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ANALYSIS OF DECISION MAKER PREFERENCES

by

Anita M. Burkard

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APPROVED: W. J. Fabrycky

W. J. Fabrycky, Chairman

F. J. Ricci

F. J. Ricci

Konstantinos P. Triantis

K. P. Triantis

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Blacksburg, Virginia

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CHAPTER 1 INTRODUCTION

Decision making is required daily in our lives, whether it be selecting produce at the grocery store, deciding where to live or work, or designing a weapon system for military applications. Most decisions require the Decision Maker (DM) to examine multiple alternatives which most typically are defined by multiple, conflicting criteria. The objective is to select the alternative which minimizes the tradeoffs between attribute levels in order to determine which alternative is "best". This selection of "best" is based on the subjective viewpoint of the DM, that is, the DM's values and preferences directly influence his or her final alternative selection. A comprehensive analysis of the preferences of the DM in order to systematically structure a decision problem should invariably assist the DM in making the "best" choice from the list of available alternatives. This comprehensive analysis of decision maker preferences is the subject of this project/report.

This project/report examines existing methods and techniques in the area of multiattribute decision making. Managers have increasingly become aware of the many, conflicting objectives involved in decision making today; consequently, this increased interest has resulted in the development of formalized approaches to solving multiattribute decision

problems [13]. Specifically, the relationship of these formalized procedures to DM preferences is examined in an effort to structure the decision problem based upon those preferences. The objective is to examine existing methodologies and to identify those which can serve as useful aids in the decision-making process.

Multiattribute decision making (MADM) involves the making of decisions in the presence of multiple, usually conflicting, objectives. MADM is concerned with the difficulty of tradeoffs between achievement of those multiple objectives. "The tradeoff issue often becomes a personal value question and, in those cases, it requires the subjective judgement of the decision maker [11]." The essence of the issue is, "How much achievement on objective 1 is the decision maker willing to give up in order to improve achievement on objective 2 by some fixed amount [11]?"

As such, the importance of the tradeoff issue cannot be overlooked in the structuring of DM preferences, with the ultimate objective of assisting the DM in making the "best" choice. This research work has been performed in order to develop an understanding of existing DM preference analysis methods, the strengths of such methods, as well as their limitations and shortcomings.

The overall research objective is to determine if there truly exists a DM preference-structuring method which selects the "best" alternative from the subjective perspective of the decision maker. This project/report provides a thorough review of existing methods of examining DM preferences as well as an in-depth analysis of each method's applicability to meeting the overall research objective.

CHAPTER 2 REVIEW OF LITERATURE

The study of decision making in a multiple criteria environment began in the late 1950's concurrently among researchers in a variety of disciplines: management science, economics, psychometrics, marketing research, applied statistics, and decision theory [9]. This study was an outgrowth of the discipline of operations research and management science, a field with its beginnings in the forties in response to the tactical national defense scenarios and the resultant decision-making requirements of World War II [18]. The decision-making research performed during the fifties was focused upon explaining and rationalizing decision-making behavior as opposed to assisting the DM in the process of making decisions. As a result, many of the developed methods may not apply directly to the determination and use of DM preference functions for determining the "best" decision behavior. However, as Hwang points out, these methods do form the basis for the development of multiple attribute decision making (MADM), also referred to as multiple criteria decision making (MCDM), today [9].

The major product of the 1950's research was in the field of goal programming, presented by Charnes and Cooper in 1961 [18]. Goal programming is defined as "the attempt to

minimize the set of deviations from prespecified multiple goals, which are considered simultaneously but are weighted according to their relative importance [18]." It is the assessment of this relative importance that is necessary in developing an understanding of DM preferences.

The first such analysis of MADM based upon DM preference was the use of a simple additive weighting method by Churchman, Ackoff, and Arnoff [9]. Subsequently in 1968 and again in 1973, MacCrimmon reviewed MADM methods including method structure and required DM preference inputs [9]. Development also was revived in the area of multiattribute utility theory (MAUT) by Fishburn and Pollak, who characterized the necessary and sufficient conditions for additive utility decomposition [18].

" Multiattribute utility theory (MAUT) evaluates utility functions intended to accurately express a decision maker's outcome or preferences in terms of multiple attributes [18]." MAUT is an outgrowth of unidimensional utility theory, which is based upon the belief that a DM always acts in a rational manner. The basic premise of MAUT is that a decision maker acts in an effort to maximize his expected utility. Thus, if a preference (or value) function can be developed which truly represents the subjective viewpoint of the DM, then, the alternative which maximizes this

preference function, is the alternative which is the DM's "best" choice. [18] Thus, MAUT attempts to formalize a decision maker's preference structure [2].

One area that has contributed greatly to the development of MAUT methodology is that of the Von Neumann and Morgenstern axioms of rational behavior. These five axioms prescribe that the DM follows certain "rational" behavior rules as delineated below [15]:

1) The complete ordering axiom

> "For any two lotteries, L1 and L2, the decision maker prefers either L1 to L2 or L2 to L1, or else is indifferent. Furthermore, if L1 is preferred to L2 and L2 to a lottery, L3, then L1 must also be preferred to L3 (called transitivity) [15]."

2) The continuity axiom

> "If $x is preferred to $y and $y to $z, then there must exist some probability p (between 0 and 1) so that the decision maker is indifferent between a sure amount $y and a lottery offering $x or $z with probabilities p and (1-p), respectively [15]."

3) The independence axiom

"If the decision maker is indifferent between alternatives x and y, then he should also be indifferent between two lotteries offering x and z in the first lottery and y and z in the second, with probabilities p and (1-p) in each lottery for any z and p value [15]."

4) The unequal probability axiom

"If x is preferred to y, then lottery L1 should be preferred to L2 when both lotteries contain only the outcomes x and y and when the probability of winning x is greater in L1 than in L2 [15]."

5) The axiom of complexity

"If two lotteries, L1 and L2, offer outcomes x and y for L1 and produce two new lotteries, L3 and L4, as the outcomes for lottery L2, with L3 and L4 offering only x and y, then the decision maker should be indifferent between L1 and L2 if, and only if, the expected values of L1 and L2 are identical. (This axiom guarantees that probabilities are calculated in accordance with traditional probability calculus.) [15]"

The Von Neumann-Morgenstern axioms develop rational assumptions for the preference orderings provided to the analyst by the DM. By ascribing to these axiomatic beliefs, the analyst and DM can develop a structured preference function which is then maximized to determine the "Best" choice in the multiattribute decision problem. This "Best" choice is the alternative which maximizes the DM's expected utility.

The study of MAUT started with development of the simple additive utility function and has progressed to multiplicative (quasi-additive) and multilinear forms. Major contributors to the development of MAUT include Fishburn, Huber, Zeleny, Keeney and Raiffa [9].

Concurrently, multiobjective programming was receiving emphasis from Saska, Radzowski, Juttler, and Geoffrion in the late sixties and early seventies [18]. An extensive analysis of multiobjective programming methods was conducted by Cohon and Marks in 1975 [8].

Thus, the seventies marked the beginning of major growth in the MADM field. The first international conference was held on multiple criteria decision making, and numerous conferences and proceedings followed. By the end of the

seventies, the field was well established in the literature and technical journals [18].

Through the eighties and into the nineties, MADM has become a field of its own. Interactive programming, descriptive decision models, and decision support systems form a major part of the MADM realm [18]. As such, this project incorporates one of the many available decision support systems, SmartEdge, by Haviland-Lee Inc., into the decision-making analysis. The incorporation of multiple criteria into the decision-making process will be the challenge facing policy makers, managers, and systems engineers for decades to come.

CHAPTER 3 MATERIALS AND METHODS

The multiattribute decision making (MADM) methods which deal directly with the analysis of decision maker preferences are reviewed and classified in this report. The basic structure and characteristics of each MADM method are presented along with an example of each method's use in a sample test case prepared especially for this report. As a starting point, one MADM method is analyzed in-depth through the use of the SmartEdge decision support tool.

3.1 Project Objectives

The basic objective of this research project is twofold:

1) to examine one particular multiattribute decision-making method in great depth, to apply it to a sample test case, and to assess its ability to accurately reflect the preferences of a surveyed group of decision makers,

and

2) to identify and analyze the current methods available for multiattribute decision making, to apply them to a sample test case, and to assess their relative performance in terms of the final decision output.

The basis for this project is a sample test case of "Choosing a VCR". Test case data is obtained from Consumer Reports, March 1991 issue [17]. As such, Consumer Reports is considered the expert, whose judgement the decision makers are willing to accept. Thus, data obtained on attributes and alternatives are considered valid and applicable to the subsequent analysis.

3.2 Basic Definitions and Concepts

During the progress of this research, numerous terminology and concepts have been encountered in the MADM literature. Knowledge of the use of these terms and understanding of the use of these concepts is necessary to ensure a complete and thorough understanding of the research performed and documented in this report. As such, the following paragraph defines MADM terms and concepts as they are used in this report.

Decision making is defined as an attempt to resolve situations involving multiple, conflicting objectives [18]. The process involves alternatives, objectives, attributes, and the perceptions of the decision maker, defined as preferences or utilities.

Alternatives are the choices available to the decision maker. These alternatives are described in terms of attributes, measures of the real-world states of nature of a particular decision situation. Objectives represent a DM's needs or desires as directions of improvement along individual attributes [18]. Thus, attribute values indicate how closely alternatives meet the objectives to which each attribute is assigned, and objectives are the standards against which the quality or performance of a given alternative may be evaluated [11].

Preference measurement is a method for modeling the decision maker's preference structure, allowing the use of prespecified decision rules for the action of the decision maker [2]. A decision rule allows a complete ranking of alternatives according to their performance measured in terms of all attribute values selected for the problem under study [2]. Attributes can be measured independent of the DM's desires or preferences [1].

There are four classifications of decision problems for analysis - decision making under certainty, decision making under risk, decision making under uncertainty, and decision making under conflict (game theory).

Decision making under certainty is purely deterministic, since the state of nature which occurs is known. Decision making under risk involves the case where the state of nature to occur is unknown. However, the probability of occurrence of each state of nature can be either subjectively or objectively estimated. Decision making under uncertainty exists when it is not possible to estimate the probabilities of the states of nature. Decision making under conflict deals with decisions among rational opponents with conflicting interest, such as that in game theory [2].

3.3 Assumptions

Multiattribute decision making is a diverse field consisting of many, varied approaches in the numerous disciplines in which the theory has been applied. In an effort to keep this research effort to a manageable level, yet still provide useful results, certain assumptions had to be incorporated during the research. Although limiting the scope of the effort, incorporation of these assumptions has allowed for an in-depth comprehensive analysis of several aspects of the theory which otherwise could not have been performed. The assumptions are presented below:

Assumption 1 -- The assessment of the uncertainties are given and the effort therefore concentrates on formalizing

the preference structure of the decision maker. Thus, the problem is one of decision making under risk with the objective of maximizing the expected value of utility.

Assumption 2 -- There is only a single decision maker -- not a group decision maker. However, group decision-making values are considered in a comparison of the SmartEdge computer model output and survey respondents' preferences.

Assumption 3 -- The decision problem has been defined, that is, the important attributes and available alternatives have been prespecified. The specification of the decision problem is addressed, but a detailed assessment of the decision problem specification is a whole study by itself, and not the subject of this report.

Assumption 4 -- Any attribute is preferentially independent of any of the other attributes, that is, the desire for a certain value of one attribute is not altered by the state or value of another attribute in the decision problem. This is a necessary assumption to utilize the SmartEdge methodology for the test case.

Assumption 5 -- The decision problem is a priori only, that is, the analyst or the decision maker cannot produce more information about the attributes or alternatives than what

is known at the beginning, when soliciting the DM preferences. Again, there exist numerous methods in the literature discussing iterative decision making, decision making post priori, etc. which will not be covered in this report.

3.4 Test Case Development

Although decision-making situations are highly diverse, there are four distinct similarities: multiple attributes, conflict among criteria, incommensurable units, and design/selection [9]. The approach is to assess a decision-making selection test case which exhibits these typical characteristics. The test case is one of VCR selection with multiple, conflicting criteria. Test data are obtained from research performed by Consumer Reports on Hi-Fi VCRs [17].

Before the test data could be employed in the analysis, the decision problem had to be analyzed to develop the list of attributes and alternatives available for selection. Table 3.4.1 highlights the five-step process utilized to determine the VCR selection data. Each step of this process is detailed below.

Table 3.4.1 Analysis of Test Data

Step	Description
Selection of Attributes	The list of attributes was reduced from fourteen to five.
Determination of Attribute Values	Values for the attributes were determined directly, by measurement, or by attribute combination.
Elimination of Dominated Alternatives	Alternatives which were dominated on all attributes by another alternative were eliminated.
Reduction of Alternatives to a Manageable Level	The number of alternatives was systematically reduced so survey respondents were not overwhelmed by the number of available choices.
Generation of Final Table	The final table consists of seven alternatives and five attributes.

Step 1 -- Selection of Attributes

There are five desirable properties of a set of attributes: completeness - representative of the areas of primary importance in VCR selection; operational - meaningful to the decision maker; decomposable - divisible into smaller parts for analysis of DM preferences; nonredundancy - necessary to avoid double counting of selection qualities; and minimum size - significant in the reduction of complexity to keep the problem manageable [11]. The chosen attributes for this research are intended to satisfy these properties. The attributes for this research are also selected based on ease of understanding by survey respondents. The final five attributes chosen are audio quality, picture quality, price, remote control use, and repair frequency.

Selected attributes must also be comprehensive, measurable, and preferentially independent. According to Keeney, a comprehensive attribute indicates that "by knowing the level of an attribute in a particular situation, the decision maker has a clear understanding of the extent that the associated objective is achieved [11]." A measurable attribute allows the decision analyst to assess the DM's preferences and develop a utility function [11]. Preferentially independent attributes indicate that the DM's

preference for the value of any one given attribute does not change based upon the value of any other given attribute.

In decision-making analysis, the attribute provides a scale for measuring the degree to which its respective objective is met. As such, the selection of objectives and their associated attributes is critical in the overall decision-making analysis and determination of the final solution [11].

The study of objective and attribute selection is an entire field of decision-making theory itself. For the purposes of this research, the attribute selection is made and assumed to be complete, operational, decomposable, nonredundant, minimal, comprehensive, and measurable. Further, attributes are considered to be preferentially independent. It is understood that attribute selection is a critical part of the decision-making process and should not be taken lightly. However, the focus of this research is on analysis of decision making as it relates to decision maker preferences, not attribute selection. Thus, the selection of attributes for the VCR problem is considered appropriate for the focus of this research.

It should be noted that the survey respondents are given the same list of attributes used in the analysis of decision-

making methodologies and the SmartEdge model. The respondents are further instructed that these are the only attributes of importance. Thus, although the selection of attributes is not performed in the strictest manner as it should be in a true decision-making arena, the results of this analysis are not affected by the method of attribute selection. This results from the fact that the decision makers are presented with the same list of attributes used in the models, in lieu of the comprehensive list contained in the original survey presented in Consumer Reports [17].

Step 2 -- Determination of Attribute Values

Some manipulation of the Consumer Reports data was necessary in the determination of the final attribute values. This was necessary to ensure that survey respondents could easily read and understand the survey. As with the selection of attributes, the manipulation of data in the determination of attribute values does not affect the overall research results. This is because once again the survey respondents are only given the final attribute list which is utilized for both decision maker preference assessment, as well as decision maker selection identification. The following details how attribute values were determined.

For the attribute Price, values were taken directly from the Consumer Reports data. Price indicated the estimated average price of each VCR. For the attributes Picture Quality and Repair Frequency, numeric values were measured and interpreted from graphical scales given. Picture quality was interpreted for Extended Play recordings only, an assumption made because of the limited variation in picture quality for Standard Play recordings.

For the attributes Audio Quality and Remote Control Use, several attributes were combined into one. For the audio quality, dynamic range, flutter, and frequency response were combined into a single overall audio quality attribute. If the combined attributes had been considered separately, then the nonredundancy aspect of attribute selection would have been violated since each of the combined attributes is an ingredient of audio quality. Thus, double counting of the audio quality attribute would have occurred, biasing the final results. Similarly, double counting of the remote control use attribute would have resulted, if the remote control attributes of visibility, ease of use, and layout were not combined into a single overall attribute for remote control use [17].

Step 3 -- Elimination of Dominated Alternatives

The original list of sixteen VCRs was reduced to thirteen by the dominance criteria, as discussed in Section 3.6.1. Table 3.4.2 shows how the three of the sixteen VCRs were eliminated. The dominance criteria refers to elimination of all alternatives where there exists another alternative whose attribute values are "better" or "equal" on all attributes [9]. For example, VCR 4 has the following attributes: Audio - 13, Price - $470, Picture - 90, Remote - 9, and Repair - 18%. VCR 12 has the following attributes: Audio - 10, Picture - 89, Price - $500, Remote - 7, and Repair - 18%. VCR 4 has "better" audio quality, lower price, "better" picture quality, "better" remote control use, and "equal" repair frequency. Thus, VCR 4 dominates VCR 12; therefore, VCR 12 has been eliminated. In a similar fashion, VCR 9 dominates VCR 15 and VCR 11 dominates VCR 13; thus, VCR 11 and VCR 13 are also eliminated. The list of nondominated alternatives is sometimes referred to as Pareto-optimal alternatives [13].

Step 4 -- Reduction of Alternatives to a Manageable Level

In order to reduce the analysis to a manageable level, six additional alternatives were eliminated. Thus, the minimum

Table 3.4.2 Elimination of Dominated Alternatives

ALTERNATIVE

Attribute	VCR 4	VCR 9	VCR 11	VCR 12	VCR 13	VCR 15
AUDIO	13	10.5	10.5	10	9.5	10
PICTURE	90	86	82	89	70	86
PRICE	$470	$455	$365	$500	$410	$455
REMOTE	9	12	11	7	8	9
REPAIR	18%	10%	12%	18%	19%	21%

VCR 4 dominates VCR 12

VCR 9 dominates VCR 15

VCR 11 dominates VCR 13

size attribute criteria was achieved. The choice of which of the remaining alternatives to eliminate was intended to keep a wide range of levels available for each of the attributes. Otherwise, the choice was somewhat arbitrary. This reduction of the number of alternatives was necessary so a comprehensive analysis of decision maker preferences could be kept to a manageable level. Further, the survey respondents would be overwhelmed with too many choices. As in the steps for attribute selection and determination of attribute values, the survey respondents are only presented with the final VCR selection list. This reduction in the number of alternatives is not a factor in the analysis of decision maker preferences considered in this research.

Step 5 -- Generation of Final Table

The final attribute table of seven VCR alternatives and five attributes was generated as given in the survey in Appendix B. The five attributes are Audio, Picture, Price, Remote, and Repair. The final attribute table data is referenced extensively throughout the remainder of this report. As a result, the final attribute table is reproduced in the body of this report as Table 3.4.3.

Table 3.4.3 - Final VCR Attribute and Alternative Selections

ALTERNATIVE

Attribute	VCR 1	VCR 2	VCR 3	VCR 4	VCR 5	VCR 6	VCR 7
AUDIO	11.5	8	11.5	13	10.5	11.5	9.5
PICTURE	80	74	88	90	86	71	70
PRICE	$330	$400	$500	$470	$455	$450	$410
REMOTE	6	11	11	9	12	8	8
REPAIR	36%	10%	16%	18%	10%	8%	19%

3.5 Part 1 - Survey Development and SmartEdge

3.5.1 Survey Development

Once the attributes and alternatives had been determined, the next process was to present the data in an easy-to-understand format for the decision maker survey. From the test case development, there are a predetermined number of alternatives which have assigned attribute values based upon information gathered from Consumer Reports. The DM is required to select the "best" alternative with the aid of the SmartEdge computer model [16].

"In order to obtain a von Neumann-Morgenstern utility function in cases of quantifying preferences over multiple objectives, one must address two separate issues: (1) value tradeoffs among objectives and (2) attitudes toward risk [11]." The SmartEdge computer model requires information on these two issues as input from the DM as described below:

Attribute utility functions -- these measure the DM's preference for different attribute states,

Attribute weights -- these measure the DM's relative preference for one attribute vs. the other [16].

A survey was developed to elicit the required preference information from a group of decision makers at Contel Federal Systems and Unisys Corporation. A copy of the survey is contained in Appendix A. The basis of the survey was the SmartEdge computer model [16]. Responses from the survey were compiled and entered into the model for analysis.

The survey also requested the respondents to indicate which VCR they would select based upon the given alternatives and attribute information. The actual selections are compared to the SmartEdge output to identify where agreement and/or disagreement exists. The model's output is a rank ordering of the alternatives based upon the entered DM preferences. Results of the survey analysis and use of the SmartEdge decision support tool are presented in the Results Chapter of this report.

Table 3.5.1.1 highlights the five-step process utilized to determine the questions posed to decision makers answering the VCR selection survey. The steps in the VCR selection survey development process are further detailed below.

Table 3.5.1.1 Generation of VCR Selection Survey

Step	Description
Identification of Attribute Extreme Values	The "worst" and "best" values for each attribute were identified as the basis for input to SmartEdge.
Derivation of Decision Trees via SmartEdge	A decision tree was developed for each of the five attributes using the attribute extreme values.
Generation of Survey Tradeoff Questions	Survey questions were generated based on the decision trees and the SmartEdge methodology.
Generation of Attribute Weighting	An Attribute weighting question was written based upon that given in the SmartEdge methodology.
Determination of the "True" Decision Maker Preference	The decision maker was instructed to numerically rank the seven alternatives from one to seven in order of preference.

Step 1 -- Identification of Attribute Extreme Values

The "worst" and "best" values for each of the five attributes were identified for input into the SmartEdge decision model. Values from worst to best are as follows: Audio 8-13; Picture 70-90, Price $500-$330, Remote 8-12, and Repair 36%-8%.

Step 2 -- Derivation of Decision Trees via SmartEdge

Data for the five attributes and seven alternatives as given in Table 3.4.3 was then entered into SmartEdge for one decision maker. The utility function assessment feature was then activated. In utility function assessment, the decision maker is asked a series of lottery questions involving each of the five attributes. The questions are intended to identify the decision maker's preference for levels of the given attribute. The structure of the questions allows the decision maker the choice between either a Sure Thing at some given attribute level or a Gamble, which is a 50-50 chance of either receiving the "worst" value of the attribute, or the "best" value of the attribute [16]. It is this given attribute level that had to be identified to allow use of the SmartEdge methodology in a survey form.

The decision maker can choose either the Sure Thing, the Gamble, or indicate Indifference between the Sure Thing and the Gamble for each question [16]. The given attribute levels for each of the questions posed to the decision maker are derived from the SmartEdge decision tree. These values were identified by repeatedly executing the utility analysis and responding either Sure Thing or Gamble in a manner to traverse all paths of the decision tree. The process was then repeated to generate decision trees and Sure Thing attribute questioning levels for the remaining four attributes.

Step 3 -- Generation of Survey Tradeoff Questions

Survey questions were then generated based on the decision trees and the SmartEdge methodology. The intent of the survey tradeoff questions is to assess the decision maker's preference for various values of each attribute. The wording of the questions was identical to that used in SmartEdge to replicate the functions of the computer program as closely as possible [16]. The branches in the decision tree were handled by instructing the survey respondent as to which question to answer next based upon his or her response to the previous survey question. Indication of indifference by the respondent ended the survey questions for that attribute. If the respondent did not indicate indifference

during the initial series of questions, he or she was eventually instructed to enter a numerical indifference value. Entry of this value meant that the end of a decision tree branch had been reached.

Step 4 -- Generation of Attribute Weighting

After the utility function assessment question development was complete, the SmartEdge attribute weighting assessment was then activated. In attribute weighting, the decision maker is asked a single question involving distribution of 100 poker chips among the given attributes. The question is intended to identify the decision maker's preference for one attribute versus another [16].

Step 5 -- Determination of the "True" Decision Maker Preference

The final survey question was a direct assessment of the decision maker's preference for the seven alternatives in question. The decision maker was asked to rank the seven alternatives in order of importance from one through seven, one indicating most preferred and seven indicating least preferred.

3.5.2 A Description of the SmartEdge Methodology

The SmartEdge computer model allows the DM to enter his subjective preferences in the form of inter-attribute comparisons (utilities) and intra-attribute comparisons (weights) as illustrated in Figure 3.5.2.1. The model combines the attribute states, attribute utilities, and attribute weights into a single number -- the expected utility score -- for each alternative. In following the basic axioms of rationality, the DM then chooses the alternative with the highest expected utility. The output of the SmartEdge model is a rank ordering of the alternatives based upon the entered DM preferences [16].

The SmartEdge methodology consists of three modes of analysis:

Five Minute Analysis:

> All attribute states are entered as point estimates. Equal confidence in all attribute values is assumed (no uncertainty). All utility values are forced to be linear -- risk neutral [16].

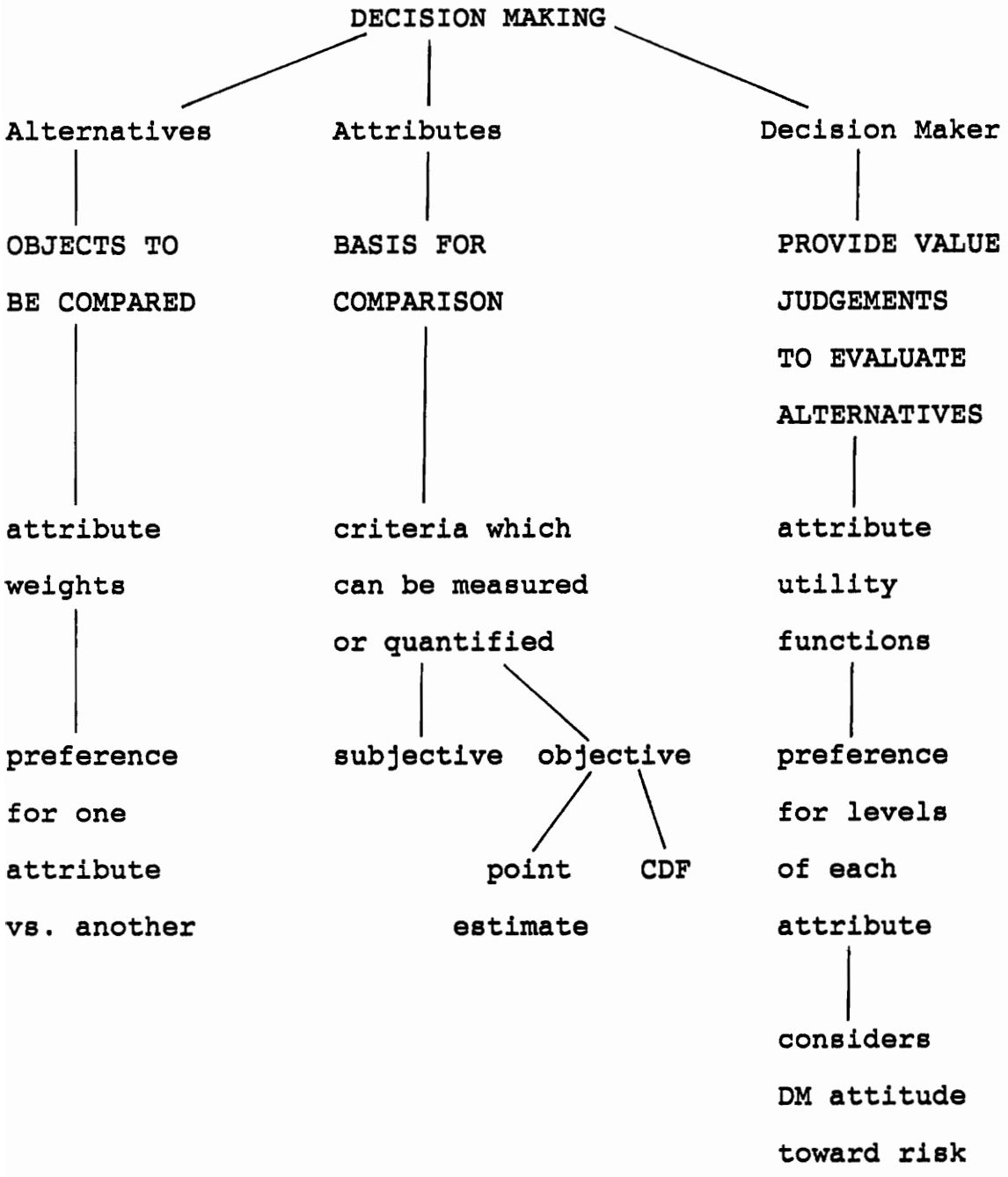

Figure 3.5.2.1 An Illustration of the SmartEdge Methodology

Detailed Mode/Deterministic:

Weights entered by the DM do NOT have to sum to one. The appropriate model (Additive or Multiplicative) is used depending upon whether or NOT the weights sum to one [16].

Detailed Mode/Probabilistic:

Includes uncertainty in attribute values via a cumulative distribution function entered directly or via a questionnaire [16].

This research analyzes the sample test case using the Detailed Mode/Deterministic mode of analysis. One assumption is that there is no uncertainty in the attribute values for the test case, so the detailed mode/probabilistic analysis mode is not necessary. Attribute weights from the surveyed decision makers were requested to sum to one so that the additive form of the utility function could be used. The additive form is shown below [16]:

$$u(x) = \sum_{n=1}^{N} k_n u_n(x_n) \qquad N = \text{number of attributes}$$

Since the detailed mode is being used, the utility function does not have to be linear. Its form is determined from the

preferences of the surveyed decision makers. The SmartEdge methodology identifies one indifference point at the 50% probability level. That is the utility is identified for the DM's preference between a sure thing and a gamble with a 50-50 chance of winning. Thus, the utility function generated by SmartEdge is actually composed of two linear segments, one from 0 to 50%, and the other from 50 to 100% of the attribute value scale [16].

SmartEdge also has the capability to assess group decision making via either the Rank Sum Rule, the Nash Bargaining Rule, or the Additive Utility Rule and provides a concordance measure indicating agreement or disagreement [16]. Due to the project's narrowed scope, group decision making is not specifically analyzed in this research. However, some comparison of the selections made by the respondents as a group using the Rank Sum Rule is examined in this report.

3.6 Multiattribute Decision Making Methods

Multiattribute decision making can be classified in a variety of ways depending upon the objectives of the researcher. Since this effort is focused upon understanding decision maker preferences, the classification methodology utilized is one of partitioning the subject area into

subsections based upon the required DM input. Figure 3.5.2.2 provides a summary of multiattribute decision making methods that are examined in this research.

For the methods that are analyzed, there are five different requirements for DM preference information as identified in Figure 3.5.2.3. The requirements on the DM progress from simplest (no required input) to the most complex (attribute utilities). Complexity is increased both by requirements for additional types of data information as well as requirements for additional magnitudes of data from the DM. Figure 3.5.2.4 identifies the additional required data in terms of the magnitude of the DM's responses for the different MADM methods.

3.6.1 Dominance

Dominance occurs when the first alternative is "equal" or "better" in all attributes over a second alternative. Also, at least one attribute of the first alternative must be "better" than the second alternative; otherwise, the two alternatives would be identical. The first alternative is said to dominate the second alternative, that is the utility of the first alternative is greater than that of the second. As a result, the first alternative is preferred by the DM [13]. No input is required from the decision maker.

No DM Input

DOMINANCE

MAXIMIN

MAXIMAX

COPELAND'S REASONABLE SOCIAL WELFARE FUNCTION

Minimum Acceptable Attribute Values

CONJUNCTIVE (EXCLUSIONARY SCREENING)

CONJUNCTIVE RANKING

DISJUNCTIVE

Ranking of Attributes

LEXICOGRAPHIC

Attribute Weights

PERMUTATION METHOD

LINEAR ASSIGNMENT METHOD

HIERARCHIAL ADDITIVE WEIGHTING

TOPSIS

ELECTRE

Attribute Weights and Attribute Utilities

SIMPLE ADDITIVE WEIGHTING (WEIGHTED AVERAGE)

Figure 3.5.2.2 Summary of MADM Methods

MADM METHOD

DM Input	D1	M1	M2	C1	C2	C3	D2	L1	P1	L2	H1	T1	E1	S1
NONE	X	X	X	X										
Attribute Weights									X	X	X	X	X	X
Minimum Attribute Values					X	X	X							
Attribute Ranking								X						
Attribute Utility														X

C1-Copeland's
C2-Conjunctive
C3-Conjunctive Rank
D1-Dominance
D2-Disjunctive

E1 - ELECTRE
H1 - HAW
L1 - Lexicographic
L2 - Linear Assign.
M1 - Maximin

M2 - Maximax
P1-Permutation
S1-Simple Addititve
T1 - TOPSIS

Figure 3.5.2.3 Types of Decision Maker Input

Method	Response
Dominance	None
Maximin	None
Maximax	None
Copeland's	None
Permutation Method	"n" attribute weights
Hierarchial Additive Weighting	"n" attribute weights
TOPSIS	"n" attribute weights
Conjunctive	"n" attribute minimum values
Conjunctive Ranking	"n-1" attribute minimum values; 1 ranking attribute
Disjunctive	"n" attribute minimum values
Lexicographic	"n" ranking of attributes
Linear Assignment Method	"n" attribute weights
ELECTRE	"n" attribute weights concordance/discordance
Simple Additive Weighting	"n" attribute weights variable number of utility assessments

Figure 3.5.2.4 Magnitude of Decision Maker Responses

3.6.2 Maximin

Maximin involves selecting the maximum of the minimum values of each of the attributes. That is, the alternative with the largest minimum value of any single attribute is chosen. The output of the maximin decision-making method is the "best" choice alternative, not a ranking of alternatives. Maximin requires that inter-attribute values be comparable. No input is required from the decision maker [13].

3.6.3 Maximax

Maximax involves selecting the maximum of the maximum values of each of the attributes. Like maximin, the output of the maximax decision-making method is the "best" choice alternative, not a ranking of alternatives. Maximax also requires that inter-attribute values be comparable. No input is required from the decision maker [13].

3.6.4 Copeland's Reasonable Social Welfare Function

Copeland's method involves paired comparisons of alternatives against values of attributes [8]. The number of pairwise comparisons depends upon the number of available alternatives. The output is a ranking of the alternatives. No input is required from the decision maker.

To use Copeland's method, the analyst compares attribute values for two alternatives on an attribute by attribute basis. The number of alternative 1 attribute values which exceed alternative 2 values (and vice versa) are counted. Whichever alternative has a higher number of "better" attribute "wins" the alternative comparison. The method then sums the number of times each alternative "wins" a pairwise comparison. Alternatives are then ordered based upon the number of pairwise comparisons "won", more comparisons won resulting in a higher final ranking.

3.6.5 Conjunctive

The conjunctive method involves setting minimal necessary levels for each of the attributes [9]. Also referred to as the satisficing method, or exclusionary screening, the conjunctive method is used mainly in cases where the number of alternatives is large. In such cases, the decision maker is usually only concerned with finding an alternative which meets a minimal set of standard criteria. Thus, the output is the selection of none, one, or a group of the available alternatives (dependent on the minimal attribute values specified), not a ranking of alternatives. A minimum acceptable value for each of the attributes is the required input from the decision maker.

3.6.6 Conjunctive Ranking

The conjunctive ranking method is a form of the conjunctive method where the decision maker sets minimal necessary levels for all but one selected attribute [8]. The one selected attribute is considered the ranking attribute used to rank the alternatives. Thus, the output of the conjunctive ranking method is the ranked set of alternatives. A minimum acceptable value for all but one selected ranking attribute is the required input from the decision maker.

3.6.7 Disjunctive

The disjunctive method chooses the "best" alternative based upon the "best" values on each of the attributes [9]. Although similar to maximax, the disjunctive method also requires the stipulation of minimum acceptable values for each of the attributes. The output of the disjunctive method is the "best" alternative, not a ranking of alternatives. A minimum acceptable value for each of the required attributes is the required input from the decision maker.

3.6.8 Lexicographic

The lexicographic method chooses the "best" alternative based upon the attribute values and the decision maker's ranking of the attributes in order of importance [9]. This method does not require comparability among the attributes. The output is a ranking of the available alternatives. An attribute ranking in order of importance is the only required input from the decision maker.

3.6.9 Permutation Method

The permutation method ranks the alternatives based upon attribute weights [9]. The method is calculation-intensive, because it determines values for every possible alternative ranking. The final output is a ranking of the available alternatives. Attribute weights are the required input from the decision maker.

Application of this method to the VCR problem required development of a computer program to determine the ideal ranking. This program was developed in BASIC and was used to perform the numerous calculations. The necessity for a computer program to perform the calculations was due to the large number of available alternatives. For the permutation

method, the number of possible alternative rankings is defined as "n!" where "n" is the number of available alternatives. Thus, for the VCR test case, "7!" or 5040 possible alternative rankings were generated.

This is the first method analyzed where attribute weights are required from the decision maker. To keep consistency among analysis of the MADM methods, attribute weights from one of the surveyed decision makers are used in all methods requiring this input. The weights chosen for the analysis are as follows: Audio - .20, Picture - .25, Price - .25, Remote - .10, and Repair - .20.

In order to use the permutation method, the values of each attribute are ordered from "0", indicating the "worst" attribute value, to a maximum of "6", indicating the "best" attribute value, as shown in Table 3.6.9.1. Note that ties are given the same attribute order number.

Next, for each of the 5040 possible alternative orderings, a 7 X 7 concordance matrix, C, is developed. The diagonal elements of this matrix are all zero. Elements above the diagonal represent the concordance between the row alternative and the column alternative. Elements below the diagonal represent the discordance between the row alternative and the column alternative.

Table 3.6.9.1 Decision Matrix for the Permutation Method

ALTERNATIVE

Attribute	VCR 1	VCR 2	VCR 3	VCR 4	VCR 5	VCR 6	VCR 7
AUDIO	3	0	3	4	2	3	1
PICTURE	3	2	5	6	4	1	0
PRICE	6	5	0	1	2	3	4
REMOTE	0	3	3	2	4	1	1
REPAIR	0	4	3	2	4	5	1

Weights Audio - .20

Picture - .25

Price - .25

Remote - .10

Repair - .20

Elements above the diagonal are determined by comparing the row alternative to the column alternative for each one of the attributes. If the attribute value for the row alternative is greater than or equal to the attribute value for the column alternative, then that attribute's weight, as obtained from by the decision maker, is part of the concordance summation which appears for that element in the concordance matrix, C. All five attributes are tested in this manner for each of the alternative pairs. This procedure is accomplished by use of the following equation for each of the j attributes [9]:

$$C_{kl} = \{ j \mid x_{kj} >= x_{lj} \}, \quad k,l = 1, 2, 3, 4, 5, 6, 7; k \neq l$$

Similarly, elements below the diagonal are determined by comparing the row alternative to the column alternative for each one of the attributes. However, in this case, attribute weights are part of the discordance summation if the attribute value for the row alternative is less than or equal to the attribute value for the column alternative. Again, all five attributes are tested in this manner for each of the alternative pairs as given by the following equation [9]:

$$D_{kl} = \{ j \mid x_{kj} <= x_{lj} \}, \quad k,l = 1, 2, 3, 4, 5, 6, 7; k \neq l$$

The overall concordance/discordance of a given alternative ranking is then determined by summing the above diagonal elements (the concordance), summing the below diagonal elements (discordance), and subtracting the discordance value from the concordance value. The final result is used as the evaluation criteria. Maximization of this value provides the best alternative ranking.

3.6.10 Linear Assignment Method

The linear assignment method also ranks the alternatives based upon attribute weights provided by the decision maker [9]. One method of ranking the alternatives is to sum the ranks of each alternative for each attribute. This method does not require any decision maker input.

A more comprehensive method is to sum the attribute rankings and multiply by their attribute weightings. The final output of both of these methods is a ranking of the available alternatives. For the second method, attribute weights are the required input from the decision maker.

For the simple case of summing the alternative rankings, the alternatives are first ranked for each attribute, and the rankings are then summed. The final alternatives are then ordered based on the summations.

For the more comprehensive linear assignment method, the assignment model of linear programming is utilized to solve the decision problem. In the VCR test case, there are seven alternatives each with seven possible alternative rankings. Since only one ranking can be assigned to one alternative, the decision problem becomes one of optimization of the effectiveness function [3],

$$E = \sum_{i=1}^{n} \sum_{j=1}^{n} e_{ij} x_{ij}$$

subject to

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad j = 1,2,\ldots,n$$

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1,2,\ldots,n.$$

The optimization is one of maximization, since the objective is to maximize the attribute combination to determine the final alternative ranking. The Hungarian method for finding the optimal assignment was applied to the VCR test case as explained in the Results Chapter for the Linear Assignment Method [3]. Once the optimal matrix is determined, then the final alternative ranking can be obtained from the optimal matrix.

3.6.11 Hierarchial Additive Weighting

The hierarchial additive weighting method ranks the alternatives based upon attribute weights provided by the

decision maker [9]. The final output is a ranking of the available alternatives. Attribute weights are the required input from the decision maker.

The hierarchial additive method formalizes the decision structure in terms of levels as illustrated in Figure 3.6.11.1 for the VCR test case. The objective is to ascertain the performance of the alternative VCRs in terms of user satisfaction after purchase. This is accomplished by a matrix pairwise comparison of components at each level of the hierarchy, with respect to a purpose from the next hierarchial level [9]. The final objective is to determine a rank ordering of available alternatives.

Elements of the 7 X 5 hierarchial matrix (7 alternatives and 5 attributes) are obtained utilizing the following two equations [9]:

$$k_j = \frac{x_{ij}}{\sum_{i=1}^{7} x_{ij}} \quad \text{for } j = 1, 2, 4 \text{ (audio, picture, remote)}$$

$$k_j = \left(1 / x_{ij} \right) / \sum_{i=1}^{7} \frac{1}{x_{ij}} \quad \text{for } j = 3, 5 \text{ (price, repair)}$$

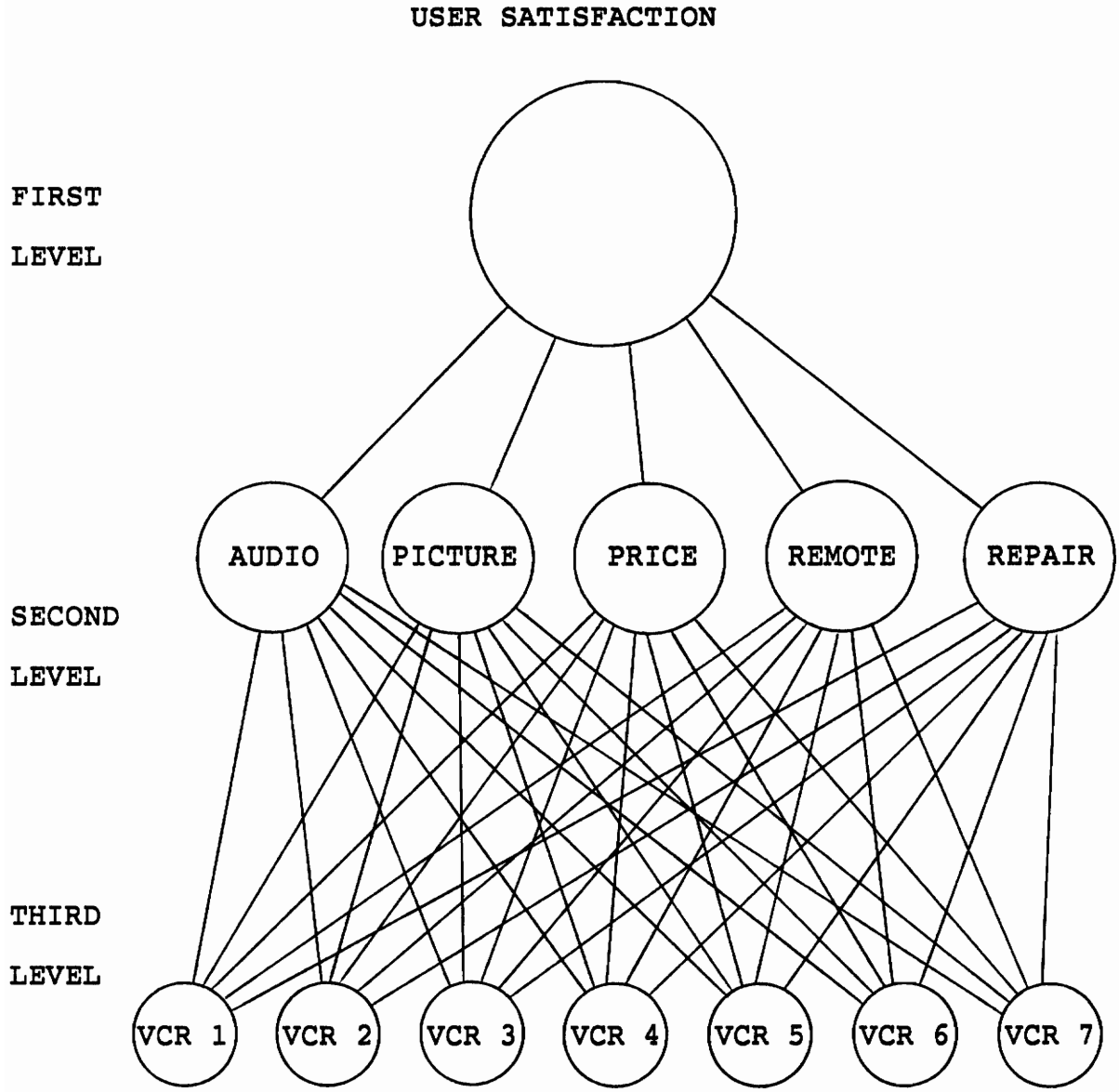

Figure 3.6.11.1 VCR Selection Hierarchy

The next step is to multiply this hierarchial matrix by the DM's attribute weights yielding the final decision values for the seven alternatives. The alternatives are then ranked based on the final decision values.

3.6.12 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method also ranks the alternatives based upon the decision maker's input of attribute weights. The method, developed by Yoon and Hwang, determines the distance of each alternative from both the "ideal" solution and the "negative-ideal" solution [9]. TOPSIS is based upon the belief that the "best" choice alternative is the one located the shortest distance from the "ideal" and the farthest distance from the "negative-ideal". Attribute weights are the required input from the decision maker.

The "ideal" solution is the one consisting of all the "best" attribute states available to the DM. Similarly, the "negative-ideal " solution is the one consisting of all the "worst" attribute states available to the DM. The method assumes that the utility function of each attribute is monotonically increasing (audio, picture, remote), or decreasing (price, repair), in order to support the above ideal solution locations.

Like the permutation method, the TOPSIS method was analyzed by writing and executing a BASIC computer program. The program was written to perform the number-crunching required in this method. Execution time was substantially less than the permutation method, since the calculations were not nearly as numerous.

From the given attributes and alternatives, the TOPSIS method first generates a normalized decision matrix, which places the attributes on a common scale. Each element in the normalized decision matrix is calculated using the following equation [9]:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{7} x_{ij}^{2}}$$

Multiplying the normalized decision matrix by the attribute weighting values provided by the DM results in the weighted normalized decision matrix.

The next step is to determine the "ideal" and "negative-ideal" solutions from the weighted normalized decision matrix. These are determined from the following equations [9]:

$$A^{*} = (\max v_{i1}, \max v_{i2}, \min v_{i3}, \max v_{i4}, \min v_{i5})$$

$$\bar{A} = (\min v_{i1}, \min v_{i2}, \max v_{i3}, \min v_{i4}, \max v_{i5})$$

Note that the price and repair values (attributes 3 and 5) are minimized while the others are maximized.

Now the separation measures, the distance of the alternatives from the "ideal" and negative-ideal" solutions, are calculated. These values are obtained from the following equations [9]:

$$S_i^* = \sqrt{\sum_{j=1}^{5} (v_{ij} - v_j^*)^2} \qquad i = 1, 2, 3, 4, 5, 6, 7$$

$$S_i^- = \sqrt{\sum_{j=1}^{5} (v_{ij} - v_j^-)^2} \qquad i = 1, 2, 3, 4, 5, 6, 7$$

Finally, the relative closeness to the ideal solution is calculated from the equation below:

$$C_i^* = S_i^- / (S_i^* + S_i^-) \qquad i = 1, 2, 3, 4, 5, 6, 7$$

The alternatives are then ranked based on the results of the above calculation.

3.6.13 ELECTRE

The ELECTRE (elimination 'et' choice translating algorithm) method attempts to reduce the number of alternatives based upon the idea of an outranking relationship [8]. The method, also referred to as concordance analysis, involves pairwise comparison of alternatives utilizing attribute weights defined by the decision maker, and concordance/discordance indices [9]. The resulting number of alternatives is dependent upon the concordance and discordance values either provided by the DM or generated from the attribute and alternative data. Attribute weights, and possibly concordance and discordance values are the required inputs from the decision maker.

The ELECTRE method is very relevant to decision making with a discrete number of alternatives. Its use was initially proposed by Benayoun, Roy, and Sussman in 1966 and improved by Roy in 1971 [8]. The output of the method is a reduced set of available alternatives.

Like TOPSIS, the ELECTRE method first generates a normalized decision matrix, which places the attributes on a common scale. Each element in the normalized decision matrix is calculated using the following equation [9]:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{7} x_{ij}^{2}}$$

Multiplying the normalized decision matrix by the attribute weighting values provided by the DM results in the weighted normalized decision matrix.

The next step is to determine the concordance and discordance sets. For each pair of alternatives, the concordance set consists of the instances where an attribute value for alternative one is greater than or equal to the attribute value for alternative two. Similarly, the discordance set consists of the instances where an attribute value for alternative one is less than the attribute value for alternative two.

A concordance matrix and a discordance matrix are calculated based upon the following equations [9]:

Concordance

$$c_{kl} = \sum_{j \in C_{kl}} w_j$$

w_j = preference weights from DM

Discordance

$$d_{kl} = \frac{\max_{j \in D_{kl}} | v_{kj} - v_{lj} |}{\max_{j \in J} | v_{kj} - v_{lj} |}$$

where v_{kl} and v_{lj} are from the weighted normalized decision matrix.

Threshold concordance and discordance values can be either provided by the DM or calculated from the alternative and attribute data. To calculate the values from the data, the average concordance and discordance indices are used. These values are obtained by summing all the elements of the matrix (except the diagonals) and dividing by the total number of elements summed.

The threshold values are used to generate a concordance dominance matrix and a discordance matrix. To create the concordance dominance matrix, if an element in the concordance matrix is greater than the concordance threshold value, then the corresponding element in the concordance dominance matrix is 1, otherwise it is 0. Similarly, to create the discordance matrix, if an element in the discordance matrix is less than the discordance threshold value, then the corresponding element in the discordance matrix is 1, otherwise it is 0.

The final step is to generate a aggregate dominance matrix, from the concordance dominance matrix and the discordance matrix. If an element position is 1 in both the initial

dominance matrices, it is also 1 in the aggregate dominance matrix, otherwise it is 0.

Examination of the aggregate dominance matrix is necessary to determine if any alternatives can be eliminated. Any columns containing a 1 can be eliminated by the ELECTRE method [9].

3.6.14 Simple Additive Weighting

The simple additive weighting method is the additive method utilized by the SmartEdge decision support model [16]. Its description and use is described in Section 3.5.2 of this report.

CHAPTER 4 RESULTS

The project Results section is divided into two parts. Part 1 describes the results of the surveyed decision maker preferences. Part 2 contains the results from the MADM methods analyzed in this report. Note that the final decision output obtained from the SmartEdge model is also included as one of the decision models in the results of MADM methodologies discussed in Part 2.

4.1 Part 1 - Survey and SmartEdge Results

4.1.1 Survey Results

There were sixteen participants who responded to the VCR selection survey. Responses from the survey included the following: (1) attribute utility values for each of the attributes, (2) attribute weights for each of the attributes, and (3) a rank ordering of the VCR alternatives, based upon the respondent's preferences. Tables 4.1.1.1, 4.1.1.2, and 4.1.1.3, respectively, summarize the above results.

The average attribute utility values are as follows: Audio - 9.91, Picture - 78.1, Price - $425, Remote - 8.4, Repair - 18.9. The average attribute weight values are as

Table 4.1.1.1 - Survey Results for Attribute Utilities

RESPONDENT

Attribute	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6
AUDIO	8.6	8.8	10.6	10.9	8.1	11
PICTURE	72	78	86	83	70.1	80
PRICE	$425	$400	$420	$377	$499	$415
REMOTE	6.7	8.6	10	11	6.1	9
REPAIR	29%	14%	13%	10.2%	35.9%	22%

Table 4.1.1.1 - Survey Results for Attribute Utilities (continued)

RESPONDENT

Attribute	NO. 7	NO. 8	NO. 9	NO. 10	NO. 11
AUDIO	10.8	10.1	10.5	10.9	9.0
PICTURE	79	80	80	78	84
PRICE	$400	$393	$415	$441	$425
REMOTE	7.5	9.4	7.5	7.5	6.3
REPAIR	18%	21%	23%	23%	8.1%

Table 4.1.1.1 - Survey Results for Attribute Utilities (continued)

RESPONDENT

Attribute	NO. 12	NO. 13	NO. 14	NO. 15	NO. 16
AUDIO	11.1	9.0	10.5	8.2	10.5
PICTURE	73	72	79	75	80
PRICE	$380	$457	$494	$457	$409
REMOTE	10	7.1	9.1	8	11
REPAIR	11	29%	21%	23%	10.5%

Table 4.1.1.2 - Survey Results for Attribute Weights

RESPONDENT

Attribute	NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6
AUDIO	.10	.20	.25	.20	.30	.25
PICTURE	.20	.20	.30	.25	.30	.25
PRICE	.50	.40	.30	.25	.25	.25
REMOTE	.05	.10	.10	.10	.05	.10
REPAIR	.15	.10	.05	.20	.10	.15

Table 4.1.1.2 - Survey Results for Attribute Weights (continued)

RESPONDENT

Attribute	NO. 7	NO. 8	NO. 9	NO. 10	NO. 11
AUDIO	.20	.25	.20	.25	.20
PICTURE	.30	.25	.25	.25	.20
PRICE	.25	.25	.25	.25	.25
REMOTE	.05	.05	.05	.05	.05
REPAIR	.20	.20	.25	.20	.30

Table 4.1.1.2 - Survey Results for Attribute Weights (continued)

RESPONDENT

Attribute	NO. 12	NO. 13	NO. 14	NO. 15	NO. 16
AUDIO	.05	.10	.25	.20	.15
PICTURE	.05	.10	.25	.20	.20
PRICE	.20	.40	.15	.25	.20
REMOTE	.50	.10	.05	.10	.05
REPAIR	.20	.30	.30	.25	.40

Table 4.1.1.3 - Survey Results for Alternative Ranking

Alternative Ranking

Surv. No.	1st	2nd	3rd	4th	5th	6th	7th
1	5*	2	4	1	3	6	7
2	6	7	1	5	4	2	3
3	1	2	5	4	3	6	7
4	6	5	2	7	4	1	3
5	4	3	5	1	6	2	7
6	4	3	5	7	2	1	6
7	1	5	4	3	6	7	2
8	4	5	3	1	6	7	2
9	5	4	1	2	7	6	3
10	6	1	4	5	7	2	3
11	6	4	5	3	2	7	1
12	5	2	3	7	4	6	1
13	4	6	5	2	7	1	3
14	5	4	6	2	3	7	1
15	6	5	2	4	7	3	1
16	2	6	5	7	4	3	1

NOTE: * indicates VCR number

follows: Audio - .20, Picture - .22, Price - .27, Remote - .10, Repair -.21. These average weight values most closely resembled the weight assessments of decision maker number four. Thus, decision maker number four's weight assessments were used when weight preferences were required by any of the multiattribute decision methods in Part 2 of this report.

Table 4.1.1.4 presents the trend of results for VCR preference of the survey respondents as a group. For first choice (i.e., "best") VCR selection, group preferences identified VCR 6. For last choice (i.e., "worst") VCR selection, group preferences identified either VCR 1 or VCR 3. For "FIRST 2" choice (i.e., either first or second), group preferences identified VCR 5. For "MID 3" choice (i.e., fourth, fifth, or sixth), group preferences identified VCR 4. And finally, for "LAST 2" choice (i.e., sixth or seventh), group preferences identified VCR 1.

4.1.2 SmartEdge Model Results

Responses from the survey were compiled and entered into the SmartEdge computer model for analysis. Table 4.1.2.1 presents the rank ordering of alternatives generated by

Table 4.1.1.4 - Number of Survey Respondents Indicating Certain VCR Preferences

Rank	VCR 1	VCR 2	VCR 3	VCR 4	VCR 5	VCR 6	VCR 7
1st	2	1	0	4	4	5	0
2nd	1	3	2	3	4	2	1
3rd	2	2	2	3	6	1	0
4th	3	3	2	2	2	0	4
5th	0	2	3	4	0	3	4
6th	3	3	2	0	0	4	4
7th	5	2	5	0	0	1	3
1&2	3	4	2	7	8	7	1
3&4&5	5	7	7	9	8	4	8
6&7	8	5	7	0	0	5	7

Table 4.1.2.1 - SmartEdge Results for Alternative Ranking

Alternative Ranking

Surv. No.	1st	2nd	3rd	4th	5th	6th	7th
1	1	2	5	4	7	6	3
2	1	5	4	3	2	6	7
3	4	1	5	3	6	2	7
4	4	5	1	3	6	2	7
5	4	5	1	6	3	2	7
6	4	5	3	1	6	2	7
7	4	5	3	1	6	2	7
8	4	5	3	1	6	2	7
9	4	5	3	1	6	2	7
10	4	5	3	1	6	2	7
11	6	4	5	1	3	7	2
12	5	2	3	6	4	7	1
13	5	2	6	4	7	1	3
14	4	5	3	6	2	1	7
15	5	4	3	6	2	1	7
16	6	5	4	3	2	1	7

SmartEdge foreach of the respondents. Table 4.1.2.2 presents the trend of results for VCR preference based on the SmartEdge results. For first choice VCR selection, SmartEdge results identified VCR 4. For last choice VCR selection, SmartEdge results identified VCR 7, without a doubt. For "FIRST 2" choice, SmartEdge results identified VCR 5. For "MID 3" choice, SmartEdge results identified VCR 3. And finally, for "LAST 2" choice, SmartEdge results identified VCR 7.

4.1.3 Comparison of Survey Results and SmartEdge Results

There was some discrepancy between the actual selections of the decision makers and the SmartEdge model results based upon the decision makers' preferences. Comparison of an individual's preference ordering to the ordering generated by SmartEdge was identical in only 31% of the cases for the VCR of first choice. For the VCR of last choice, the comparison was identical for only 25% of the respondents. However, examining the distribution of choice for the first two choices, the middle three choices, and the last two choices did reveal some trends.

Table 4.1.2.2 - Number of SmartEdge Results Indicating Certain VCR Preferences

Rank	VCR 1	VCR 2	VCR 3	VCR 4	VCR 5	VCR 6	VCR 7
1st	2	0	0	9	3	2	0
2nd	1	3	0	2	10	0	0
3rd	2	0	8	2	3	1	0
4th	6	0	4	2	0	4	0
5th	0	4	2	1	0	7	2
6th	4	8	0	0	0	2	2
7th	1	1	2	0	0	0	12
1&2	3	3	0	11	13	2	0
3&4&5	8	4	14	5	3	12	2
6&7	5	9	2	0	0	2	14

For the first two, the survey respondents indicated a preference for VCR 5, followed closely by VCR 4 and then VCR 6. Similarly, SmartEdge also selected VCR 4 and VCR 5; however, VCR 6 was not selected. Thus, it appears as though both VCR 4 and VCR 5 are considered superior selections.

Survey responses were rather evenly spread between VCR selections for the middle choices, where SmartEdge showed a definite preference for VCR 3 and VCR 6 in the middle. In contrast to SmartEdge's placement of VCR 6 in the middle range, survey respondents seemed to either "like" or "dislike" VCR 6, with very little preference in the middle.

The last two choices trend was more pronounced in two ways. First, neither SmartEdge nor any respondent chose VCR 4 or VCR 5 in the last two. This is significant because VCR 4 and VCR 5 were also highly rated in the first two choices as discussed above. Second, SmartEdge identified VCR 7 as the "big loser" with a whopping 88% of the choices in the last two. Survey respondents were not that emphatic, with only 44%; however, VCR 7 did appear only once in the first two choices for the sixteen survey respondents. Thus, it is apparent that both survey respondents and SmartEdge consider VCR 7 to be an inferior selection.

Table 4.1.3.1 shows the calculations using the Rank Sum Rule for both survey respondents and SmartEdge. The Rank Sum Rule sums the ordinal ranks for each VCR alternative, thus, the lowest sum is the most preferred [16]. The final survey group rank ordering is 5-4-6-2-1-3-7 and the final SmartEdge group rank ordering is 4/5-3-1-6-2-7 where VCR 4 and VCR 5 are tied.

Resulting data are then converted to an "approval" rating between -1 and +1 for each of the VCR alternatives, as shown in Table 4.1.3.1. An approval rating of +1 indicates "best" choice, 0 indicates "middle-of-the-road" choice, and -1 indicates "worst" choice. The approval ratings are then graphed in Figure 4.1.3.1 for both survey results and SmartEdge so output between the survey and SmartEdge can be visually compared.

Additionally, to consider slight variances in the original ranking results, the data for the combined 1st/2nd, 3rd/4th/5th, 6th/7th alternative rankings were also analyzed as above. The final survey group rank ordering using this data is 5-4-6-2-1/3-7 and the final SmartEdge group rank ordering is 5-4-6-1/3-2-7 where VCR 1 and VCR 3 are tied in both cases. The results are strikingly similar. Approval

Table 4.1.3.1 Alternative Ordering via Rank Sum Rule

Survey

VCR 1 2(1) + 1(2) + 2(3) + 3(4) + 0(5) + 3(6) + 5(7) = 75

SmartEdge

VCR 1 2(1) + 1(2) + 2(3) + 6(4) + 0(5) + 4(6) + 1(7) = 65

	Original Rank Values		Approval Values	
	Survey	SmartEdge	Survey	SmartEdge
VCR 1	75	65	-.2292	-.0208
VCR 2	67	81	-.0625	-.3542
VCR 3	80	64	-.3333	0
VCR 4	47	32	+.3542	+.6667
VCR 5	38	32	+.5417	+.6667
VCR 6	58	68	+.1250	-.0833
VCR 7	83	106	-.3958	-.8750

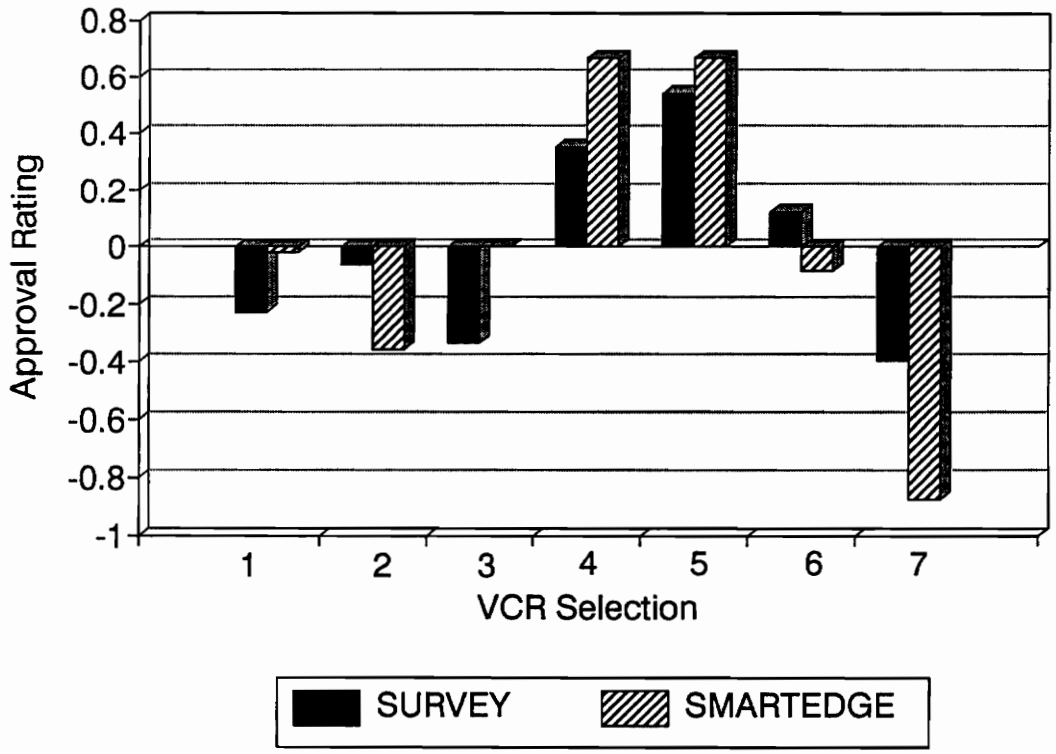

Figure 4.1.3.1 Rank Sum Comparison of Survey and SmartEdge Results

ratings were also calculated as shown in Table 4.1.3.2, with the results graphically displayed in Figure 4.1.3.2.

4.2 Part 2 - MADM Method Results

4.2.1 Dominance

Dominance was used during the analysis of test data to eliminate some of the VCR alternatives. Its use resulted in the elimination of three of the initial sixteen VCR alternatives as demonstrated previously in Table 3.4.2.

4.2.2 Maximin

For the VCR test case, the assumption was that each scale was linear with a range from the minimum available attribute value to the maximum available attribute value. For example, for audio quality, minimum value is 8, maximum value is 13, 50% audio quality value is 10.5, etc.

Applying the maximin methodology then involved comparing the following minimum attribute values for each VCR alternative:

VCR 1 Remote = 6 or Repair = 36%

VCR 2 Audio = 8 VCR 3 Price = $500

Table 4.1.3.2 Group Alternative Ordering via Rank Sum Rule

	Original Rank Values		Approval Values	
	Survey	SmartEdge	Survey	SmartEdge
VCR 1	37	34	-.3125	-.1250
VCR 2	33	38	-.0625	-.3750
VCR 3	37	34	-.3125	-.1250
VCR 4	25	21	+.4375	+.6875
VCR 5	24	19	+.5000	+.8125
VCR 6	30	32	+.1250	0
VCR 7	38	46	-.3750	-.8750

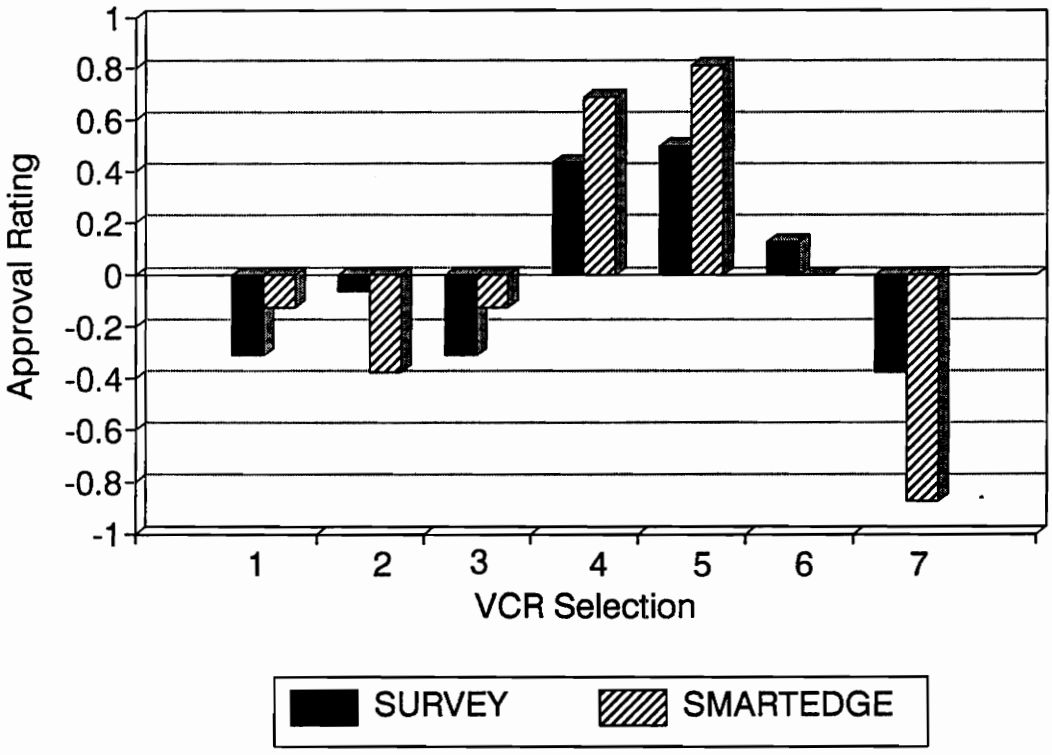

Figure 4.1.3.2 Group Rank Sum Comparison of Survey and SmartEdge

VCR 4 Price = $470 VCR 5 Price = $455

VCR 6 Picture = 71 VCR 7 Picture = 70

Note that VCRs 1, 2, 3, and 7 are immediately eliminated, each having the minimum values for their respective attributes. Of the remaining three VCRs, VCR 6 picture quality is nearly minimal and is therefore eliminated. VCR 5 has a "better" price than VCR 6; therefore, VCR 5 is selected via the maximin method.

4.2.3 Maximax

As with maximin, the assumption was that each scale was linear with a range from the minimum available attribute value to the maximum available attribute value. Applying the maximax methodology then involved comparing the following maximum attribute values for each VCR alternative:

VCR 1 Price = $330 VCR 2 Repair = 10%

VCR 3 Picture = 88 VCR 4 Audio = 13 or Picture = 90

VCR 5 Remote = 12 VCR 6 Repair = 8%

VCR 7 Repair = 19%

Note that VCRs 1, 4, 5, and 6 have the maximum values for their respective attributes. Thus, via the maximax method, any one of these four VCRs can be chosen. All maximax has

done in this case is reduced the decision space of alternatives from seven to four.

4.2.4 Copeland's Reasonable Social Welfare Function

For the VCR test case of seven alternatives, there are 21 pairwise comparisons. Figure 4.2.4.1 presents the results of each of these comparisons using the Copeland's method. Note that ties between comparisons result in each alternative in the pairwise comparison being credited with .5 of a point. For example, the total for Alternative 3 is determined as follows: 1 point vs. Alternative 1, .5 point vs. Alternative 2, .5 point vs. Alternative 6, and 1 point vs. Alternative 7, for a total of 3 points. The final point summation results in the following possible rankings of the alternatives: 5 - 4 - 2 - 3 - 6 - 1 - 7,

or 5 - 4 - 2 - 6 - 3 - 1 - 7.

Note that a tie occurs between alternatives 3 and 6, explaining the resulting two possible alternative rankings.

4.2.5 Conjunctive

The minimal attribute levels set by the decision maker determine the output of the conjunctive model. That is, depending on the level set for each of the attributes, either none, one or several alternatives can be considered

Alternative Numbers		Winner	Alternative Numbers		Winner
1	2	1	3	4	4
1	3	3	3	5	5
1	4	4	3	6	3,6
1	5	5	3	7	3
1	6	1,6	4	5	5
1	7	1	4	6	4
2	3	2,3	4	7	4
2	4	2	5	6	6
2	5	5	5	7	5
2	6	2	6	7	6
2	7	2			

Alternative	Number of "Wins"	Final Rank
1	2.5	6th
2	3.5	3rd
3	3	4th/5th
4	4	2nd
5	5	1st
6	2	4th/5th
7	0	7th

Final Ranking 5-4-2-3-6-1-7; or 5-4-2-6-3-1-7

Figure 4.2.4.1 Calculations for Copeland's Method

as the decision choice. In the VCR test case, if a minimum attribute level of 25% of the level of each attribute is requested by the decision maker, and a linear attribute scale is assumed, then only one choice, VCR 5, meets this criteria for all attributes.

4.2.6 Conjunctive Ranking

For the VCR problem, the minimal attribute levels set by the decision maker would eliminate VCR 1 due to minimal remote and maximum repair, VCR 2 due to minimal audio, VCR 3 due to maximum price, and VCR 7 due to minimal picture. Only if the decision maker believed that one of the attributes had no effect on his VCR choice would one of these VCRs remain as a viable alternative. Assuming that the remaining three VCRs meet the minimal acceptable levels established, the final order would depend upon which attribute is chosen as the ranking attribute as detailed below:

Ranking Attribute	Final Alternative Ranking
Audio	4 - 6 - 5 - 2
Picture	4 - 5 - 6 - 7
Price	6 - 5 - 4 - 3
Remote	5 - 4 - 6
Repair	6 - 5 - 4

Note that for audio, picture, and price, VCRs 2, 7, and 3 would not have been eliminated due to minimal attribute values, so they are part of the final alternative ranking. For remote and repair, VCR 1 is minimal in both; therefore, regardless of which ranking attribute is chosen, VCR 1 would be eliminated on the other one. Thus, VCR 1 is not included in any of the alternative final rankings.

4.2.7 Disjunctive

For the VCR selection problem, the best values of each of the attributes are as follows:

Audio - 13	VCR 4	Picture - 90	VCR 4
Price - $330	VCR 1	Remote - 12	VCR 5
Repair - 8%	VCR 6		

There is also a requirement for minimal acceptable attribute values identified by the decision maker. This stipulation eliminates VCR 1 due to minimal values for remote and repair. Thus, the choice is between VCR 4, VCR 5, and VCR 6. Note that the picture quality for VCR 6 is extremely low and the price for VCR 4 is rather high. If these values did not meet the minimal acceptable attribute levels prescribed by the DM, then the final decision choice would be VCR 5.

4.2.8 Lexicographic

The output of the lexicographic method is a "best" choice among alternatives based upon the decision maker's ranking of the attributes. Since there is only one VCR for the maximum value of each attribute in the VCR problem, the lexicographic method in this case gives the following results depending upon decision maker attribute ranking.

Attribute Ranked First	Alternative Selection
Audio	VCR 4
Picture	VCR 4
Price	VCR 1
Remote	VCR 5
Repair	VCR 1

If there had been a tie on the value of one of the attributes, then the value of the attribute ranked second by the decision maker would be used to break the tie among the alternatives.

4.2.9 Permutation Method

The derivation of the permutation method results are best illustrated with a sample calculation from the VCR test case. To determine the evaluation criteria value for the

rank ordering 1-2-3-4-5-6-7, the concordance matrix, C, is developed as illustrated in Figure 4.2.9.1. For element C_{12} which indicates the concordance of alternative 1 and alternative 2, there are three attributes (audio, picture, and price) for which alternative 1 is better or equal to alternative 2. The sum of these three attribute weights appears as the value of element C_{12}. Similarly, the calculations for the remainder of concordance with alternative 1 are illustrated. Once the matrix is complete, the above diagonal elements (top) and below diagonal elements (bottom) are summed as shown in the figure. The difference is then the final evaluation criteria.

The permutation method ranks the alternatives based upon attribute weights supplied by the DM. For the seven alternatives, the BASIC program was incredibly slow taking over 3 hours to determine a final solution. The final output resulted in the following VCR alternative ranking: 5 - 4 - 3 - 1 - 2 - 6 - 7.

The final evaluation criteria concordance value for this ranking is 5.1, significantly better than the 1.7 value calculated in the sample alternative ranking of 1 - 2 - 3 - 4 - 5 - 6 - 7 in Figure 4.2.9.1. Again, this calculation is based on the following weights entered by the sample

	1	2	3	4	5	6	7
1	0	0.70	0.45	0.25	0.45	0.70	0.70
2	0.30	0	0.55	0.55	0.45	0.60	0.80
3	0.75	0.55	0	0.30	0.45	0.55	0.75
4	0.75	0.45	0.70	0	0.45	0.55	0.75
5	0.55	0.75	0.55	0.55	0	0.35	0.75
6	0.50	0.40	0.65	0.45	0.65	0	0.75
7	0.30	0.20	0.25	0.25	0.25	0.35	0

Sample Calculations

$C_{12} = .20 + .25 + .25 = .70$

$C_{13} = .20 + .25 = .45$

$C_{14} = .25$

$C_{15} = .20 + .25 = .45$

$C_{16} = .20 + .25 + .25 = .70$

$C_{17} = .20 + .25 + .25 = .70$

Sum above diagonal = 11.85 Sum below diagonal = 10.15

Evaluation criteria = 11.85 - 10.15 = 1.70

Figure 4.2.9.1 Calculations for the Permutation Method

decision maker: Audio - .20, Picture - .25, Price - .25, Remote - .10, and Repair - .20.

4.2.10 Linear Assignment Method

The linear assignment method ranks the alternatives based upon attribute weights provided by the decision maker. For the simple case of summing the alternative rankings, Figure 3.7 illustrates the calculations involved to determine the final alternative ranking. The alternative ranking results of the simple method of summation of attribute ranks (no required DM input) are 5 - 4 - 3 - 2 - 6 - 1 - 7.

For the comprehensive linear assignment method, the attribute ranking illustrated in Figure 4.2.10.1 is used as the starting point for determination of the initial decision matrix as presented in Figure 4.2.10.2. In order to get the values within the matrix, each alternative ranking is multiplied by the weight of the associated attribute. When an alternative has the same ranking on several attributes, the weighted ranking values are summed together. For example, the value of .45 for element 4,1 is the weighting when VCR 4 is ranked first. This occurs for the Audio attribute with weight .20, and also for the Picture attribute with weight .25. Thus, the element value is calculated as .20 + .25 = .45. Similar calculations are

Rank	Audio	Picture	Price	Remote	Repair
1	4*	4	1	5	6
2	1,3,6	3	2	2,3	2,5
3	----	5	7	----	----
4	----	1	6	4	3
5	5	2	5	6,7	4
6	7	6	4	----	7
7	2	7	3	1	1

* indicates VCR number

Rank VCR 1 = 1 + (2 + 3 + 4)/3 + 4 + 7 + 7 = 22

Rank VCR 2 = 2 + (2 + 3)/2 + (2 + 3)/2 + 5 + 7 = 19

Rank VCR 3 = (2 + 3 + 4)/3 + 2 + (2 + 3)/2 + 4 + 7 = 18.5

Rank VCR 4 = 1 + 1 + 4 + 5 + 6 = 17

Rank VCR 5 = 1 + (2 + 3)/2 + 3 + 5 + 5 = 16.5

Rank VCR 6 = 1 + (2 + 3 + 4)/3 + 4 + (5 + 6)/2 + 6 = 19.5

Rank VCR 7 = 3 + (5 + 6)/2 + 6 + 6 + 7 = 27.5

Final Ranking is: 5 - 4 - 3 - 2 - 6 - 1 - 7

Figure 4.2.10.1 Calculations for Simple Sum of Rankings

VCR	Rank 1st	2nd	3rd	4th	5th	6th	7th
1	0.25	0.07	0.07	0.32	0	0	0.30
2	0	0.40	0.15	0	0.25	0	0.20
3	0	0.37	0.12	0.27	0	0	0.25
4	0.45	0	0	0.10	0.20	0.25	0
5	0.10	0.10	0.35	0	0.45	0	0
6	0.20	0.07	0.07	0.32	0.05	0.30	0
7	0	0	0.25	0	0.05	0.45	0.25

Initial Decision Matrix

Figure 4.2.10.2 Calculations for Linear Assignment Method

VCR	Rank 1st	2nd	3rd	4th	5th	6th	7th
1	-.25	-.07	-.07	-.32	0	0	-.30
2	0	-.40	-.15	0	-.25	0	-.20
3	0	-.37	-.12	-.27	0	0	-.25
4	-.45	0	0	-.10	-.20	-.25	0
5	-.10	-.10	-.35	0	-.45	0	0
6	-.20	-.07	-.07	-.32	-.05	-.30	0
7	0	0	-.25	0	-.05	-.45	-.25

Negative Decision Matrix

Figure 4.2.10.2 Calculations for Linear Assignment Method (continued)

VCR	Rank 1st	2nd	3rd	4th	5th	6th	7th
1	.07	.25	.25	0	.32	.32	.02
2	.40	0	.25	.40	.15	.40	.20
3	.37	0	.25	.10	.37	.37	.12
4	0	.45	.45	.35	.25	.20	.45
5	.35	.35	.10	.45	0	.45	.45
6	.12	.25	.25	0	.27	.02	.32
7	.45	.45	.20	.45	.40	0	.20

Matrix A

Figure 4.2.10.2 Calculations for Linear Assignment Method (continued)

VCR	Rank 1st	2nd	3rd	4th	5th	6th	7th
1	.05	.25	.23	0	.32	.32	0
2	.38	0	.23	.40	.15	.40	.18
3	.35	0	.23	.10	.37	.37	.10
4	0	.47	.45	.37	.27	.22	.45
5	.33	.35	.08	.45	0	.45	.43
6	.10	.25	.23	0	.27	.02	.30
7	.43	.45	.18	.45	.40	0	.18

Matrix B

Figure 4.2.10.2 Calculations for Linear Assignment Method (continued)

VCR	Rank 1st	2nd	3rd	4th	5th	6th	7th
1	.13	.33	.23	0	.40	.40	0
2	.38	0	.15	.32	.15	.40	.10
3	.35	0	.15	.02	.37	.37	.02
4	0	.47	.37	.29	.27	.22	.37
5	.33	.35	0	.37	0	.45	.35
6	.18	.33	.23	0	.35	.10	.30
7	.43	.45	.10	.37	.40	0	.10

Matrix C

Figure 4.2.10.2 Calculations for Linear Assignment Method (continued)

Rank

VCR	1st	2nd	3rd	4th	5th	6th	7th
1	.13	.33	.08	0	.25	.35	0
2	.38	0	0	.32	0	.35	.10
3	.35	0	0	.02	.22	.32	.02
4	0	.47	.22	.29	.12	.15	.37
5	.48	.50	0	.52	0	.55	.50
6	.18	.33	.08	0	.20	.05	.30
7	.48	.50	0	.42	.30	0	.15

Matrix D

There are three possible optimal assignments

4-2-3-6-5-7-1 ==> .45 + .40 + .12 + .32 + .45 + .45 + .30

4-3-2-6-5-7-1 ==> .45 + .37 + .15 + .32 + .45 + .45 + .30

4-3-5-6-2-7-1 ==> .45 + .37 + .35 + .32 + .25 + .45 + .30

Maximum value of 2.49 as determined from the initial matrix

Figure 4.2.10.2 Calculations for Linear Assignment Method (continued)

performed to determine the values of the remaining elements in the matrix.

Since the problem is maximization, the initial step is to replace each element with its negative as shown in the Negative decision matrix. Then, the most negative element in each row is subtracted from all elements in the row to produce Matrix A. Since Matrix A is not optimal, successive iterations are performed, as described in Fabrycky, to produce Matrices B, C, and D [3]. Note that Matrix D is an optimal Matrix so the optimization procedure is complete.

The optimization of the linear assignment model with weights from the same surveyed decision maker produced the following three possible alternative ranking possibilities:
4 - 2 - 3 - 6 - 5 - 7 - 1; 4 - 3 - 2 - 6 - 5 - 7 - 1; or
4 - 3 - 5 - 6 - 2 - 7 - 1 as illustrated in Figure 4.2.10.2
Note that all three possibilities result in the optimal value of 2.49 as determined from summing the elements in the initial decision matrix for each of the alternative ranking results.

4.2.11 Hierarchial Additive Weighting

Calculations for the hierarchial additive weighting method are presented in Figure 4.2.11.1. The decision maker

VCR	Audio	Picture	Price	Remote	Repair
1	.1523	.1431	.1835	.0923	.0531
2	.1060	.1324	.1514	.1692	.1910
3	.1523	.1574	.1211	.1692	.1194
4	.1722	.1610	.1288	.1385	.1061
5	.1391	.1538	.1331	.1846	.1910
6	.1523	.1270	.1345	.1231	.2388
7	.1258	.1252	.1477	.1231	.1005

Alternative	Result	Ranking
VCR 1	.13196	6th
VCR 2	.14727	3rd
VCR 3	.14089	5th
VCR 4	.14196	4th
VCR 5	.15621	1st
VCR 6	.15591	2nd
VCR 7	.12580	7th

Final Ranking 5 - 6 - 2 - 4 - 3 - 1 - 7

Figure 4.2.11.1 Calculations for the Hierarchial Additive Weighting Method

weighting vector is w = [.20 .25 .25 .10 .20]. This vector has been multiplied by the matrix to produce the final Result value shown for each VCR alternative. The final ranking from the hierarchial additive weighting method is 5-6-2-4-3-1-7.

4.2.12 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

For the VCR test problem, note that the "ideal" solution consists of the following values for each of the attributes: Audio - 13, Picture - 90, Price - $330, Remote - 12, and Repair - 8%. The "negative-ideal" solution consists of the following values: Audio - 8, Picture - 70, Price - $500, Remote - 6, and Repair - 36%. These values are noted for the DM's point of reference. It is the weighted normalized values of these "ideals" that are utilized for comparability among the attributes in the TOPSIS method.

The normalized decision matrix and weighted normalized decision matrix are presented in Figure 4.2.12.1, weights being those supplied by the DM of [.20, .25, .25, .10, .20]. The "ideal " and "negative-ideal" solutions, obtained from the weighted normalized decision matrix of Figure 4.2.12.1, are given in Figure 4.2.12.2. Figure 4.2.12.2 also presents the separation measures from the "ideal" and "negative-

	1	2	3	4	5	6	7
Audio	.399	.278	.399	.451	.365	.399	.330
Picture	.377	.349	.415	.424	.405	.334	.330
Price	.288	.348	.436	.409	.396	.392	.357
Remote	.239	.438	.438	.358	.478	.318	.318
Repair	.720	.200	.320	.360	.200	.160	.380

Normalized Decision Matrix - R

	1	2	3	4	5	6	7
Audio	.0798	.0555	.0798	.0902	.0729	.0798	.0659
Picture	.0942	.0872	.1036	.1060	.1013	.0836	.0824
Price	.0719	.0871	.1089	.1024	.0991	.0980	.0893
Remote	.0239	.0438	.0438	.0358	.0478	.0318	.0318
Repair	.1440	.0400	.0640	.0720	.0400	.0320	.0760

Weighted Normalized Decision Matrix - V

Figure 4.2.12.1 Matrices for the TOPSIS Method

$A^* = [.0902, .1060, .0719, .0477, .0320]$ "ideal"

$A^- = [.0555, .0824, .1089, .0239, .1440]$ "negative-ideal"

$S_1^* = .1156$	$S_1^- = .0458$	$C_1^* = .2839$
$S_2^* = .0433$	$S_2^- = .1082$	$C_2^* = .7143$
$S_3^* = .0524$	$S_3^- = .0885$	$C_3^* = .6379$
$S_4^* = .0517$	$S_4^- = .0844$	$C_4^* = .6202$
$S_5^* = .0336$	$S_5^- = .1102$	$C_5^* = .7663$
$S_6^* = .0393$	$S_6^- = .1154$	$C_6^* = .7458$
$S_7^* = .0603$	$S_7^- = .0720$	$C_7^* = .5440$

Final Alternative Ranking 5 - 6 - 2 - 3 - 4 - 7 - 1

Figure 4.2.12.2 Results of Calculations for the TOPSIS Method

ideal" and the relative closeness values to the "ideal" solution. Based upon the relative closeness values, the final alternative ranking from the TOPSIS method is 5-6-2-3-4-7-1.

4.2.13 ELECTRE

The calculations for the normalized matrix and the initial normalized matrix are the same as those for TOPSIS, as presented in Figure 4.2.12.1. The concordance and discordance sets, presented in Figure 4.2.12.2, are determined by pairwise comparisons of alternatives for each of the attribute values.

A concordance matrix and a discordance matrix are calculated as shown in Figure 4.2.13.1. Threshold concordance and discordance values are based on the average concordance and discordance indices and are also presented in Figure 4.2.13.1.

The concordance dominance matrix and discordance dominance matrix generated from the above matrices and threshold values are presented in Figure 4.2.13.2. Figure 4.2.13.2 also presents the aggregate dominance matrix, which is used to determine which, if any, alternatives can be eliminated.

	1	2	3	4	5	6	7
1	----	.70	.45	.25	.45	.70	.70
2	.30	----	.55	.55	.45	.60	.80
3	.65	.50	----	.30	.45	.45	.75
4	.75	.45	.70	----	.45	.55	.75
5	.55	.55	.55	.55	----	.35	.75
6	.40	.40	.55	.45	.65	----	.75
7	.30	.20	.25	.25	.25	.30	----

Concordance Matrix - C

	1	2	3	4	5	6	7
1	----	1	1	1	1	1	1
2	.234	----	1	1	1	1	.289
3	.463	.988	----	1	1	1	.925
4	.424	.982	.769	----	1	1	539
5	.262	.690	.288	.541	----	.500	.272
6	.233	.494	.625	.560	1	----	.198
7	.256	1	1	1	1	1	----

Discordance Matrix - D

Figure 4.2.13.1 ELECTRE Concordance and Discordance Matrix

$$C = \begin{vmatrix} ---- & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & ---- & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & ---- & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & ---- & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & ---- & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & ---- & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & --- \end{vmatrix}$$

$$D = \begin{vmatrix} ---- & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & ---- & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & ---- & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & ---- & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & ---- & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & ---- & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & --- \end{vmatrix}$$

$$C+D = \begin{vmatrix} ---- & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & ---- & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & ---- & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & ---- & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & ---- & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & ---- & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & --- \end{vmatrix}$$

Figure 4.2.13.2 ELECTRE Dominance Matrices

Examination of the aggregate dominance matrix reveals that all alternatives except VCR 5 and VCR 6 can be eliminated by the ELECTRE method. Further examination shows the extreme dominance of VCR 5. That is, VCR 5 dominates all alternatives except VCR 6.

4.2.14 Simple Additive Weighting

Simple additive weighting results are the output of the SmartEdge decision support model. These results are described in Section 4.1 of this report.

CHAPTER 5 DISCUSSION

Like the Results Chapter, the Discussion Chapter is also divided into two parts. This Part 1 analyzes the results of the surveyed decision maker preferences as compared to the results generated by the SmartEdge computer model. This Part 2 discusses the results from the MADM methods analyzed in this report. The outputs of the various methods are interpreted for agreement/disagreement among the final decisions.

5.1 Part 1 - Survey and SmartEdge Methodology

5.1.1 Use of SmartEdge in Survey Form

The SmartEdge methodology was employed using the Detailed Mode/Deterministic additive model. The multiplicative model would be used if the weighted rankings did not sum to one. It was believed that the methodology for assessment of weights for the multiplicative model would be too difficult for the respondents to understand in a survey form. Thus, the survey was written for the weights to sum to one so that the additive form would be used.

When answering questions interactively using the SmartEdge system, the decision maker is prompted for data entry and

questioned when inconsistencies appear in the responses. Thus, the model assures that no inconsistencies can be entered into the system. A survey, on the other hand, would not be able to ensure that "mistakes" are not made by the respondents.

As a matter of fact, some respondents did have difficulty answering one of the questions in the current survey. During utility assessment, over one-half of the respondents misunderstood the wording of the final decision tree question which directly assesses the decision maker's indifference point. The question, "For what value of the "Sure Thing" are you indifferent? Choose a value between 'x' and 'y' =" is posed to the decision maker if he or she has not selected indifference to one of the previous attribute values specified. The question was repeatedly interpreted to include the values of "x" and "y" as one of the choices. Thus, the use of the word "between", indicating values of "x" and "y" are not included, was repeatedly overlooked. As a result, many respondents selected either the "x" or the "y" value instead of a value "between" x and y.

If the SmartEdge model were being utilized interactively, the "x" or "y" value would not have been accepted by the system. Instead the respondent would have been alerted that

the value must be between "x" and "y". At this point, he or she would have been able to either enter a value between "x" and "y", or start the utility assessment over at the beginning for that particular attribute. Thus, using the interactive system, the respondent would have been prevented from making this mistake.

To eliminate this respondent error so the SmartEdge model could be utilized in this report analysis, the indifference value entered in direct response to an indifference question was used as the point of indifference. This required retracing the decision tree to find the question where the "x" or "y" value was given as the Sure Thing for the lottery. Answering Indifferent to that question, as opposed to the Gamble or Sure Thing response of the individual answering the survey, resulted in the indifference point that was later given directly by the respondent.

5.1.2 SmartEdge Additive Model Methodology

The SmartEdge methodology used in this report is based on the simple additive weighting model. To utilize this model, the decision maker must input attribute weights and utility preference data. Thus, a disadvantage of this method is the amount of data required from the decision maker. Further, the attributes must be on a comparable scale so that the

weights and utilities obtained from the decision maker can be multiplied and added as required by the model. The main advantages of the method are its easy implementation, once all DM data is obtained, and the fact the method utilizes all attribute values of all alternatives in the calculations.

5.2 Part 2 - MADM Methods

5.2.1 Dominance

One of the main advantages of the use of dominance in decision making is that no preference information is required from the decision maker. Additionally, a common scale across attributes is not required. A major disadvantage is that generally if there are a large number of alternatives or attributes, dominance does not eliminate many of the alternatives. This was evidenced in the VCR test case by the fact that only three of the original sixteen alternatives were eliminated. Generally, dominance is used as a screening process to initially reduce the number of available alternatives, after which subsequent method(s) are applied.

5.2.2 Maximin

Like dominance, one of the main advantages of maximin is the fact that no preference information is required from the decision maker. On the other hand, a main disadvantage of maximin is the requirement for a comparative scale of measurement between attributes. This effective requirement for comparability between attributes may require subjective input from the decision maker. Some type of conversion to a comparable scale is required by the "expert" in the problem solution, be that either the decision analyst, the decision maker, or someone else. Further, maximin may eliminate a reasonably "good" alternative due to poor performance on one attribute and favor another alternative with only "average" performance on all attributes. Thus, use of maximin as a decision-making strategy has its limitations.

5.2.3 Maximax

As with dominance and maximin, maximax too does not require any decision maker preference input. The comparable scale of measurement requirement is a major limitation of the use of this method. Similar to maximin, a "poor" alternative with one exceptional attribute could be selected over an alternative with all "good" attributes but no exceptional attributes. Thus, the decision-making situation must be

thoroughly analyzed, possibly with input from the decision maker or other expert, to determine if the maximax method is to be applied.

5.2.4 Copeland's Reasonable Social Welfare Function

A strength of Copeland's method is the fact that it also does not require any DM input. It also does not require that attributes have a comparable scale of measurement. A disadvantage is that all attributes are treated with the same weight. This disadvantage can be overcome by assigning weights to the attributes, although that process eliminates the major advantage of no required DM input. Copeland's is a good method for guidance to the DM for trends, although it is not recommended that alternatives be eliminated by it, or that decisions be made based solely on its use.

5.2.5 Conjunctive

The conjunctive method requires the decision maker to set minimal attribute levels. Depending on the level set for each of the attributes, either none, one or several alternatives can be considered as the decision choice. One advantage of the conjunctive method is that attributes do not have to be measured on a common scale. Further, attribute values are not required to be numerical. A

disadvantage is the elimination of alternatives having many exceptional attribute values due to the presence of one attribute with a substandard value.

The conjunctive method is usually applied in cases with a large number of alternatives where only an acceptable alternative (one which meets a minimum set of standard criteria) is required by the decision maker. The method also has wide use as a preliminary method to narrow the list of alternatives. This reduces the mathematical complexity of other methods to be applied later due to the lower number of available alternatives.

5.2.6 Conjunctive Ranking

As in the conjunctive method, the conjunctive ranking method requires minimal attribute levels from the decision maker for all but one attribute. An advantage of the conjunctive ranking method is that it provides at ranking of attributes, rather than only a "best" choice alternative. The disadvantage is that this ranking is only dependent upon one attribute chosen by the decision maker. Thus, an alternative with inferior performance on all but one attribute may be selected as first choice by using this method. However, if the attribute chosen as the ranking

attribute has far greater importance than any of the other attributes, this method may be acceptable.

5.2.7 Disjunctive

As in the conjunctive method, the disjunctive method does not require attributes to be measured on a common scale. Further, attribute values are not required to be numerical. There is also a requirement for minimal acceptable attribute values identified by the decision maker. The output of this method is a best choice, not a ranking. A major disadvantage is the elimination of alternatives having many exceptional attribute values due to the presence of one attribute with a substandard value. The use of the disjunctive method is rather limited.

5.2.8 Lexicographic

The output of the lexicographic method is a "best" choice among alternatives. One advantage of the lexicographic method is that the method does not require a common scale for the attributes. Additionally, it only requires the decision maker's subjective ranking of the attributes, not a numerical attribute weighting. A disadvantage is that depending upon this ranking, one alternative may be selected over another alternative because of one slightly better

attribute value; even though the remaining attribute values of the discarded alternative are far superior to those of the alternative selected.

To compensate for the above deficiency of the lexicographic method, a lexicographic semiorder has been proposed by Luce and Tversky [9]. This method places bands on the attribute values instead of using only their absolute values. This method eliminates the problem described above; however, in some cases use of lexicographic semiordering leads to intransitivity [9]. The decision maker would then be required to decide where alternative is preferred.

5.2.9 Permutation Method

The major drawback of using the permutation method is the fact that the method is so calculation-intensive. For example, note that if there were only one additional alternative in the test case (eight alternatives as opposed to seven), the permutation method would have required 8X5040 or 40320 separate ranking calculations! If there are many alternatives, its use would be extremely time-consuming, especially if sensitivity analysis is performed among different weighting schemes to generate additional alternative rankings.

On the other hand, the calculations required by the method are straightforward and easily implemented on a computer. Sensitivity analyses can be performed to determine the sensitivity of the weighting of the attributes, thus offsetting the method's heavy reliance on this subjective input from the decision maker. A further advantage is that the method's output is a ranking of alternatives, with relative attribute weights as the only input required of the decision maker. There is also no need for a common scale among the attributes, a shortcoming of some of the previously discussed methods.

One disadvantage is that the method relies heavily on the absolute attribute values given in the problem. Although exact attribute values are not used, there is no distinction between small differences in the value of one attribute and large differences in the comparison of that attribute level for two alternatives. For example, in comparing VCR 6 and VCR 7, the picture quality of 71 and 70, respectively, results in VCR 6 being "better" than VCR 7 on this attribute, even though such a difference may be insignificant.

The permutation method is easy to implement and measures the level of concordance of the complete preference order [9]. Its method of maximizing the level of concordance is also

intuitively sound, and as such, the method is quite useful in determining alternative rankings.

5.2.10 Linear Assignment Method

The simple method is easy to implement, but it is not comprehensive in its use of attribute and alternative information. The more comprehensive method not only uses information about attribute rankings for each alternative, but combines the information between alternatives as well. Again, all that is required are attribute weights from the decision maker. Optimizations of the resultant linear assignment model are well documented in the literature, thus, implementation of the method is not difficult.

5.2.11 Hierarchial Additive Weighting

Hierarchial additive weighting is used most often for decisions involving a large number of attributes, usually more than seven [9]. One advantage is that attribute weights are all that are required from the decision maker. Further, the final output is a ranking of the available alternatives, as opposed to a best choice.

5.2.12 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method, as many of the others, only requires attribute weighting information from the decision maker. Its major disadvantage is the assumption that the utility function is monotonically increasing or decreasing. However, the plausibility of such an assumption should be easily refuted or validated with minimal additional input from the DM.

An advantage of TOPSIS is that it considers not only maximizing the distance from the ideal solution but also minimizing the distance from the negative-ideal solution at the same time. The method is also another one that is easily implemented on a computer so that sensitivity analysis of the attribute weighting provided by the DM can be performed.

5.2.13 ELECTRE

ELECTRE is a good method for decision situations involving a discrete number of alternatives. A major advantage of the method is its structure and ease of use. The only requirement is for attribute weights to be defined by the decision maker. The DM may be requested to provide

concordance and discordance indices, as well. The major disadvantage of this method is its high dependence on these indices. A suggested approach is to perform sensitivity analysis by varying the values of the indices and determining the resultant effect on the final list of alternatives. This will either give the DM more confidence in the elimination of certain alternatives or else possibly retain some alternatives which may otherwise have been eliminated.

5.2.14 Simple Additive Weighting

Simple additive weighting is easily implemented and tractable. This is one of the methods employed by the SmartEdge computer model, and its use has been previously discussed in that section of the report.

CHAPTER 6 CONCLUSIONS

6.1 Part 1 - SmartEdge Methodology

In general, on a respondent-by-respondent basis, the SmartEdge methodology rankings did not match the surveyed alternative ordering of the decision makers. This poor correlation may be a result of the sample size being too small - only 16 survey respondents. Further, the sample population itself consisted of accountants and engineers, not a random sample by any means. Use of such a population also could have altered the results. In contrast to the one-on-one comparison, Figures 4.1.3.1 and 4.1.3.2 do show that the average results of the survey respondents and SmartEdge were remarkably close.

In using the additive model, the SmartEdge methodology makes some simplifications. First, as mentioned earlier, only one indifference point is requested from the decision maker for each of the attributes. This results in a utility function consisting of two linear segments, as opposed to either a function with more linear segments, or a curve. Selection of a greater number of indifference points may make the utility function more closely represent the decision maker's preference structure. This may result in a better

correlation between SmartEdge and surveyed responses, an area requiring further study.

However, remember that additional indifference points would require additional information to be supplied by the decision maker. This added complexity of requesting additional information and the ability of the decision maker to consistently and accurately reflect his or her preferences has yet to be proven. One of the basic assumptions of the theory, that of transitivity of preferences, is more likely to be violated as additional information is requested of the DM. One reason for this belief is that information would have to be gathered over time instead of at one sitting. Even if information were gathered at one sitting, DM fatigue could play a role in intransitivity of preferences at some point during the data gathering session.

Further, additional indifference points could involve questions for gambles other than 50-50, which are believed to be more difficult for the decision maker to respond to with a high degree of accuracy [11]. Actually, even for gambles involving 50% probabilities, the ability of the decision maker to respond rationally is still suspect.

Overall, on a person-by-person basis, the SmartEdge additive model did not accurately predict the rankings of the individual decision maker.

6.2 Part 2 - MADM Methods

Table 6.2 presents the results of each of the MADM methods considered in this study, including the results obtained from SmartEdge for the "test" decision maker. Many of the non-ranking MADM methods chose VCR 5 as the preferred VCR. Many of the ranking MADM methods selected VCR 5 for first choice as well. Further, in examining the DM VCR preference ranking, there was also a general trend towards VCR 5.

Other ranking methods (those not ranking VCR 5 first) preferred either VCR 4 or VCR 6 for first choice. Thus, the overall consensus of the MADM methods analyzed in this study is that either VCR 4, VCR 5, or VCR 6 is the preferred choice and other alternatives can, and should, be eliminated from further consideration.

6.3 Summary

This study has demonstrated that many MADM methods must be applied in order to comprehensively analyze a decision problem in its entirety. Some methods were "very good" at

Table 6.2 Summary of Results of MADM Methods

Method	Results
DOMINANCE	Eliminated 3 of 16 initial VCR alternatives
MAXIMIN	VCR 5
MAXIMAX	VCR 1, VCR 4, VCR 5, or VCR 6
COPELAND'S	5 - 4 - 2 - 3 - 6 - 1 - 7, or
	5 - 4 - 2 - 6 - 3 - 1 - 7
CONJUNCTIVE	VCR 5
CONJUNCTIVE RANKING	VCR 4, VCR 5, or VCR 6
DISJUNCTIVE	VCR 5
LEXICOGRAPHIC	VCR 1, VCR 4, or VCR 5
PERMUTATION	5 - 4 - 3 - 1 - 2 - 6 - 7
LINEAR ASSIGNMENT	5 - 4 - 3 - 2 - 6 - 1 - 7 (simple)
	4 - 2 - 3 - 6 - 5 - 7 - 1, or
	4 - 3 - 2 - 6 - 5 - 7 - 1, or
	4 - 3 - 5 - 6 - 2 - 7 - 1
HIERARCHIAL	5 - 6 - 2 - 4 - 3 - 1 - 7
TOPSIS	5 - 6 - 2 - 3 - 4 - 7 - 1
ELECTRE	VCR 5 or VCR 6
SIMPLE ADDITIVE	5 - 4 - 3 - 1 - 6 - 2 - 7

reflecting decision maker preferences, that is their choices closely matched those given by the decision maker. However, others were so far off the mark that their use would certainly give the analyst and/or the decision maker a "poorer" choice, that is, one which is certainly not the "best". As a result, the reliance on only one decision-making method to determine the final decision is ludicrous, if not foolhardy. But, how to choose which MADM method to use? That is a question for a subsequent study, yet, the beginnings of an answer to such a question can be considered now.

The value of the MADM ranking methods is that by their use, the decision maker can possibly eliminate some of the obviously less favorable alternatives. This fact was evidenced by the apparent elimination of VCR 7 from the analysis after applying several of the MADM methods and noticing the consistently "poor" showing of VCR 7. Note that VCR 7 also performed poorly in both the surveyed decision makers responses and with SmartEdge.

It was also apparent from this study that when faced with too many possibilities, decision makers tend to be overwhelmed with the number of choices and have difficulty making small discriminations between them. Analysis of decision maker preferences either by simple lottery

questions, or by requesting the ranking of alternatives becomes increasingly difficult as the number of alternatives is increased.

Reducing the number of alternatives is certainly a goal to strive for in any MADM problem. Use of the dominance method is advisable as a means of reducing the number of available alternatives. Reducing the number of alternatives certainly reduces the problems' complexity both from the subjective point of view of the decision maker and also from the objective point of view of implementation of the various MADM methods.

In summary, it appears as though the decision-making methodologies should be used as guidance to the analyst and decision maker in coming to a decision. Using any one of the methods as the only method of analysis certainly seems unwise, and being able to determine which methods to apply in which situations, appears nearly impossible. Thus, the most effective approach is to use a combination of MADM methods as guidance to the decision maker, not to use one method as the absolute. Hopefully, as additional methods are applied to the problem, more insight into the decision making will be gained, some alternatives can be eliminated as definitely inferior, and the decision maker will have a

smaller sample space of alternatives on which to apply subsequent methods for the next step of analysis.

And finally, "Are decision makers rational in their decision-making behavior?" This is the major premise of some of the current methodologies, such as SmartEdge, on which all subsequent questioning, calculations, and rankings rely. Is it wise to uphold such beliefs as rational decision-making behavior? Until such questions are answered, it is the decision maker who still has and will have the final ultimate decision, theories or not withstanding.

It is this author's belief that the theories and methodologies do serve a purpose in guiding the decision maker (especially when the number of choices become overwhelming), and in helping him or her eliminate some of the poorer alternatives from the decision space. However, the ultimate decision still rests with every decision maker and the MADM methods cannot and should not be relied upon to make this decision for them.

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APPENDIX - WHICH VCR DO YOU CHOOSE?

This study attempts to structure your decision-making process and preferences in order to systematically determine which VCR you would choose given a list of alternative VCRs. Your preferences for various attributes (features/distinguishing characteristics) of VCRs will be assessed during Sections 1 and 2 of this survey. This data will then be input into a computerized decision model. The output of the model will indicate an ordering (from first choice through last choice) of which VCR you would choose based on your surveyed attribute preferences. This computer result will then be compared with your actual ordering of the VCRs taken from Section 3 of this survey to analyze the effectiveness of the computer decision model.

SECTION 1 -- DETERMINING YOUR PREFERENCES FOR VCR FEATURES

This section of the study assesses how you, the VCR purchaser, feel about the levels of each VCR attribute. The following interactive questions are intended to help quantify your attitudes towards options with uncertain outcomes. Your attitudes toward uncertain outcomes (e.g., a 50-50 chance of either winning or losing $1000) may differ from another's attitudes toward the same situation due to differences in asset positions and personal tastes. It is not necessary to know your asset position, but it is necessary to model your tastes so that an analysis of complicated options can be made with your tastes as input.

BACKGROUND INFORMATION

In this hypothetical situation, you must choose which of the following three options you would prefer to face:

(1)	a sure thing	"S"
(2)	a gamble	"G" with uncertain outcomes
(3)	indifference	"I" no preference between (1) & (2)

Compared to the sure thing "S", the gamble "G" leads to an outcome which is of greater or equal value ("best" option) or which is of lesser or equal value ("worst" option).

You must weigh the sure thing "S" against the chance (gamble "G") of obtaining the more valuable, but risky, "best" option versus the less valuable, but risky, "worst" option.

Instead of choosing either the sure thing "S" or the gamble "G", you may indicate indifference "I" between them. Choosing "I" means that you cannot distinguish between whether you prefer "S" or "G" or do not care which occurs given the values specified.

You will be asked a series of hypothetical questions and you should consider each choice as if it were the only one to be made at this time. You should not consider possible outcomes which may result from previous choices.

Circling "S" indicates that you prefer the sure thing.
Circling "G" indicates that you prefer the gamble.
Circling "I" indicates that you are indifferent between the two.

EXAMPLE: Suppose you are purchasing a car and are told that you can expect to pay anywhere from $10,000 (best option price) to $15,000 (worst option price).

Question: If you were given a choice between definitely purchasing the car for $12,000 (sure thing "S") or a 50-50 chance of either purchasing the car for $10,000 or $15,000 (gamble "G"), which option would you choose?

(1) Circling "S" means that you would purchase the car for $12,000
(2) Circling "G" means that you would purchase the car for either
    a) $10,000 (if you "won" the 50-50 gamble) or
    b) $15,000 (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Note that if you choose the gamble "G", there are only two possible results - either "best" case purchase for $10,000 or "worst" case purchase for $15,000. You can only purchase the car for $12,000 if you select the sure thing "S".

INSTRUCTIONS

Each PART in SECTION 1 analyzes your preference for a given VCR attribute/feature. Your responses from one PART should not have any effect on your responses in subsequent PARTs.

Note there are only 5 attributes of importance to be considered in this survey. Although there are certainly many more VCR features that you as a buyer would surely consider, for the purposes of this survey, assume that only these 5 attributes are of any importance. The attributes are listed in alphabetical order to prevent any bias from entering into your preferences. The attributes for this study are: Audio Quality, Picture Quality, Price, Remote Control, and Repair Frequency.

Question 1 in each PART will explain your choices in detail. The remaining questions in each PART will follow the same pattern with only your choices indicated. Refer back to question 1 for any detail you may need. However, please do not allow answers to previous questions to affect your response to the current question.

After answering a question you will be further instructed in one of two ways:

1) Based upon your response to the question, you will be directed to answer another question in the same PART.

OR

2) You will be told that your answers for that PART of the survey are complete. You will then be directed to the next part; or will be told that this section of the survey is complete.

NOTE: You will NOT be answering every question in every PART. After answering PART 1 - Question 1, you will then be directed to the next question to answer for the remainder of the survey. Please answer ONLY the questions which you are directed to answer in each PART.

Remember that this is an attempt to model very subjective options. THIS MAKES YOU THE EXPERT. There are no right or wrong answers. Please consider each question carefully and respond as you would if truly confronted with these options.
Thank you for taking the time to answer this survey.
Please begin with PART 1 - Question 1.

SECTION 1 -- PART 1 : VCR AUDIO QUALITY

Consumer Reports has rated the quality of the VCR audio based on three parameters: dynamic range, flutter, and frequency response.

> Dynamic range is the difference between the loudest and softest sounds that can be recorded on the hi-fi tracks.
>
> Flutter is the measurement of freedom from flutter (a wavery sound) in linear-track recordings.
>
> Frequency response measured the VCR's accuracy in reproducing the audible spectrum at SP and EP speeds. The ratings are for linear-track recordings.

The three above parameters were combined into one overall audio quality rating. Audio quality was rated on a scale of 1 to 15, with "1" the "worst" audio quality and 15" the "best". The scale is relative.

For the models from which you can choose, the results were a "worst" case of "8" and a "best" case of "13".

PART 1 - Question 1

If you were given a choice between definitely purchasing a VCR of audio quality rating 9.2 (sure thing "S") or a 50-50 chance of either purchasing a VCR with audio quality of 8 or purchasing a VCR with audio quality of 13 (gamble "G"), which option would you choose?

(1) Circling "S" means you choose a VCR with audio quality 9.2
(2) Circling "G" means you choose a VCR with audio quality either
    a) 13 (if you "won" the 50-50 gamble) or
    b) 8 (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 2.
If you circled "G", please go to PART 1 - Question 3.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 2

Sure thing	"S"	is 8.6
Gamble	"G"	is 50-50 chance of audio quality 8 or 13
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 4.
If you circled "G", please go to PART 1 - Question 5.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 3

Sure thing "S" is 11.1
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 6.
If you circled "G", please go to PART 1 - Question 7.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 4

Sure thing "S" is 8.3
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 8.
If you circled "G", please go to PART 1 - Question 9.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 5

Sure thing "S" is 8.9
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 10.
If you circled "G", please go to PART 1 - Question 11.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 6

Sure thing "S" is 10.1
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 12.
If you circled "G", please go to PART 1 - Question 13.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 7

Sure thing "S" is 12
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 14.
If you circled "G", please go to PART 1 - Question 15.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 8

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8 and 8.3 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 9

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8.3 and 8.6 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 10

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8.6 and 8.9 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 11

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8.9 and 9.2 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 12

Sure thing "S" is 9.6
Gamble "G" is 50-50 chance of audio quality 8 or 13
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 16.
If you circled "G", please go to PART 1 - Question 17.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 13

Sure thing	"S"	is	10.6
Gamble	"G"	is	50-50 chance of audio quality 8 or 13
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 18.
If you circled "G", please go to PART 1 - Question 19.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 14

Sure thing	"S"	is	11.5
Gamble	"G"	is	50-50 chance of audio quality 8 or 13
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 20.
If you circled "G", please go to PART 1 - Question 21.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 15

Sure thing	"S"	is	12.5
Gamble	"G"	is	50-50 chance of audio quality 8 or 13
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 1 - Question 22.
If you circled "G", please go to PART 1 - Question 23.
If you circled "I", you have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 16

For what value of the "Sure Thing" are you indifferent?
Choose a value between 9.2 and 9.6 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 17

For what value of the "Sure Thing" are you indifferent?
Choose a value between 9.6 and 10.1 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 18

For what value of the "Sure Thing" are you indifferent?
Choose a value between 10.1 and 10.6 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 19

For what value of the "Sure Thing" are you indifferent?
Choose a value between 10.6 and 11.1 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 20

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11.1 and 11.5 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 21

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11.5 and 12 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 22

For what value of the "Sure Thing" are you indifferent?
Choose a value between 12 and 12.5 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

PART 1 - Question 23

For what value of the "Sure Thing" are you indifferent?
Choose a value between 12.5 and 13 = > _____

You have completed PART 1. Please go to PART 2 - Question 1.

SECTION 1 -- PART 2 : VCR PICTURE QUALITY

Consumer Reports has rated the quality of the VCR picture based on judgements by experienced TV viewers who watched tapes each VCR had recorded. They judged sharpness, "noise", and freedom from unnatural edges. Picture quality was rated on a scale of 1 to 100, with "1" the "worst" picture quality and "100" the "best". The scale is relative. A difference of 10 points was easily visible.
For the models from which you can choose, the results were a "worst" case of "70" and a "best" case of "90".

PART 2 - Question 1

If you were given a choice between definitely purchasing a VCR of picture quality rating 75 (sure thing "S") or a 50-50 chance of either purchasing a VCR with picture quality of 70 or purchasing a VCR with picture quality of 90 (gamble "G"), which option would you choose?

(1) Circling "S" means you choose a VCR with picture quality 75
(2) Circling "G" means you choose a VCR with picture quality either
    a) 90 (if you "won" the 50-50 gamble) or
    b) 70 (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 2.
If you circled "G", please go to PART 2 - Question 3.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 2

Sure thing	"S"	is picture quality 72
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 4.
If you circled "G", please go to PART 2 - Question 5.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 3

Sure thing	"S"	is picture quality 82
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 6.
If you circled "G", please go to PART 2 - Question 7.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 4

For what value of the "Sure Thing" are you indifferent?
Choose a value between 70 and 72 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 5

Sure thing	"S"	is picture quality 73
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 8.
If you circled "G", please go to PART 2 - Question 9.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 6

Sure thing	"S"	is picture quality 78
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 10.
If you circled "G", please go to PART 2 - Question 11.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 7

Sure thing	"S"	is picture quality 86
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 12.
If you circled "G", please go to PART 2 - Question 13.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 8

For what value of the "Sure Thing" are you indifferent?
Choose a value between 72 and 73 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 9

For what value of the "Sure Thing" are you indifferent?
Choose a value between 73 and 75 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 10

Sure thing	"S"	is	picture quality 76
Gamble	"G"	is	50-50 chance of picture quality 70 or 90
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 14.
If you circled "G", please go to PART 2 - Question 15.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 11

Sure thing	"S"	is	picture quality 80
Gamble	"G"	is	50-50 chance of picture quality 70 or 90
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 16.
If you circled "G", please go to PART 2 - Question 17.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 12

Sure thing	"S"	is	picture quality 84
Gamble	"G"	is	50-50 chance of picture quality 70 or 90
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 18.
If you circled "G", please go to PART 2 - Question 19.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 13

Sure thing	"S"	is picture quality 88
Gamble	"G"	is 50-50 chance of picture quality 70 or 90
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 2 - Question 20.
If you circled "G", please go to PART 2 - Question 21.
If you circled "I", you have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 14

For what value of the "Sure Thing" are you indifferent?
Choose a value between 75 and 76 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 15

For what value of the "Sure Thing" are you indifferent?
Choose a value between 76 and 78 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 16

For what value of the "Sure Thing" are you indifferent?
Choose a value between 78 and 80 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 17

For what value of the "Sure Thing" are you indifferent?
Choose a value between 80 and 82 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 18

For what value of the "Sure Thing" are you indifferent?
Choose a value between 82 and 84 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 19

For what value of the "Sure Thing" are you indifferent?
Choose a value between 84 and 86 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 20

For what value of the "Sure Thing" are you indifferent?
Choose a value between 86 and 88 = > _____

You have completed PART 2. Please go to PART 3 - Question 1.

PART 2 - Question 21

For what value of the "Sure Thing" are you indifferent?
Choose a value between 88 and 90 = > _____
You have completed PART 2. Please go to PART 3 - Question 1.

SECTION 1 -- PART 3 : VCR PRICE

The price range for VCRs that you can purchase is from $330 for the least expensive model to $500 for the most expensive model.

PART 3 - Question 1

If you were given a choice between definitely purchasing a VCR for $457 (sure thing "S") or a 50-50 chance of either purchasing the VCR for $330 or $500 (gamble "G"), which option would you choose?

(1) Circling "S" means that you would purchase the VCR for $457
(2) Circling "G" means that you would purchase the VCR for either
    a) $330 (if you "won" the 50-50 gamble) or
    b) $500 (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 2.
If you circled "G", please go to PART 3 - Question 3.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 2

Sure thing	"S"	is $478
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 4.
If you circled "G", please go to PART 3 - Question 5.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 3

Sure thing	"S"	is $393
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 6.
If you circled "G", please go to PART 3 - Question 7.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 4

Sure thing	"S"	is $489
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 8.
If you circled "G", please go to PART 3 - Question 9.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 5

Sure thing	"S"	is $467
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 10.
If you circled "G", please go to PART 3 - Question 11.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 6

Sure thing	"S"	is $425
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 12.
If you circled "G", please go to PART 3 - Question 13.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 7

Sure thing	"S"	is $361
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 14.
If you circled "G", please go to PART 3 - Question 15.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 8

For what value of the "Sure Thing" are you indifferent?
Choose a value between 489 and 500 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 9

For what value of the "Sure Thing" are you indifferent?
Choose a value between 478 and 489 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 10

For what value of the "Sure Thing" are you indifferent?
Choose a value between 467 and 478 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 11

For what value of the "Sure Thing" are you indifferent?
Choose a value between 457 and 467 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 12

Sure thing	"S"	is $441
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 16.
If you circled "G", please go to PART 3 - Question 17.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 13

Sure thing	"S"	is $409
Gamble	"G"	is 50-50 chance of $330 or $500
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 18.
If you circled "G", please go to PART 3 - Question 19.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 14

Sure thing "S" is $377
Gamble "G" is 50-50 chance of $330 or $500
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 20.
If you circled "G", please go to PART 3 - Question 21.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 15

Sure thing "S" is $345
Gamble "G" is 50-50 chance of $330 or $500
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 3 - Question 22.
If you circled "G", please go to PART 3 - Question 23.
If you circled "I", you have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 16

For what value of the "Sure Thing" are you indifferent?
Choose a value between 441 and 457 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 17

For what value of the "Sure Thing" are you indifferent?
Choose a value between 425 and 441 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 18

For what value of the "Sure Thing" are you indifferent?
Choose a value between 409 and 425 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 19

For what value of the "Sure Thing" are you indifferent?
Choose a value between 393 and 409 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 20

For what value of the "Sure Thing" are you indifferent?
Choose a value between 377 and 393 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 21

For what value of the "Sure Thing" are you indifferent?
Choose a value between 361 and 377 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 22

For what value of the "Sure Thing" are you indifferent?
Choose a value between 345 and 361 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

PART 3 - Question 23

For what value of the "Sure Thing" are you indifferent?
Choose a value between 330 and 345 = > _____

You have completed PART 3. Please go to PART 4 - Question 1.

SECTION 1 -- PART 4 : VCR REMOTE CONTROL

Consumer Reports has rated the use of the remote control with the VCR based on three parameters: visibility, ease of use, and layout.

Visibility indicates how easy it was to identify buttons in a darkened room.

Ease of use is based on the buttons' size, shape, spacing, and feel.

Layout is judgement of how well the most frequently used controls -- Power, Stop, Play, and Rewind -- are grouped.

The three above parameters were combined into one overall remote control rating. Remote control quality was rated on a scale of 1 to 15, with "1" the "worst" remote control quality and "15" the "best". The scale is relative.

For the models from which you can choose, the results were a "worst" case of "6" and a "best" case of "12".

PART 4 - Question 1

If you were given a choice between definitely purchasing a VCR of remote control quality rating 7.5 (sure thing "S") or a 50-50 chance of either purchasing a VCR with remote control quality of 6 or purchasing a VCR with remote control quality of 12 (gamble "G"), which option would you choose?

(1) Circling "S" means you choose a VCR with remote control quality 7.5
(2) Circling "G" means you choose a VCR with remote control quality either
    a) 6 (if you "won" the 50-50 gamble) or
    b) 12 (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 2.
If you circled "G", please go to PART 4 - Question 3.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 2

Sure thing	"S"	is remote control quality 6.7
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 4.
If you circled "G", please go to PART 4 - Question 5.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 3

Sure thing	"S"	is remote control quality 9.7
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 6.
If you circled "G", please go to PART 4 - Question 7.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 4

Sure thing	"S"	is remote control quality 6.3
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 8.
If you circled "G", please go to PART 4 - Question 9.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 5

Sure thing	"S"	is remote control quality 7.1
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 10.
If you circled "G", please go to PART 4 - Question 11.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 6

Sure thing	"S"	is remote control quality 8.6
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 12.
If you circled "G", please go to PART 4 - Question 13.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 7

Sure thing	"S"	is remote control quality 10.8
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 14.
If you circled "G", please go to PART 4 - Question 15.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 8

For what value of the "Sure Thing" are you indifferent?
Choose a value between 6 and 6.3 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 9

For what value of the "Sure Thing" are you indifferent?
Choose a value between 6.3 and 6.7 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 10

For what value of the "Sure Thing" are you indifferent?
Choose a value between 6.7 and 7.1 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 11

For what value of the "Sure Thing" are you indifferent?
Choose a value between 7.1 and 7.5 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 12

Sure thing	"S"	is remote control quality 8
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 16.
If you circled "G", please go to PART 4 - Question 17.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 13

Sure thing	"S"	is	remote control quality 9.1
Gamble	"G"	is	50-50 chance of remote control quality 6 or 12
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 18.
If you circled "G", please go to PART 4 - Question 19.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 14

Sure thing	"S"	is	remote control quality 10.2
Gamble	"G"	is	50-50 chance of remote control quality 6 or 12
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 20.
If you circled "G", please go to PART 4 - Question 21.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 15

Sure thing	"S"	is	remote control quality 11.4
Gamble	"G"	is	50-50 chance of remote control quality 6 or 12
Indifferent	"I"		

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 22.
If you circled "G", please go to PART 4 - Question 23.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 16

For what value of the "Sure Thing" are you indifferent?
Choose a value between 7.5 and 8 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 17

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8 and 8.6 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 18

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8.6 and 9.1 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 19

Sure thing	"S"	is remote control quality 9.4
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 24.
If you circled "G", please go to PART 4 - Question 25.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 20

For what value of the "Sure Thing" are you indifferent?
Choose a value between 9.7 and 10.2 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 21

For what value of the "Sure Thing" are you indifferent?
Choose a value between 10.2 and 10.8 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 22

Sure thing	"S"	is remote control quality 11.1
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 26.
If you circled "G", please go to PART 4 - Question 27.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 23

Sure thing	"S"	is remote control quality 11.7
Gamble	"G"	is 50-50 chance of remote control quality 6 or 12
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 4 - Question 28.
If you circled "G", please go to PART 4 - Question 29.
If you circled "I", you have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 24

For what value of the "Sure Thing" are you indifferent?
Choose a value between 9.1 and 9.4 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 25

For what value of the "Sure Thing" are you indifferent?
Choose a value between 9.4 and 9.7 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 26

For what value of the "Sure Thing" are you indifferent?
Choose a value between 10.8 and 11.1 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 27

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11.1 and 11.4 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 28

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11.4 and 11.7 = > _____

You have completed PART 4. Please go to PART 5 - Question 1.

PART 4 - Question 29

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11.7 and 12 = > _____
You have completed PART 4. Please go to PART 5 - Question 1.

SECTION 1 -- PART 5 : VCR REPAIR FREQUENCY

Consumer Reports has surveyed readers about the frequency of VCR repair. The frequency of repair ratings are based on responses from readers concerning over 177,000 VCRs bought new between 1985 and 1990. The data has been adjusted to eliminate variations due solely to age or usage.

The frequency of repair ratings indicate the percent of VCRs that have ever needed repair. Readers report that a typical repair cost about $80. The frequency of repair rating refers to all models within a brand line, not just the mid-priced models used for this survey.

Frequency of repair ratings are given on a percentage scale from 0 to 100, with "100" the "worst" repair rating, all VCRs required repair, and "0" the "best" repair rating, no VCRs required repair. The scale is relative. Differences of fewer than three points aren't meaningful.

For the models from which you can choose, the results were a "worst" case of "36%" of VCRs required repair and a "best" case of "8%" of VCRs required repair.

PART 5 - Question 1

If you were given a choice between definitely purchasing a VCR with a repair percentage of 29% (sure thing "S") or a 50-50 chance of either purchasing a VCR with repair percentage of 8% or purchasing a VCR with a repair percentage of 36% (gamble "G"), which option would you choose?

(1) Circling "S" means you choose a VCR with repair percentage 29%
(2) Circling "G" means you choose a VCR with repair percentage either
    a) 8% (if you "won" the 50-50 gamble) or
    b) 36% (if you "lost" the 50-50 gamble)
(3) Circling "I" means that you don't have a preference between choices (1) and (2)

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 2.
If you circled "G", please go to PART 5 - Question 3.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 2

Sure thing	"S"	is repair percentage 32%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 4.
If you circled "G", please go to PART 5 - Question 5.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 3

Sure thing "S" is repair percentage 18%
Gamble "G" is 50-50 chance of repair percentage 8% or 36%
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 6.
If you circled "G", please go to PART 5 - Question 7.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 4

Sure thing "S" is repair percentage 34%
Gamble "G" is 50-50 chance of repair percentage 8% or 36%
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 8.
If you circled "G", please go to PART 5 - Question 9.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 5

Sure thing "S" is repair percentage 30%
Gamble "G" is 50-50 chance of repair percentage 8% or 36%
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 10.
If you circled "G", please go to PART 5 - Question 11.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 6

Sure thing "S" is repair percentage 23%
Gamble "G" is 50-50 chance of repair percentage 8% or 36%
Indifferent "I"

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 12.
If you circled "G", please go to PART 5 - Question 13.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 7

Sure thing	"S"	is repair percentage 13%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 14.
If you circled "G", please go to PART 5 - Question 15.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 8

For what value of the "Sure Thing" are you indifferent?
Choose a value between 34% and 36% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 9

For what value of the "Sure Thing" are you indifferent?
Choose a value between 32% and 34% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 10

For what value of the "Sure Thing" are you indifferent?
Choose a value between 30% and 32% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 11

For what value of the "Sure Thing" are you indifferent?
Choose a value between 29% and 30% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 12

Sure thing	"S"	is repair percentage 26%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 16.
If you circled "G", please go to PART 5 - Question 17.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 13

Sure thing	"S"	is repair percentage 20%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 18.
If you circled "G", please go to PART 5 - Question 19.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 14

Sure thing	"S"	is repair percentage 15%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 20.
If you circled "G", please go to PART 5 - Question 21.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 15

Sure thing	"S"	is repair percentage 10%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 22.
If you circled "G", please go to PART 5 - Question 23.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 16

Sure thing	"S"	is repair percentage 27%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 24.
If you circled "G", please go to PART 5 - Question 25.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 17

Sure thing	"S"	is repair percentage 24%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 26.
If you circled "G", please go to PART 5 - Question 27.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 18

Sure thing	"S"	is repair percentage 21%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 28.
If you circled "G", please go to PART 5 - Question 29.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 19

For what value of the "Sure Thing" are you indifferent?
Choose a value between 18% and 20% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 20

Sure thing	"S"	is repair percentage 16%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 30.
If you circled "G", please go to PART 5 - Question 31.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 21

For what value of the "Sure Thing" are you indifferent?
Choose a value between 13% and 15% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 22

Sure thing	"S"	is repair percentage 11%
Gamble	"G"	is 50-50 chance of repair percentage 8% or 36%
Indifferent	"I"	

Circle one choice: S G I

If you circled "S", please go to PART 5 - Question 32.
If you circled "G", please go to PART 5 - Question 33.
If you circled "I", you have completed PART 5. Please go to SECTION 2.

PART 5 - Question 23

For what value of the "Sure Thing" are you indifferent?
Choose a value between 8% and 10% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 24

For what value of the "Sure Thing" are you indifferent?
Choose a value between 27% and 29% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 25

For what value of the "Sure Thing" are you indifferent?
Choose a value between 26% and 27% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 26

For what value of the "Sure Thing" are you indifferent?
Choose a value between 24% and 26% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 27

For what value of the "Sure Thing" are you indifferent?
Choose a value between 23% and 24% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 28

For what value of the "Sure Thing" are you indifferent?
Choose a value between 21% and 23% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 29

For what value of the "Sure Thing" are you indifferent?
Choose a value between 20% and 21% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 30

For what value of the "Sure Thing" are you indifferent?
Choose a value between 16% and 18% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 31

For what value of the "Sure Thing" are you indifferent?
Choose a value between 15% and 16% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 32

For what value of the "Sure Thing" are you indifferent?
Choose a value between 11% and 13% = > _____

You have completed PART 5. Please go to SECTION 2.

PART 5 - Question 33

For what value of the "Sure Thing" are you indifferent?
Choose a value between 10% and 11% = > _____

You have completed PART 5. Please go to SECTION 2.

SECTION 2 -- DETERMINING YOUR PREFERENCES FOR VCR FEATURES

This section of the study assesses how you, the VCR purchaser, feel about the 5 attributes relative to each other.

Imagine you have 100 poker chips; each chip represents 1 unit of importance.
Allocate chips appropriately below to specify the relative importance of each Attribute.
You must assign all 100 chips for proper scaling of results.

EXAMPLE: If all 5 attributes were equally important to you,
you would divide your 100 chips evenly between them as shown below:

AUDIO QUALITY _____20_____

PICTURE QUALITY _____20_____

PRICE _____20_____

REMOTE CONTROL _____20_____

REPAIR FREQUENCY _____20_____

Total = 100

Please enter your preferences below:

AUDIO QUALITY _____

PICTURE QUALITY _____

PRICE _____

REMOTE CONTROL _____

REPAIR FREQUENCY _____

Total = 100

Please be sure that your inputs total to 100.

SECTION 3 -- WHICH VCR WOULD YOU CHOOSE?

The following table presents 7 VCRs from which you can choose. The values of each of the 5 attributes (audio quality, picture quality, price, remote control, and repair frequency) are indicated for each of the 7 alternatives. Please indicate your order of preference in choosing among the 7 VCR alternatives.

For example, if VCR "1" were your first choice, you would indicate

First choice VCR ___1___

Please note that you must make a preference decision among all 7 choices, that is all VCRs (1-7) must be ordered to make this study successful.

ALTERNATIVE

Attribute	VCR 1	VCR 2	VCR 3	VCR 4	VCR 5	VCR 6	VCR 7
AUDIO	11.5	8	11.5	13	10.5	11.5	9.5
PICTURE	80	74	88	90	86	71	70
PRICE	$ 330	$ 400	$ 500	$ 470	$ 455	$ 450	$ 410
REMOTE	6	11	11	9	12	8	8
REPAIR	36%	10%	16%	18%	10%	8%	19%

Notes: Audio Quality is rated on a scale of 1 (worst) to 15 (best)
Picture Quality is rated on a scale of 1 (worst) to 100 (best)
Price is the amount of $ you must pay $500 (worst) to $330 (best)
Remote control is rated on a scale of 1 (worst) to 15 (best)
Repair frequency is rated on a scale of 100 (worst) to 0 (best) (lower values are better)

For more descriptive information on the attributes, refer to Section 1 -- Part 1 - Audio, Part 2 - Picture, Part 3 - Price, Part 4 - Remote Control, Part 5 - Repair Frequency

First choice is VCR _____

Second choice is VCR _____

Third choice is VCR _____

Fourth choice is VCR _____

Fifth choice is VCR _____

Sixth choice is VCR _____

Seventh choice is VCR _____

The survey is complete. Again thank you for your time in completing this survey.