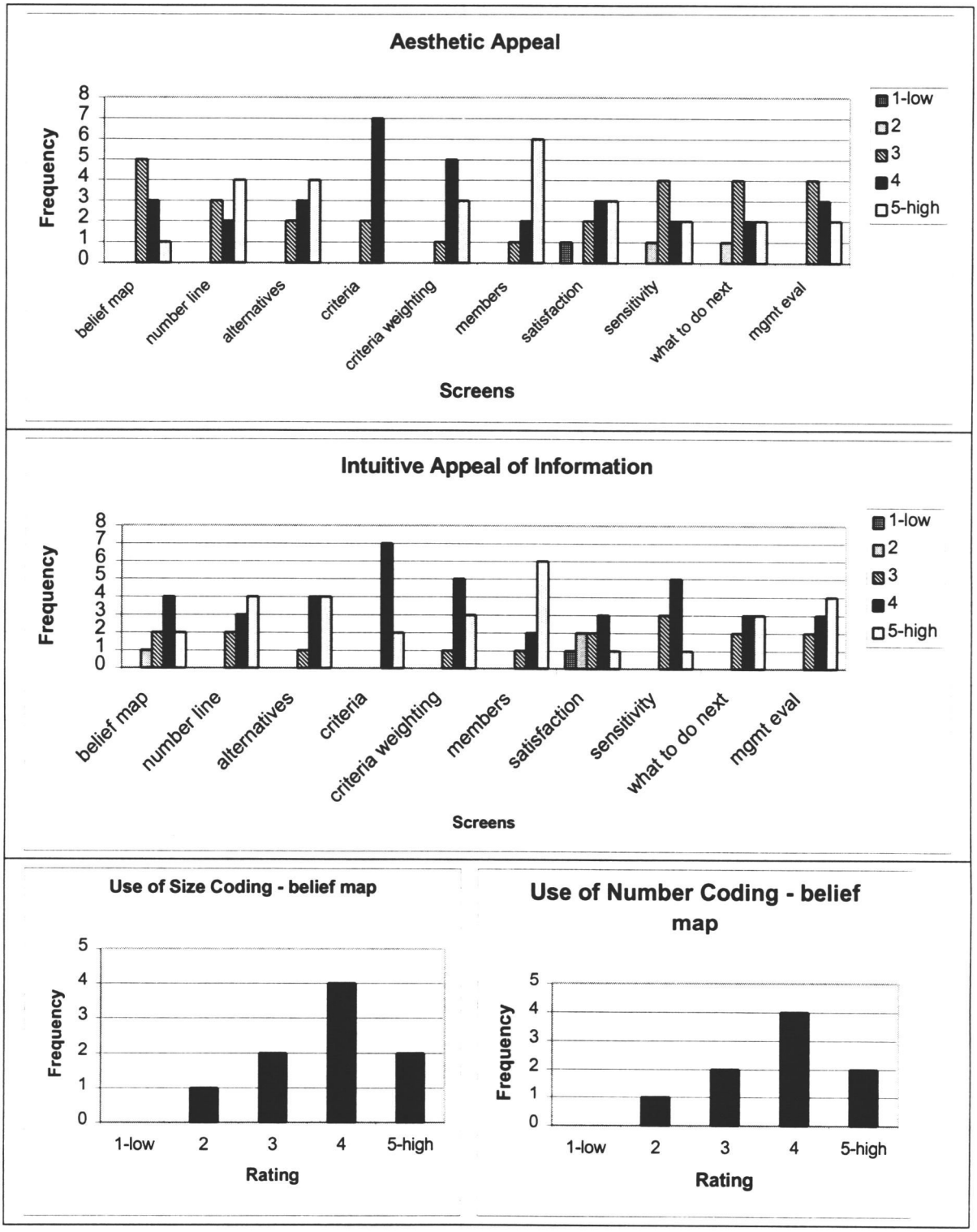
5-high


Aesthetic Appeal
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criteria
criteria weighting
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satisfaction
sensitivity
what to do next
mgmt eval
Screens
1-low
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4
5-high
Intuitive Appeal of Information
Frequency
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6
7
8
belief map
number line
alternatives
criteria
criteria weighting
members
satisfaction
sensitivity
what to do next
mgmt eval
Screens
1-low
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3
4
5-high
Use of Size Coding - belief map
Frequency
0
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4
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1-low
2
3
4
5-high
Rating
Use of Number Coding - belief map
Frequency
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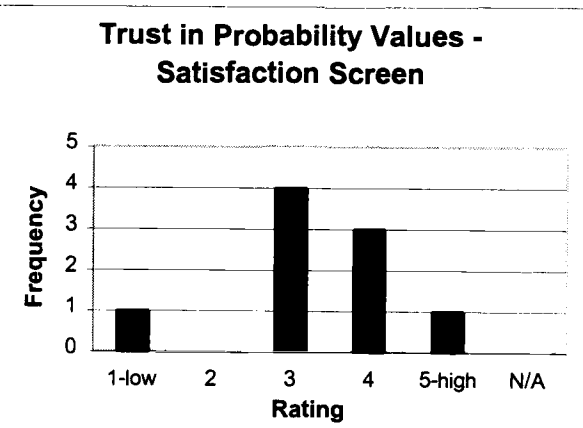
5-high
Rating



2. What portions of the instruction in the use of Consensus Builder were useful?

The "hands On" approach was most beneficial to me because I can watch people do things, but until I do it I am not sure exactly how to do it. T11
Implementing confidence and knowledge in the decision making process. T12
All. T13
Example of the problem is simple which made me understand how the software is used. T21
Having a pamphlet of power point. T22
All of the portions were helpful since I had no idea how to use it. T23
The hands-on example (entering our own data) was most useful, gut the initial explanation was a necessary foundation. T32
There needs to be more instruction to this program. T33

3. What did you like/dislike about the instruction in the use of Consensus Builder and why?

I liked the overall decision process involved in picking the alternatives. T11
It seemed confusing at first, but when I saw an example and the application I was interested. T12
Simple example given. T13
I like the instruction because it's user friendly. It is easy to use and simple in terms of how it can be applied to the problem. It can be adapted to many types of problems, which have both tangible and intangible criteria. T21
Like – the flow of instruction. Dislike – crowded colors. T22
I liked that we walked through step-by-step in how to use it. That it was projected so we could all see it easily. Also, that we each got hands on use. T23
I like the purpose of building this software, but it needs lots of improvement. T31
I thought it was effective. Having sample screens is good. It might be better if they were larger (less space for notes would be OK). T32
The program was good, but it could use a help menu. T33

4. What changes, if any, would you make to Consensus Builder to improve the effectiveness of the tool?

I would have help buttons of FAQs to help with instruction. T11
Give more examples. T12
Any use of 3D might (?) help. T13
I would improve the belief map by mapping the value of criteria with confidence axis. Also, you might try different graphs, i.e., line. T21
Need for quicker input tool. T22
I really can't think of any except for the suggestions I gave previously. T23
Don't try to keep everything on a single window. T31
Help menu? A button you could click on labeled "next step" that would send you to the logical

next step? Would this help if you didn't have the "cookbook?" T32 I would make a change on the satisfaction/probability of being best screen. T33
5. What advantages or disadvantages exist for using Consensus Builder in the decision-making process?
Advantages are making the most effective solution. Disadvantages – takes more time & money, dissatisfied people. T11 Disadvantages – can be time consuming. Advantages – very proficient in making "robust" decisions. If unreasonable people stick to their unreasonable positions and don't look at new data. T13 Simplicity and adaptability of software T21 Advantage – quick. Disadvantage – sensitivity analysis. T22 I think the advantages definitely outweigh the disadvantages. Advantage – it helps many different people come to a decision eventually, I hope. Disadvantage – some of the screens are confusing. T23 This can help a bit in making a decision. T31 I think it objectifies the process a bit, which might make resolving issues a bit less "sticky." T32 It allows people to make decisions/say opinions, without people saying what they said was wrong. T33
6. What did you like about using Consensus Builder?
I love using computers! T11 I liked the sensitivity analysis screen to go back and change data according to new information. T12 Colors, two hour learning curve. T13 User friendly, interesting to apply for complex problems and also the validity or comparison of this method with another software. T21 Ease of use. T22 That it helps a group of very different individuals make a decision together. T23 I don't know. T31 The mapping of our data was helpful. T32 It is a good program that would be a good product for companies to use. T33
7. What didn't you like about using Consensus Builder?
Didn't see Help/Use files. T13 What are the limitations? What are the assumptions behind it? T21 The price is too high for me. T22 I didn't really like the criteria weighting screen. T23 I don't know, as I don't feel the real impact of this system. T31 It wasn't very useful for me in the particular decision we chose, because my knowledge level was so low. T32 The fascia of the program seems kind of bland. T33

APPENDIX X Post Exercise ConsensusBuilder Usability Results

1. Now that you've had a chance to use ConsensusBuilder, did your impression of the tool change? Yes/No If so, how?
Yes, now that I felt like the decision of a real situation was upon me I didn't feel as confident using the program and felt rushed through the entire process. T11
No, I was originally impressed and now being able to do an example problem it was the same as when I was first introduced to it. T12
No, everything I learned in the 1st day demo was realized in the session. T13
Yes, it is simple and can be applied to solve the complex problem. The tools can be used to help the decision maker to analyze the problem faster than using manual calculations. The logic pf decision making is good. T21
No. T22
No, not much. I realized that the program is very mouse oriented. Almost everything has to be done with the mouse. T23
Yes, it's a fairly good tool, but needs to be improved. This would ease the work of the engineers. T31
Yes, I was more comfortable using it this time and it is pretty intuitive. T32
Yes, slightly. The program needs to be changed a little. Needs less clutter. T33
2. Did the use of Consensus affect your team's ability to develop your proposed solution? Yes/No Please describe.
No, we didn't have any differences with our proposed solution. We all came up with the same one and only had slight variance. T11
Yes, using CB helped us to more fully analyze the given information and weight our decisions regarding the various companies according to our confidence and knowledge level. T12
Yes, it guided us in a non-subjective manner towards a solution that was impartial in many ways. It focused us on a solution. T13
Yes, it helps in terms of calculations and decision making using all criteria and weights for criteria. It is nice to show graph and present the satisfaction value and group. Important thing is the significant information that are given, which are limited by time. T21
No. T22
Yes, I think it helped in a positive way. We got to discuss things, but then we each got our turn at the computer to input our thoughts & opinions without the other group member's opinions. T23
Yes, we got a lot of insight into our initial proposed solution. T31
Yes, it was a good basis for more extended discussions. T32
No, we decided on the same company as we did without CB. CB only encouraged us to pick the product with more confidence. T33
3. Did the use of ConsensusBuilder affect your team's ability to arrive at consensus? Yes/No Please describe.
No, we arrived at the same consensus in the time allowed and seemed to be extremely accurate. T11
No, because while we discussed our opinions and evidence, we already seemed to be at consensus. T12
Yes, it gave us numerical feedback based on data we input. T13
No, we got the information that was enough to analyze and using CB is simple. It doesn't affect our ability to arrive at consensus. T21
No. T22
Yes, I think it helped us organize our thoughts & decide what is most important. It made it easier to come to a decision. T23
Yes, it helped us to make sure that our initial alternatives were the best. T31
Yes, it identified specific areas in which we had a low % of consensus, which allowed us to focus our discussion. T32

No, the team actually was easy going. We were pretty much in consensus the whole time. T33
4. Do you think your impression of ConsensusBuilder would change as you used the tool more? Yes/No Please describe.
Yes, the more familiar I would get using ConsensusBuilder I would have more confidence with using it and more confidence in its results. T11 Yes, I think at least two or more trials would be necessary to determine the usefulness of it. T12 Yes, more use would allow more understanding about the importance of my data entry. T13 Yes, in some complex problems, but not for simple problems. It's good to solve complex problems in limited time. No, might not result in the final solutions after making comparisons. T21 Yes, it will be more clear. T22 Yes, with anything, the more you do it, the more familiar you become with it & you figure out what you like & dislike. T23 Hmmm... I don't know. I think I had enough of it. T31 Yes, I think I would analyze data more quantitatively earlier in the process as I had more experience being required to enter values. For example, if I were starting this evening's process again, I would have developed a grid more quickly and entered more data. T32 Yes, I am sure that my opinion might change after I got familiar with the tool more. T33
5. Would you use ConsensusBuilder as a group decision-making aid if it was available to you? Yes/No Why or why not?
Yes, if I was familiar with the program or was working (making a decision) with someone who was then I would definitely use it. It would be pointless to use this program if no one knew how to use it properly. T11 Yes, I would use CB only if I could explain its functionality in a simplified manner. It seemed a little confusing at first, but when I was getting used to the operations and data inputs, it became easier to use. T12 Yes, it would most surely aid in rating gaps in set-criteria comparison data entry and what to do for the 'next' step. T13 Yes, if I were the decision maker I would consider CB as one of the tools for solving problems. T21 Yes, it is a great "smooth" talker and very "diplomatic." T22 Yes, because there are times when it is so hard to come to a decision whether it be because of the people or just the situation. I feel that CB would help so much. T23 Yes, as it makes work easier. T31 Yes, I think it would be helpful in focusing discussion, clarifying issues and avoiding "talking past" each other. T32 Yes, this is a very good tool to use. The only problem is that it is time consuming to get everyone's information put into the computer. T33
6. What changes, if any, would you make to ConsensusBuilder to make it a more effective tool?
I would have more help sections and FAQs. Having help sections would help troubleshoot problems and results of ConsensusBuilder. T11 I would separate the bar graph with probability and satisfaction levels. T12 Help menus. As far as the present software – can't think of any changes I'd make. T13 In the results of CB we can see the comparison of all alternatives for each decision maker. However, it would be nice to show all of these groups on the same screen, i.e. in a pareto diagram. T21 Speed and data input. T22 I really am not sure. T23 I would like to see lots of "statistical analysis" tools. T31 The one major thing that I think I would do is make the "confidence/knowledge" screen more progressive. Once you put information onto the screen then you could use it to compare & to make your decisions on the other products. T33

APPENDIX Y CGDSA Study Data. Assessment of the ConsensusBuilder Evaluation and several MAUT Evaluations found in the literature in terms of the General Methodology for the Evaluation of CGDSAs

CGDSA STUDY DATA (using the Generalized Methodology for the Evaluation of CGDSAs from Table 5.2.)	
Key CB = Consensus Builder study Study 1 = study described in section 5.2.1 Study 2 = study described in section 5.2.2 Study 3 = study described in section 5.2.3 Study 4 = study described in section 5.2.4 Study 5 = study described in section 5.2.5 Study 6 – study described in section 5.2.6	i = internal variable e = external variable p = process variable b = problem variable u = usability item c = practical consideration item
Techniques used: (D = experimental design, S = survey, O = observation, E = expert assessment)	
	Internal Variables – group member associated parameters
1i	**Variation in domain experience within the group** CB: S – participants were asked about their printed circuit experience & no participants had any experience Study 1: D – participants chose a problem of personal importance so all participants had domain experience with the problem Study 2: D – domain specific for all participants – arts & mass media; variation unknown Study 3: unknown/not reported Study 4: unknown/not reported Study 5: D – domain specific for all participants – financial analysis; variation unknown Study 6: unknown/not reported
2i	**Variation in education within the group** CB: S – established with participant survey – all college level – undergraduate to post-graduate Study 1: S – established with participant survey – all undergraduate students Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: known that participants are students, but not education level
3i	**Authority level mix within the group** CB: S – established with participant survey – one participant in test group #1 was a professor and one participant in test group #3 was a university employee; by design no participant was given more authority than any other participant Study 1: D – all participants were undergraduate students; authority level unknown Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported

4i	**Group size** CB: D – 3 control groups & 3 test groups with 3 subjects in each group Study 1: D – 35 subjects divided into 2 groups Study 2: D – four groups of subjects with 3,5,6 & 8 in each group respectively Study 3: D – one group of 40 subjects Study 4: D – three groups of unknown size Study 5: unknown/not reported Study 6: unknown/not reported
5i	**Team dynamics training and/or experience** CB: S – established with self-report on participant surveys; very little or no formal training for all subjects Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
6i	**Prior history of working with group members** CB: unknown Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
7i	**Diversity mix (gender, race, age, values)** CB: S – gender, age & race established with self-report on participant surveys & observation; most subjects were in the age range of 19 – 26 years old with two exceptions – participant in test group #1 – professor, and participant in test group #3 – university employee; mix of male & female in all groups; participants were a mix of Caucasian, Chinese and Thai Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
8i	**Personality Mix** CB: S – S - mix in all groups according to change and problem solving behavior inventories Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
9i	**Individual & Group Biases** CB: O – tendency for groupthink and anchoring seen in both control and test groups. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported

10i	**Dominance of one or more group members** CB: O – observed in Control Group 2 and Test Group 3 Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
11i	**Degree of consensus reached by the group** CB: O – agreement on preferred alternative by all group members in all groups Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
12i	**Level of individual problem understanding** CB: O – all subjects appeared to understand the problem in all groups Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
13i	**Ability of the group to break the problem into components** CB: O – all subjects in all groups discussed problem in terms of criteria Study 1: unknown/not reported Study 2: O - reported discussion of attribute dimensions Study 3: O - reported clarification of the decision problem Study 4: O - reported more attributes considered for counselor- and computer-supported decision making Study 5: unknown/not reported Study 6: unknown/not reported
	External Variables – influences imposed upon group members
1e	**Authority figure support** CB: D – subjects were made aware that task completion was supported by the researcher Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
2e	**Perceived importance by authority figures** CB: D - subjects were made aware that the task was important to the researcher Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6:

3e	**Time constraints** CB: D – Maximum time for the control group was 90 min. & 120 min. for the test group Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
4e	**Authority figure expectations** CB: D – No expectation for a particular solution were given to the subjects. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
5e	**Resource constraints – money, experts...** CB: D – Resources were limited by what was immediately available to the subjects during testing. Study 1: D – Limited by what was immediately available to the subjects during testing. Study 2: D – Limited by what was immediately available to the subjects during testing. Study 3: D – Limited by what was immediately available to the subjects during testing. Study 4: D – Limited by what was immediately available to the subjects during testing. Study 5: D – Limited by what was immediately available to the subjects during testing. Study 6: D – Limited by what was immediately available to the subjects during testing.
6e	**Historical decision-making approaches used by organization** CB: S – asked subjects about their previous decision-making training & experiences; very limited for all subjects except for one subject in Test Group 1 Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
	Process Variables – variables associated with the problem-solving process
1p	**Formal methodology (problem clarification, criteria identification, alternative generation)** CB: D,O – no methodology given to control group; methodology inherent in CB for test group Study 1: D - formal methodology for both groups – MAUD3 & human decision analyst Study 2: D - formal methodology (MAUD) available to the group Study 3: D - formal methodology (MAUD) available to the group Study 4: D - no methodology given to control group; methodology given to the test group Study 5: D - available to groups using computerized aid & with formal decision support aid training Study 6: D - available to test group the computerized decision support aid; not the control group
2p	**Information availability** CB: D – limited by the information provided to the subjects during the testing Study 1: unlimited due to time span of 1 week between session 1 and session 2 Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: D - test group had more information available than the control group Study 6: unknown/not reported

3p	**Information consistency** CB: D –information containing inconsistencies was supplied to the subjects by the researcher Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
4p	**Perceived value of information** CB: O – Subjects tended to value testimonial information more than vendor reported information. Very little attention was paid to subject matter information. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
5p	**Information complexity** CB: D – testing information was not complex & supplied in 3 forms: testimonials, vendor information, process information Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
6p	**Decision making process documentation** CB: D - CB user information was given verbally & in as a handout Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
7p	**Preference determination - method reliability** CB: D – An algorithm internal to the CB program was used to determine "probability of being best" given subject's self assessment of knowledge level, criteria weighing and alternative preference in light of criteria. Reliability of the method was not known. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
8p	**Methodology/problem type alignment** CB: O – A test problem in alignment with CB capabilities was selected for testing. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported

9p	**Guidance on where to concentrate efforts** CB: O – A CB feature directed subjects where to direct their efforts once an initial probability of being best determination was made. Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
10p	**Time to generate a solution** CB: D,O – total time to complete the task was measured Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: O - total time needed to analyze the decision problem was measured Study 5: O - total time needed for decision making was measured Study 6: unknown/not reported
11p	**Time spent researching the problem** CB: O – time spent clarifying the problem was measured Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: time measured was not split into different tasks Study 5: time measured was not split into different tasks Study 6: unknown/not reported
12p	**Number of alternatives considered & time spent generating them** CB: D – the number of alternatives (4) was pre-determined by the experimental design Study 1:D - subjects were told to generate 4 alternatives Study 2: unknown/not reported Study 3: unknown/not reported Study 4: time measured was not split into different tasks Study 5: O - number of alternatives generated was measured Study 6: unknown/not reported
13p	**Time spent assessing the alternatives** CB: O – time spent analyzing alternatives was measured Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: O - time measured was not split into different tasks Study 5: O - time measured was not split into different tasks Study 6: unknown/not reported
14p	**Time spent on criteria development** CB: O – time spent developing criteria was measured Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: O - time measured was not split into different tasks Study 6: unknown/not reported

15p	**Number of criteria considered** CB: O – number of criteria considered was measured Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: O - number of attributes (criteria) was measured Study 5: unknown/not reported Study 6: unknown/not reported
	Problem Variables – variables associated with the test problem & its alternatives
1b	**Problem type** CB: D – problem type was ill-structured, knowledge based decision making Study 1: unknown/not reported Study 2: unknown/not reported (problems in the arts and mass media) Study 3: unknown/not reported Study 4: unknown/not reported Study 5: D - ill-structured business decision problem Study 6: unknown/not reported
2b	**Domain neutrality** CB: D – the test problem was not domain neutral – it involved printed circuit board electroplating Study 1: D – not domain neutral – individual personal problems Study 2: D – not domain neutral – arts and mass media Study 3: D – not domain neutral – examples included choosing a job or an education Study 4: unknown/not reported Study 5: D – not domain neutral – business decision problem Study 6: unknown/not reported
3b	**Information requirements** CB: D – information limited by what was supplied to the subjects Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: more information given to one group, but amount not given Study 6: unknown/not reported
4b	**Problem Complexity** CB: D – problem had multiple considerations & was ill-structured, but not overly complex Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
5b	**Prevalence of value-based issues** CB: D – no obvious value-based issues present Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported

6b	**Degree to which criteria are met by the preferred alternative** CB: O – rated by individual subjects as part of using the software Study 1: S - rated by individual subjects Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
7b	**Was the correct problem solved?** CB: O – subjects in all groups solved the correct problem Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
8b	**Perceived solution quality by a panel of experts** CB: E – solution quality was assessed as acceptable, but not outstanding by the researcher Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: independent raters judged the problem solution quality
9b	**Comparison of solution quality to the unsupported decision making process or other CGDSAs** CB: D – CB was compared to unsupported decision making Study 1: D – MAUD3 was compared to a human decision analyst Study 2: D – no comparison to unsupported decision making or to another CGDSA Study 3: D – no comparison to unsupported decision making or to another CGDSA Study 4: D – CGDSA compared to a trained counselor and to unsupported decision making Study 5: D – CGDSA availability, CGDSA training, and information availability were compared Study 6: D – CGDSA was compared to unsupported decision making
	GDSA USABILITY
1u	**Perceived usefulness of the tool** CB: S – subjects were asked about perceived usefulness after CB training and after testing completion Study 1: S – asked to judge usefulness of MAUD3 versus the human decision analyst Study 2: S – asked about their satisfaction with the process Study 3: S – asked about perceived usefulness of the tool Study 4: S – asked about their satisfaction with the procedure Study 5: S – subjects were asked about their confidence in their decision Study 6:S - subjects were asked about their attitudes toward the CDSA

2u	**Confidence in the approach** CB: S – subjects were asked to rank their confidence in CB algorithms – not all subjects were fully confident in the approach Study 1: S – subjects were asked about their confidence in the results Study 2: not asked Study 3: not asked Study 4: S – subjects were asked about their acceptance of the decision-analytic method Study 5: S – subjects were asked about their confidence in the decision Study 6: not asked
3u	**Requirement for training & training effectiveness** CB: E,S – trained was viewed as essential and offered to the subjects using the CGDSA; subjects were asked questions about training effectiveness Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
4u	**Ease of use** CB: S – subjects were asked questions about ease of use Study 1: unknown/not reported Study 2: unknown/not reported Study 3: S – subjects were asked questions about ease of use Study 4: S – subjects were asked about experienced difficulty of the procedure Study 5: unknown/not reported Study 6: unknown/not reported
5u	**Help screens** CB: O – no help screens available with CB Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
6u	**Access to procedural guidance** CB: O – subjects had the training handout available during testing Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
7u	**Computer screen characteristics: clarity of information, helpfulness of screen component, ease of editing, clarity of relationship to other screen components, aesthetic appeal, intuitive appeal of the information, use of color, number or size coding** CB: S – subjects were asked about computer screen characteristics as part of a usability survey Study 1: unknown/not reported Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported

EVALUATION METHOD PRACTICAL USE CONSIDERATIONS	
1c	**Length of time required to complete an evaluation should be short.** CB: D – total time was 27 hours of experimental time over a 3 week time period Study 1: 2 sessions over a 1 week time span Study 2: unknown/not reported Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
2c	**Number of individuals required to complete the evaluation should be few** CB: 18 subjects Study 1: 35 subjects Study 2: 24 subjects Study 3: 40 subjects Study 4: unknown/not reported (3 groups) Study 5: unknown/not reported Study 6: unknown/not reported
3c	**Should be able to observe the overall decision making process** CB: entire process was videotaped Study 1: unknown/not reported Study 2: unknown/not reported Study 3: behavior observation data existed Study 4: unknown/not reported Study 5: unknown/not reported Study 6: unknown/not reported
4c	**Evaluation test problem should be similar to real problems for which the software will be used** CB: subjects were asked whether they thought the problem represented a real world problem Study 1: subjects selected problems of personal importance Study 2: most likely similar – problems in the arts & mass media Study 3: unknown/not reported Study 4: unknown/not reported Study 5: unknown/not reported – financial analysis problem Study 6: unknown/not reported

APPENDIX Z CGDSA Effectiveness – ability to transform, affect or assess control & noise variables

Key	i = internal variable
CB = Consensus Builder study	e = external variable
S1 = study described in section 5.2.1	p = process variable
S2 = study described in section 5.2.2	b = problem variable
S3 = study described in section 5.2.3	u = usability item
S4 = study described in section 5.2.4	c = practical consideration item
S5 = study described in section 5.2.5	N/A = not applicable
S6 – study described in section 5.2.6	N = noise variable
Before = prior to use of the CGDSA	C = control variable CD = control via CGDSA
After = after/during use of the CGDSA	M = measured variable MD = mea. by the CGDSA
Techniques used: (D = experimental design, S = survey, O = observation, E = expert assessment)	

		CB	S1	S2	S3	S4	S5	S6
1i - Variation in domain experience within the group	Before	N	N	N	N	N	N	N
	After	M	C	C	C	C	C	C
2i - Variation in education within the group	Before	N	N	N	N	N	N	N
	After	C	C	N	N	N	N	N
3i - Authority level mix within the group	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
4i - Group size	Before	N	N	N	N	N	N	N
	After	C	C	C	C	C	C	C
5i - Team dynamics training and/or experience	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
6i - Prior history of working with group members	Before	N	N	N	N	N	N	N
	After	N	N	N	N	N	N	N
7i - Diversity mix (gender, race, age, values)	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
8i - Personality Mix	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
9i - Individual & Group Biases	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
10i - Dominance of one or more group members	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
11i - Degree of consensus reached by the group	Before	N	N	N	N	N	N	N
	After	MD	N	N	N	N	N	N
12i - Level of individual problem understanding	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
13i - Ability of the group to break the problem into components	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
1e - Authority figure support	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
2e - Perceived importance by authority figures	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
3e – Time constraints	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
4e - Authority figure expectations	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
5e - Resource constraints – money, experts...	Before	N	N	N	N	N	N	N
	After	C	C	C	C	C	C	C
6e - Historical decision-making approaches used	Before	N	N	N	N	N	N	N

by organization	After	M	N	N	N	N	N	N
1p - Formal methodology (problem clarification, criteria identification, alternative generation)	Before	N	N	N	N	N	N	N
	After	CD	C	C	C	C	N	N
2p - Information availability	Before	N	N	N	N	N	N	N
	After	C	N	N	N	C	N	N
3p - Information consistency	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
4p - Perceived value of information	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
5p - Information complexity	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
6p - Decision making process documentation	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
7p - Preference determination - method reliability	Before	N	N	N	N	N	N	N
	After	N	N	N	N	N	N	N
8p - Methodology/problem type alignment	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
9p - Guidance on where to concentrate efforts	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
10p - Time to generate a solution	Before	N	N	N	N	N	N	N
	After	M	N	N	N	M	M	N
11p - Time spent researching the problem	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
12p - Number of alternatives considered & time spent generating them	Before	N	N	N	N	N	N	N
	After	MD	C	N	N	N	M	N
13p - Time spent assessing the alternatives	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
14p - Time spent on criteria development	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	N
15p - Number of criteria considered	Before	N	N	N	N	N	N	N
	After	MD	N	N	N	M	N	N
1b - Problem type	Before	N	N	N	N	N	N	N
	After	C	C	C	N	N	C	N
2b - Domain neutrality	Before	N	N	N	N	N	N	N
	After	C	N	C	N	N	C	N
3b – Information requirements	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	C	N
4b – Problem complexity	Before	N	N	N	N	N	N	N
	After	C	N	C	C	C	C	C
5b - Prevalence of value-based issues	Before	N	N	N	N	N	N	N
	After	C	N	N	N	N	N	N
6b - Degree to which criteria are met by the preferred alternative	Before	N	N	N	N	N	N	N
	After	MD	N	N	N	N	N	N
7b – Was the correct problem solved?	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
8b – Perceived solution quality by a panel of experts	Before	N	N	N	N	N	N	N
	After	M	N	N	N	N	N	M
9b - Comparison of solution quality to the unsupported decision making process or other CGDSAs	Before	N	N	N	N	N	N	N
	After	C	C	C	C	C	C	C
1u - Perceived usefulness of the tool	Before	N	N	N	N	N	N	N

	After	M	M	M	M	M	M	M
2u – Confidence in the approach	Before	N	N	N	N	N	N	N
	After	M	M	N	N	M	M	N
3u - Requirement for training & training effectiveness	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
4u – Ease of use	Before	N	N	N	N	N	N	N
	After	M	N	N	M	M	N	N
5u –Help screens	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
6u - Access to procedural guidance	Before	N	N	N	N	N	N	N
	After	CD	N	N	N	N	N	N
7u - Computer screen characteristics	Before	N	N	N	N	N	N	N
	After	MD	N	N	N	N	N	N
1c - Length of time required to complete an evaluation should be short	Before	N	N	N	N	N	N	N
	After	C	C	N	N	N	N	N
2c - Number of individuals required to complete the evaluation should be few	Before	N	N	N	N	N	N	N
	After	C	C	C	C	C	C	C
3c – Should be able to observe the overall decision making process	Before	N	N	N	N	N	N	N
	After	C	N	N	C	N	N	N
4c - Evaluation test problem should be similar to real problems for which the software will be used	Before	N	N	N	N	N	N	N
	After	C	C	C	N	N	C	N

APPENDIX AA Raw Video-tape Data

Control 1 Time	clarifying problem	developing criteria	analyzing alternatives	Comments/Discussion Topic
30	X	X		Plating current density for capacity
32		X	X	cost & line width of different vendors
34		X	X	capacity
36		X	X	cost of initial make-up, testimonials
38		X	X	technical support, costs
40		X	X	quality of plate, 1st decision – Bernie's – cost & support
42			X	eliminate Universal – can't expand capacity
44		X	X	availability
46			X	**1st – Bernie's** – cost & 24 hour support
48	X			Revisit problem sheet A – discuss plating process
50	X		X	maintenance costs, plating process
52			X	Bernie's vs. PCB – maintenance costs insignificant
54		X		plating speed, aspect ratio 6:1 OK
56	X			calculations – plating thickness
58	X			plating thickness, aspect ratio
1:00	X			Silence – looking through materials, information review
1:02	X			testimonials – problem with one lot of product
1:04		X	X	quality, cost, support, reputation ,delivery, Mil specs
1:06	X	X		defects, sheet H, brightener – what is better?
1:08	X			surface finish & brightener
1:10			X	PCB – shiny finish, corrosion resistance give best quality
1:12			X	brochures – should we trust these?
1:14	X		X	should we stick to Bernie's? conflicts in testimonials
1:16			X	trying to justify original choice of Bernie's
1:18		X		any other criteria to consider? Reasons for Bernie's
1:20			X	reasons for Bernie's: make-up costs & delivery " We're making a lot of assumptions here – board size, production, maintenance cost basis, new solution cost greater than maintenance costs"
1:22		X		capacity; sheet F
1:24			X	capacity calculations
1:26				silence
1:28			X	maintenance cost calculations
1:30	**BERNIE"S** – can fulfill everything discussed in testimonials, can always switch to PCB later if delivery is a problem, best for future capacity expansion			

1 – 30 min. Observation: reviewed materials & took notes individually – no discussion; primarily compared & contrasted vendor brochures; handout F reviewed

Criteria: (discussed) cost, delivery, plating capacity, technical support, years in business, availability, line width, aspect ratio, vendor reputation, surface finish, ability to upgrade

General Observations: no consideration of customer, no apparent problem solving method used, no ranking of criteria, discussion of many criteria – but only used costs, delivery & expansion to make decision, all participated

Control 2 Time	clarifying problem	developing criteria	analyzing alternatives	Comments/Discussion Topic
30	X	X	X	define ASF – higher is better? PCB – good quality, too expensive
32		X	X	PCB – poor support, eliminate PCB, Bemie's?, make-up vs. maintenance costs?
34		X	X	PCB – poor tech. support, best quality? – don't know, Universal quality varies
36			X	Universal tech. support is good, quality not great, cost OK
38		X	X	written matrix – vendors vs. cost, quality, support, delivery
40		X		weighting & ranking criteria (rank: 4=good, 1 = bad), PCB – no, Universal – no, therefore Global or Bemie's
42		X	X	Global – no costs listed – assume expensive? Tech. support not important
44			X	Bemie's – delivery problems, process eng. mgr. likes Global
46			X	**1st choice – Global** – PCB has problems, Bemie's – delivery problems, Universal – eng. mgr. doesn't like
48		X		What other criteria should we consider?? quality & cost most important
50			X	costs for all vendors compared – assign ratings to each
52			X	quality & technical support ratings
54			X	delivery ratings, PCB- delivery problems
56			X	delivery ratings
58		X	X	cost & quality – both important, Universal or Global is best – equal scores
1:00			X	delivery? if not considered, then Global is best
1:02			X	cost favors Universal, but lower quality, therefore go for Global
GLOBAL – used weightings and ratings for cost, quality, technical support & delivery to get highest score				
1 – 30 min. Observation: reviewed all handouts (25 min.) and brochures (5 min.) individually – no discussion, no notes taken Criteria: (discussed) make up costs, maintenance costs, technical support, quality & delivery General Observations: did not understand the significance of maintenance costs, criteria were weighted & rated to arrive at a decision, no in-depth look at what constituted good quality, participation primarily by two group members				

Control 3 Time	clarifying problem	developing criteria	analyzing alternatives	Comments/Discussion Topic
30	X			mils vs. microns? calculations on plating speed
32		X	X	plating speed for each vendor, ASF?, Universal is faster
34		X	X	costs for each vendor; tech support – how important is it?
36		X	X	delivery more important than reputation, Bernie's best?
38		X	X	use of matrix – ranking & rating criteria
40			X	silence – writing out matrix – quality (5), cost (4), tech. support (3)
42			X	reputation (2), delivery (1) - ranking
44			X	longevity is part of quality, continue rating each vendor
46			X	**Bernie's** – cheaper, tech. support, fast plate, quality
48			X	continuation of matrix, reviewing testimonials
50			X	continuation of matrix, quality based on testimonials
52			X	PCB worst delivery, Bernie's - slow
54			X	Global – reputation is good (no complaints), calculate results
56			X	calculation of matrix results – Global & Universal equal
58			X	Universal is better – lower costs, quality OK, technical support, reliable, on-time delivery, reputation unknown – but not that important
1:00			X	Does everyone agree? yes
UNIVERSAL – matrix results (weighted & ranked) tie with Global, lower costs, quality OK, on time delivery, reputation not known – but not that important				
1 – 30 min. Observation: reviewed all handouts & brochures individually – no discussion, took notes Criteria: quality, cost, technical support, reputation, delivery General Observations: somewhat unsure how to define quality, criteria were weighted & ranked to arrive at a decision				

Test 1 Time	clarifying problem	developing criteria	analyzing alternatives	Comments/Discussion Topic
30	X			hole ratios, tank capacity, current required for ½ ounce copper
32			X	calculate plating capacity for each vendor, costs
34			X	use testimonials for initial recommendation – need more time
36			X	not Global, not PCB, not universal – quality varies, Bernie's OK
38		X	X	pro's & cons of different vendors
40		X	X	pro's & cons of different vendors
42			X	pro's & cons of different vendors
44			X	pro's & cons of different vendors
46			X	**Bernie's** – engineering recommendation, negatives with others
48		X		5 criteria listed plus others – enter alt. & criteria into CB
50		X		Assume no technical plating issues, don't know ratio of initial & maintenance costs, one group member working on cost & quality
52**				entering criteria into CB
54**	X			entering criteria into CB, 500 gal. Tanks adequate at low ASF
56**		X		entering alternatives into CB, consider maintenance costs? no
58**				entering criteria into CB
1:00**				entering criteria into CB, Bernie's knowledge/conf. – 1/1
1:02				reviewing materials
1:04			X	longevity of Bernie's good, calculate time to plate
1:06			X	calculations – don't know board size
1:08				"Seems like we should enter a group weighting rather than individual ratings"
1:10**				entering data into CB belief map
1:12**				entering data into CB belief map
1:14**				entering data into CB belief map
1:16			X	Probability of being best: Bernie's – 57%, 59%, 57%
1:18			X	What to do next: Recommend Madison, Global
1:20**				entering additional data into CB belief map
1:22**				" testimonials more important for delivery" change quality criteria to >
1:24**				entering additional data into CB belief map, changing data
1:26**				entering additional data into CB belief map, changing data
1:28**				"don't do criteria weighting now," entering additional data into CB belief map
1:30**				change vendor reputation criteria to >, entering more belief map data
1:32**				more belief map data, "upside down brochure – ha!"
1:34**				changing BM data, reviewing materials
1:36				"default BM value has 0.5 confidence", clicking different CB screens
1:38			X	What to do next: Recommend Bernie's, clicking different CB screens
1:40				clicking different CB screens
1:42				clicking different CB screens , "I don't think the values are correct in the satisfaction & probability of being best graphs"
1:44		X		weighting criteria – quality & cost are highest for all (sum method)
1:46			X	"If a vendor has a good reputation, everything else will be good"
1:48				"entering data for one point lowers the others by default"
1:50				"..can't tweak anything in 10 minutes", clicking different CB screens
1:52		X		Are there additional criteria? No, clicking different CB screens
1:54				"there isn't enough time to process all of this into."
1:56				Low battery alarm on computer becomes the focus
1:58				clicking different CB screens

Test 1
BERNIE'S – probability of being best from all viewpoints – 73%, 72%, 72%, highest satisfaction ~ 90%
1 – 30 min. Observation: reviewed materials & took notes individually – no discussion
Criteria: cost (start-up), delivery, quality, vendor reputation, technical support
General Observations: start up costs only, did not understand maintenance costs, used confidence & knowledge ratings incorrectly – didn't understand definition of confidence (closeness to delighted value), each person did not enter info. on all alternative/criteria pairs, spent a lot of time moving points around in the belief map, not much time spent on understanding the problem

Test 2 Time	clarifying problem	developing criteria	analyzing alternatives	Comments/Discussion Topic
30	X	X		aspect ratio, silence
32	X			writing out matrix individually, calculations
34			X	one member - +'s & -'s for testimonials by vendor
36		X	X	Universal (-) no maint. costs
38	X		X	cost information – Bernie's, PCB cost high, Cu thick requirement
40			X	All OK for aspect ratio, line/space width, ASF
42			X	Costs – Bernie's is the best, testimonial review
44		X	X	"If it's bad, someone would have said something," longevity
46			X	**Bernie's** - qualitative scoring based on testimonials
48**				names & weights into CB, alternatives entered into CB
50		X		criteria: aspect ratio?, quality – what is quality? (disagreement)
52**				enter criteria: aspect ratio, cost (make up)
54		X		cost – high/low, tech support (hrs), reputation (yrs)
56		X		reputation = # years in business (1 – 100)
58		X		disagreement on definition of reputation, delivery (speed)
1:00		X		quality – based on testimonials (yes/no)
1:02			X	review of testimonials for different vendors
1:04**				silence, reviewing materials, enter belief map (BM) data
1:06**				enter belief map data – member 1
1:08**				enter belief map data – member 1
1:10**				enter belief map data – member 1
1:12**				enter belief map data – member 1
1:14**				enter belief map data – member 2
1:16				Select **Bernie's** since we selected it before
1:18**				enter belief map data – member 2
1:20**				enter belief map data – member 2
1:22**				enter belief map data – member 2
1:24**				enter belief map data – member 2
1:26**				enter belief map data – member 2
1:28**				enter belief map data – member 2
1:30**				enter belief map data – member 2
1:32**				enter belief map data – member 2
1:34**				enter belief map data – member 2
1:36**				enter belief map data – member 3
1:38**				enter belief map data – member 3
1:40**				enter belief map data – member 3
1:42**				enter belief map data – member 3
1:44**				enter belief map data – member 3
1:46**				enter belief map data – member 3
1:48**				2nd member making BM changes
1:50**				2nd member making BM changes
1:52**				2nd & 3rd members making BM changes
1:54			X	probability of being best: Bernie's – 82%, 81%, 81%
1:56			X	what to do next: Recommend Bernie's
1:58				done
Bernies's – probability of being best for all viewpoints and highest satisfaction				
1 – 30 min. Observation: reviewed materials individually & took notes – no discussion Criteria: aspect ratio, cost (make-up), technical support, reputation, delivery, quality General Observations: one member used cost info. availability rather than actual cost quantities, all members participated				