

[76]

TFR -81-7-101-1

AN OUTLINE OF
DECISION MAKING

ANTONIO LEAL

July 1981

Tetrax
CORPORATION

20234 Cantara Street, Unit 347 • Canoga Park, California 91306 • Telephone (213) 709-8700

Report TFR-81-7-101-1

AN OUTLINE OF
DECISION MAKING

Antonio Leal

July 1981

TETRAX Corporation
20234 Cantara Street, Unit 347
Canoga Park, California 91306

Prepared for:
Dr. Ewald Heer
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
Contract No. LI-737361

TABLE OF CONTENTS

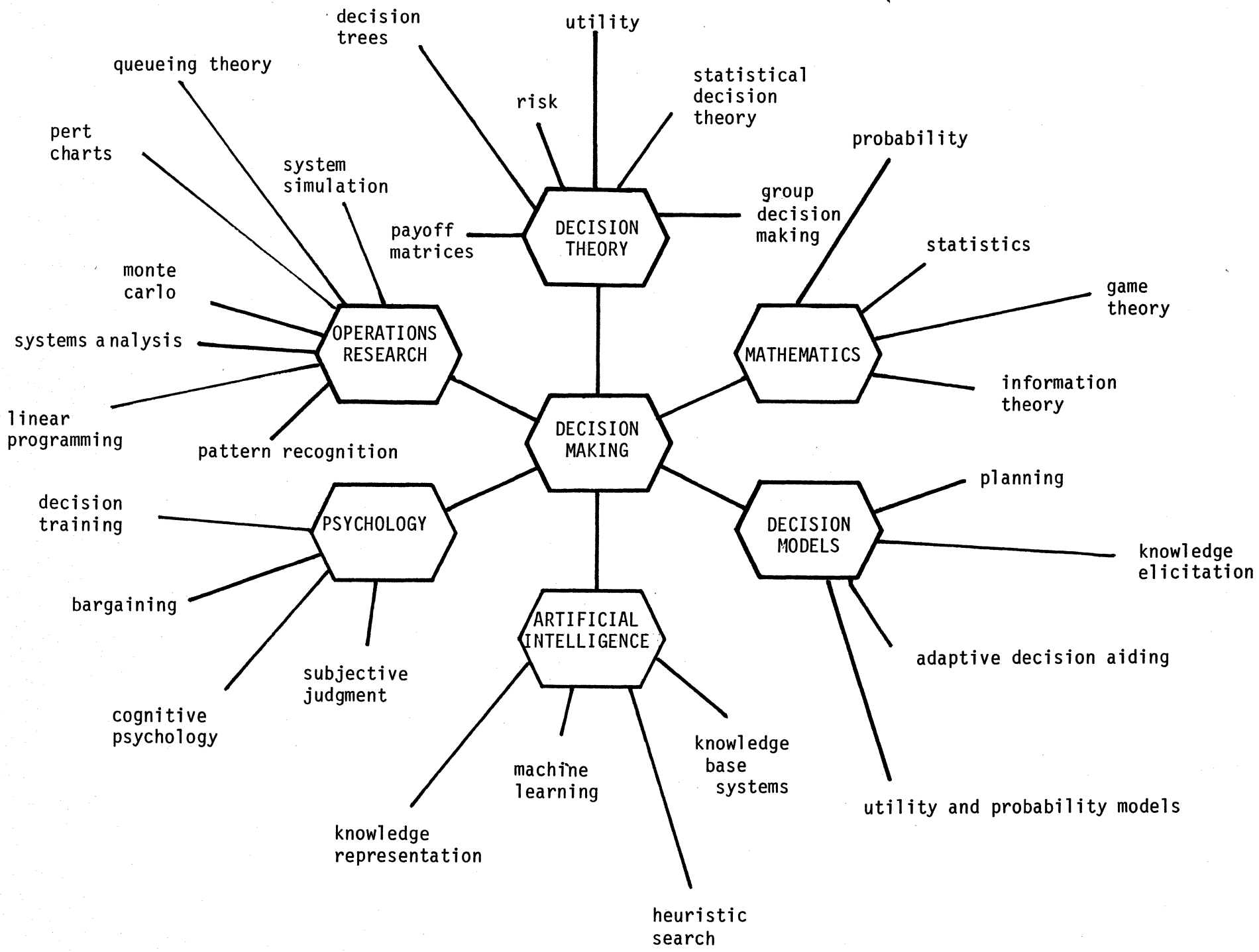
1. Introduction	1
2. Decision Making Outline	3
3. Definitions	9
4. References	37
APPENDIX - Abbreviations	45

1. INTRODUCTION

Decision Making is the scientific study of the processes involved in the rational selection of a best alternative from among a group of available alternatives. Decision Making comes in two forms. "Descriptive" decision making attempts to characterize how a single individual or a group of individuals actually make decisions; "prescriptive" decision making attempts to formulate guidelines for how individuals should make decisions. In the more general sense, decision making is problem solving and, thus, touches many related scientific fields: Mathematics, Computer Science, Psychology, Operations Research, etc. This report outlines decision making and its relation to other scientific areas of study:

1. Decision Theory
2. Mathematics
3. Decision Models
4. Artificial Intelligence
5. Psychology
6. Operations Research

Section 3 presents a collection of definitions of all of the terms found in the outline with a list of references found in Section 4. The Appendix lists frequently used abbreviations of companies and institutions.



2. DECISION MAKING OUTLINE

1. Decision Theory

1.1 Utility Theory

- 1.1.1 Axioms
- 1.1.2 Subjective Utility
- 1.1.3 Indifference Curves
- 1.1.4 Multi-Attribute Utility

1.2 Decision Trees

- 1.2.1 Optimal Paths
- 1.2.2 Sensitivity Analysis

1.3 Payoff Matrices

- 1.3.1 Maxi-min Strategy
- 1.3.2 Maxi-max Strategy
- 1.3.3 Hurwicz Strategy
- 1.3.4 Savage Regret Strategy
- 1.3.5 Expected Value Strategy

1.4 Value of Information

1.5 Statistical Decision Theory

- 1.5.1 Hypothesis Testing
- 1.5.2 Levels of Significance
- 1.5.3 Type I and Type II Errors
- 1.5.4 Statistical Decision Rules
- 1.5.5 Statistical Inference
- 1.5.6 Expected Opportunity Loss
- 1.5.7 Economics of Sampling
- 1.5.8 Revision of Prior Probabilities

1.6 Group Decision Making

- 1.6.1 Group Utility
- 1.6.2 Pareto Optimality
- 1.6.3 Conflict Resolution

1.7 Risk Analysis

- 1.7.1 Alpha Beta Risk
- 1.7.2 Risk Sharing

2. Mathematics

2.1 Probability Theory

- 2.1.1 Probability Measurement
- 2.1.2 Conjunctive Events
- 2.1.3 Disjunctive Events
- 2.1.4 Venn Diagrams
- 2.1.5 Frequency Analysis
- 2.1.6 Marginal Probability
- 2.1.7 Joint Probability
- 2.1.8 Conditional Probability
- 2.1.9 Event Dependence
- 2.1.10 Bayes' Rule
- 2.1.11 Binomial Distribution
- 2.1.12 Expectation

2.2 Statistics

- 2.2.1 Statistical Measurement
 - 2.2.1.1 Mean
 - 2.2.1.2 Median
 - 2.2.1.3 Mode
 - 2.2.1.4 Average Deviation
 - 2.2.1.5 Variance
 - 2.2.1.6 Standard Deviation
- 2.2.2 Normal Distribution
- 2.2.3 Sampling
- 2.2.4 Regression Analysis

2.3 Game Theory

- 2.3.1 Mini-Max Strategy
- 2.3.2 Gambling

2.4 Information Theory

3. Decision Models

3.1 Knowledge Elicitation

3.1.1 Decision Tree Program

3.1.2 TREE

3.1.3 GODDESS

3.2 Adaptive Decision Aiding

3.2.1 ADDAM

3.2.2 ACTS

3.3 Utility Models

3.3.1 MAUM

3.3.2 EVAL

3.4 Probability Models

3.4.1 PIP

3.4.2 Lotteries

3.5 Planning Models

3.5.1 GAKU

3.5.2 Group Decision Aid

4. Artificial Intelligence

4.1 Knowledge Base Systems

4.1.1 MYCIN

4.1.2 PROSPECTOR

4.1.3 HEARSAY

4.1.4 EUPHID

4.1.5 DENDRAL

4.1.6 INTERNIST

4.1.7 Problem Solving System

4.1.8 RITA

4.2 Heuristic Search

4.2.1 Resource Allocation Search

4.2.2 Mini-Max Search

4.2.3 Alpha Beta Pruning

4.3 Knowledge Representation

4.3.1 Semantic Nets

4.3.2 Frames

4.3.3 Production Rules

4.4 Machine Learning

5. Psychology

5.1 Subjective Judgment

5.1.1 Subjective Utility

5.1.2 Subjective Probability

5.1.3 Probability Calibration

5.2 Cognitive Psychology

5.2.1 Perception

5.2.2 Learning

5.2.3 Memory

5.3 Decision Training

5.4 Bargaining

6. Operations Research

6.1 Pattern Recognition

6.1.1 Linear Classifiers

6.1.2 Non-Deterministic Classifiers

6.1.3 Feature Extraction

6.1.4 Error Estimation

6.1.5 Clustering

6.2 Linear Programming

6.3 Monte Carlo Simulation

6.4 Systems Analysis

6.5 Management

6.6 PERT Charts

6.7 Queueing Theory

6.8 Systems Simulation

6.9 Scheduling

3. DEFINITIONS

ACTS - The Adaptive Computerized Training System (ACTS) was developed at Perceptronics, Inc. in 1976. It uses the technique of adaptive decision aiding to train students in electronic circuit analysis. The system can build an internal model of the trainee's decision strategy while debugging an electronic circuit fault. This model, when compared with an expert model already stored in the machine, directs the area of required training.
(17,35,36,62)

Adaptive Decision Aiding - Adaptive Decision Aiding is a decision support technique based on pattern recognition. A computer decision model monitors (in real time) the decision alternatives chosen by a human operating an interactive computer system. The pattern recognition component builds an internal model of the operator's decision strategy and then uses it to aid the human in his task through feedback on a display terminal.
(5,17,35,36,37,62,65,100)

ADDAM - The Adaptive Dynamic Decision Aiding Model (ADDAM) was developed at Perceptronics, Inc. in 1975. It uses the adaptive decision aiding technique to aid the Tactical Coordination Officer aboard the P3-C anti-submarine warfare aircraft for the Navy.
(35,36,62)

Alpha Beta Pruning - The number of possible combinations that must be explored when using mini-max heuristic search can be greatly reduced by employing the technique of alpha-beta pruning. The method ignores certain strategies which would produce an inferior action when compared to those that have already been found. It permits a tree to be searched approximately twice as deep in the same amount of time.
(9,28,65,80,115)

Alpha Beta Risk - Alpha risk is the maximum probability of encountering a Type I error; beta risk is the maximum probability of a Type II error.
(7,23,53,89)

Artificial Intelligence - Artificial intelligence is the branch of Computer Science that deals with the machine simulation of human mental and cognitive processes, behavior, and problem solving activities.
(2,9,18,27,28,50,59,71,75,80,81,91,96,115)

Average Deviation - A statistical measure, the average deviation is an indication of the uniformity or dispersion within a set of numbers.

$$\frac{\sum |X - \bar{X}|}{n}$$

where n is the number of numbers in the set and \bar{X} is the mean (average). This measure computes the average distance of each number X from the average of the entire set.
(42,53,101)

Axioms - The axioms of Utility were formulated by R.D. Luce and H. Raiffa in 1967. The axioms specify rational decision making behavior with respect to the selection of a best decision alternative given a series of preference choices.
(23)

Bargaining - The area of bargaining includes methodologies and techniques to aid the mutually agreeable division of limited resources among a group of individuals such that personal utility is maximized.
(89)

Bayes' Rule - Bayes' Rule makes it possible to determine a conditional probability when given the complementary (reverse) conditional probability and the relevant marginal probabilities.

$$P(X|E) = \frac{P(E|X)P(X)}{\sum_i P(E|X_i)P(X_i)}$$

where E is an event and X is one of a set of mutually exclusive events X_i .
(23,26,29,45,53,87,89,114)

Binomial Distribution - The general binomial distribution is a family of probability distributions describing the probabilities of the possible experimental outcomes for all possible combinations of the total number of experimental trials n and the probability of success on each trial p. If r is the number of successes in n trials, then:
(13,26,53)

$$P(r|n,p) = \frac{n!}{r!(n-r)!} p^r(1-p)^{n-r}$$

Clustering - Clustering is a technique in pattern recognition used to formulate major classes of objects when these classes are not known in advance.
(5,37,41,79,115,116)

Cognitive Psychology - Cognitive psychology is the psychology of human mental processes involving intelligent thought and its relation to learning, perception, and memory.
(2,19,50,70,76,90,92)

Conditional Probability - The conditional probability is the probability that a sample from a large population has a specific characteristic given that it already possesses certain other pre-specified characteristics.
(7,13,26,42,45,53,89,101)

Conflict Resolution - Relating to decision making, conflict resolution is the attempt to arrive at an agreeable group estimate when individual members of the group differ widely in their personal estimates. Methods include averaging, majority voting, multi-attribute utility modeling, and one-man rules.
(6,21,24,63)

Conjunctive Events - A conjunctive event is a single probabilistic event which is composed of two or more related events all of which must occur before the major event can be said to occur.
(7,26,53)

Decision Making - Decision Making is the scientific study of the processes involved in the rational selection of a best alternative from among a group of available alternatives. "Descriptive" decision making attempts to characterize how individuals actually make decisions; "prescriptive" decision making attempts to formulate guidelines for how individuals should make decisions.
(23,55,89)

Decision Models - A decision model is a structure or a procedure (usually a computer program), that has embedded within it, mathematical algorithms for good decision making. The purpose of a decision model is to help a human decision maker structure and solve his problem by (1) decomposing it into manageable parts, (2) analyzing each part separately, and (3) deriving a decision conclusion by computational means.
(1,3,5,29,36,40,58,62,63,64,71,86,88,97,100,104,117,122)

Decision Theory - Decision Theory or Decision Analysis involves the construction of guidelines for advising individuals how to make rational decisions that will maximize their personal utility. Mathematical models and algorithms are used which deal with problem structuring and alternative selection independently of domain application.

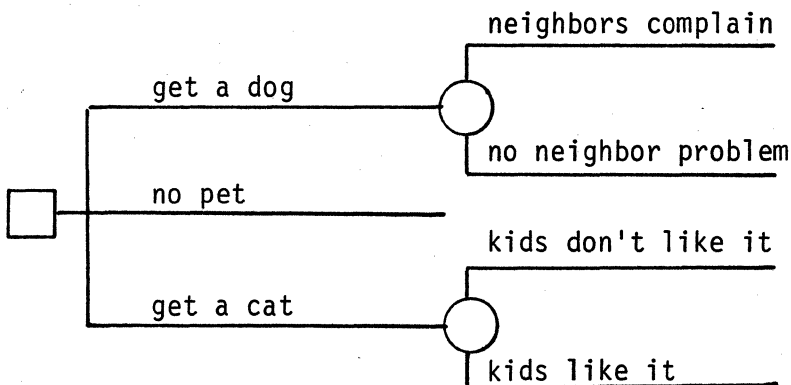
(23,53,55,89,105,108,120)

Decision Training - The ability to make good decisions is one that can be taught. A good decision maker chooses a best alternative according to pre-set criteria given the amount of available information and should not be judged solely on the basis of successful outcomes.

(97,98)

Decision Trees - A decision tree is a picture of possible alternative courses of action interspersed with events that have an uncertain outcome. Each path in the tree corresponds to one possible state of affairs in the future. By assigning utilities and probabilities to various nodes and arcs in the tree, a best (optimal) path can be determined which forms the basis for the decision choice.

(3,7,10,11,13,15,34,43,47,53,56,57,63,64,74,82,84,88,89,104,122)



Decision Tree Program - The Decision Tree Program is a computerized elicitation model developed in 1976 at UCLA by A. Leal. It aids a decision maker in constructing a decision tree for any application area. The system uses sensitivity analysis to direct the tree growth and recommends a best alternative based on the optimal paths.
(63,64)

DENDRAL - DENDRAL is a knowledge-based system developed at Stanford University by E.A. Feigenbaum, B. Buchanan, and J. Lederberg for the purpose of expert consultation in the area of analysis of electron emission spectrograms for determining chemical structures.
(6)

Disjunctive Events - A disjunctive event is a single probabilistic event which is composed of two or more related events. The major event can be said to occur if any one of the related events occurs. For example, a tournament chess game can be won by (1) the opponent resigning, (2) the opponent's clock running out first, or (3) check-mating the opponent's King.
(7,26,53)

Economics of Sampling - Sampling economics attempts to place a monetary value on the information that may be gained by sampling. This includes the calculation of expected value of sample information, the expected value of perfect information, the selection of an optimal sample size, and the calculation of the net gain from sampling.
(7,13,42,53,93)

Error Estimation - Pattern recognition systems are not 100% correct in their classification of objects. Error estimation, as related to pattern classifiers, is a process of determining the probability of correct classification.

(26,79,116)

EUFID - The End-User Friendly Interface to Data Management Systems (EUFID) is a knowledge-based system developed at System Development Corp., Santa Monica, Ca. by J. Burger, I. Kameny, and A. Leal for the purpose of natural language interface to relational data management systems.

(6)

EVAL - A decision aiding model developed at DDI, EVAL incorporates decision payoff matrices with probability estimates for solving single "one-shot" decision problems.

(10,11,12,29,57,83)

Event Dependence - An event B is said to be "independent" of an event A if $P(B|A)=P(B)$. That is, the probability of B given that A has occurred is the same as the probability of B alone. Event A has no effect on event B.

(7,26,53)

Expectation - The expectation of a particular event X is the value (worth) of each possible outcome $V(X_i)$ multiplied by the corresponding probability of occurrence $P(X_i)$ and summed.

$$E(X) = \sum_i V(X_i)P(X_i)$$

where X_i are the mutually exclusive outcomes of event X.

(7,13,26,53)

Expected Opportunity Loss - Loss of expected opportunity is the cost of uncertainty when making a decision with less than perfect information. It can be determined by summing the losses for each expected event outcome multiplied by the corresponding probability of the events.
(7,13,53,89,101)

Expected Value Strategy - The expected value strategy is a decision rule for use with a decision payoff matrix that contains estimates of the probability of occurrence for each outcome (column). For each row (decision strategy), multiply each entry by the corresponding probability and sum. Then choose the strategy with the highest (expected) value .
(55)

Feature Extraction - The success of a pattern recognition system is dependent upon the quality of the features (attributes) of the objects that are to be classified. Feature extraction is the process of identifying the relevant attributes to be measured. No adequate procedure for automatic feature extraction has yet been derived.
(41,62,79,115,116)

Frames - Frames are a method of representing knowledge in a knowledge-based system. A frame is a knowledge "chunk" that has a collection of definitional and procedural knowledge items about a particular object, action, or concept. It is characterized by the existence of "slots" (blanks) which can be filled in to describe any particular instance of the object, action, or concept.
(6)

Frequency Analysis - Analysis of frequency involves the breakdown of a population into relevant subsets with measures describing the relative sizes of the subsets with respect to the entire population. Such analysis leads to the construction of a frequency table and the determination of marginal and conditional probabilities. For example,

	<u>MALE</u>	<u>FEMALE</u>	<u>Totals</u>
Smokers	3	2	5
Non-Smokers	1	4	5
Totals	4	6	10

GAKU - The GAKU System (from a Japanese word for learning) is a computerized planning model developed at System Development Corp. in 1970 by A. Hormann and A. Leal. The planning model allows for the statement of objectives and decision actions with a capability for recursion to solve sub-problems.

(50)

Gambling - To gamble is to engage in a game of chance in which the outcome determines a gain or loss of money. Gambling games provide a simple environment for the study of human decision making.

(14,20,26,46,52,102,118,121)

Game Theory - Game theory is the study of conflict between individuals and groups. Game theory assumes an active, aggressive opponent rather than a passive random world.

(18,20,22,26,46,52,54,55,61,75,91,95,102,109,111,118,121)

GODDESS - The Goal-Directed Decision Structuring System (GODDESS) is currently under development at UCLA by J. Pearl, J. Saleh, and A. Leal and is a decision knowledge elicitation model that structures the decision problem starting from the goal and working backwards through possible actions that could be taken to achieve the goal. Action preconditions as well as side effects that could hinder goal fulfillment, are also taken into account.

(88)

Group Decision Aid - The Group Decision Aid was developed at Perceptronics Inc. in 1977 by A. Leal, S. Levin, and P.C. Gardiner and is based on a decision tree elicitation model for the structuring of a decision problem by a small panel of experts working as a unified group. Conflict resolution is solved by using multi-attribute utility analysis.

(63)

Group Decision Making - Group decision making is the attempt, by a group of individuals working together, to combine their knowledge and expertise to solve a common decision problem.

(24,47,51,63,89,103,107)

Group Utility - Group utility is a single measure of utility which is mathematically derived from the utilities of all members of a group. Common measures are the arithmetic mean and the geometric mean.

(51,63,89,103,107)

HEARSAY - The HEARSAY system is a knowledge-based system developed at Carnegie Mellon University, Pittsburg, Pa. by D.R. Reddy for the purpose of speech understanding.

(6)

Heuristic Search - Heuristic search is a technique from the field of Artificial Intelligence which explores possible future outcomes given the current state of affairs and actions which can be taken. All possible future situations are simulated and evaluated and a best current action is chosen based on its likelihood of producing a desirable outcome.

(8,9,18,28,65,71,75,80,81,91,115)

Hurwicz Strategy - The Hurwicz strategy is a decision rule for use with a decision payoff matrix. Take each decision strategy (row) and compute a weighted average of the best value b and the worst value w using weight α .

$$A_j = \alpha b + (1-\alpha)w$$

Select the strategy with the highest average A_j .

(55)

Hypothesis Testing - A "hypothesis" in statistics is any unambiguous statement concerning a characteristic of a large population of items. "Hypothesis testing" is a procedure of classical statistical inference which incorporates sampling in a decision process to (1) accept the hypothesis, (2) reject the hypothesis, or (3) postpone the decision until more information can be collected.

(7,13,42,53)

Indifference Curves - Indifference curves are a sets of curves describing a person's preferences over a wide range of alternatives. All points on a single curve depict different selection situations in which the person is indifferent as to choice.

(55,89)

Information Theory - Information theory was developed in 1948 by C.E. Shannon and describes the concepts dealing with the production and transmission of data along a number of discrete channels. The theory encompasses channel capacity, entropy, coding theorems, and error-correcting codes.

(25,110)

INTERNIST - INTERNIST is a knowledge-based system developed at the University of Pittsburg by H. Pople and J. Myers for the purpose of medical diagnosis for internal medicine using abduction.

(6)

Joint Probability - The probability that a sampled item from a population has multiple characteristics from a frequency table is a joint probability. The probability of each characteristic separately is taken from the marginal probabilities.

(7,26,53)

Knowledge Base Systems - A knowledge base is a computed-based system in which knowledge (data and procedures) is stored and collected in one or more "compartments" (called knowledge sources) in order to facilitate problem solving and reasoning in a single, well-defined problem domain. Unlike generalized problem-solving systems, knowledge-based systems must accumulate large amounts of knowledge in specific domains and rely on domain-specific problem-solving techniques that can be developed to a high level of expertise.

(6,27,71,76,80,106)

Knowledge Elicitation - A knowledge elicitation decision model depends on problem-specific input from the decision maker. This knowledge, combined with the capability to structure decision problems, allows the model to aid the decision maker in a wide range of application areas. Such models behave like decision analysts who are familiar with decision making techniques but require detailed problem information to solve specific decision tasks.

(3,10,12,21,23,29,31,50,57,63,64,87,88,89,99,122)

Knowledge Representation - Knowledge representation schemes allow human knowledge to be input to a computer system and used to solve problems. The selected scheme is based on the type and amount of knowledge to be stored. Typical schemes are numerical data arrays, text data banks, logical deduction networks, concept graphs, semantic graphs, hierarchical structures, meta-data systems, etc.

(2,4,6,15,34,59,60,80,96,)

Learning - A branch of Cognitive Psychology, learning theory attempts to model the intelligent human capacity for creating generalizations, relations, and inference based on a few observed objects and events.

(2,50,61,70,73,90,)

Levels of Significance - Part of hypothesis testing in statistics, a level of significance is a probability level at which the hypothesis will be tested. It is the point at which the sample results will be considered inconsistent with the hypothesis and is identified in advance of obtaining the sample.

(7,13,53))

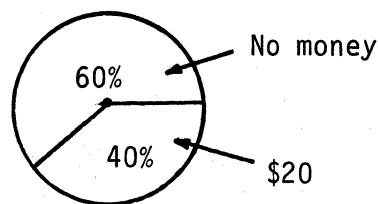
Linear Classifiers - A linear classifier is a pattern recognition model that uses a linear function as a discriminant for the categorization of objects. As such, a linear classifier does not perform well if the objects cannot be separated by straight hyper-planes.

(5,35,36,37,115,116)

Linear Programming - Linear programming is a computational technique that attempts to maximize a series of linear functions given a set of linear constraints on the inputs.

(7,13,22,95,109,118)

Lotteries - A lottery is a device used to determine a person's subjective utility about different choices. The lottery is usually depicted in the form of a random spinner with known outcomes and probabilities. For example, which would you rather have: (1) \$10 for certain or (2) a chance to play this lottery?



Machine Learning - Machine learning is a term applied to a computer software system that is able to be modified as a result of its use. Modification can come from a number of different sources including the program itself. Typical sources of modification are: a programmer changing the internal code, a user inputting new parameters, a program that adjusts its own internal parameters by experience, a system that re-writes its own programs, a system that organizes itself.

(5,17,28,35,36,37,41,50,61,62,65,79,80,91,100,115,116)

Management - The process of management concerns the allocation of an organization's inputs (human and economic resources) by planning, organizing, directing, and controlling for the purpose of producing outputs (goods and services) desired by its customers so that organizational objectives are accomplished. In the process, work is performed with and through organization personnel in an ever-changing business environment.

(7,13,22,52,53,94,95,96,109)

Marginal Probability - The probability of occurrence of a particular row or column in a frequency table is called a marginal probability. These probabilities are found in the "margins" of the table.

(7,13,53)

Mathematics - The science dealing with numbers and the measurement, properties, and relationships of quantities.

MAUM - The Multi-Attribute Utility Model (MAUM) developed at SSRI decomposes a decision problem into component attributes (characteristics) weights (importance values), and utilities (worth assessments) and aggregates them computationally into a best decision alternative.

$$D_{\max} = \text{MAX}_i^{-1} \sum_j U_{i,j} W_j$$

where $U_{i,j}$ is the utility of attribute j on alternative i and W_j is the weight of attribute j across all alternatives.

(21,23,56,63,77,78,84,107)

Maxi-Max Strategy - The maxi-max strategy is a decision rule for use with decision payoff matrices. For each available strategy (row), consider only the best possible outcome (value). Then, choose that strategy with the best of the best outcomes. That is, maximize the maximum outcome.

(55)

Maxi-Min Strategy - The maxi-min strategy is a decision rule for use with decision payoff matrices. For each available decision strategy (row), consider only the worst possible outcome (lowest value). Then, choose that strategy with the best of the worst outcomes. That is, maximize the minimum outcome.

(55)

Mean - The mean is another term for "average": the sum of the numbers in a set divided by the number of numbers in the set.

$$\bar{X} = \frac{\sum X}{n}$$

where n is the number of numbers in the set X.

(7,13,26,42,53,55,89)

Median - The median is a number which, when positioned within a set of ordered numbers, would fall in the center, i.e. at the 50% fractile.

(7,13,26,42,53,55)

Memory - A branch of Cognitive Psychology, memory analysis attempts to model the information retention structures and characteristics of the human brain.

(2,19,33,39,68,76,90,105)

Mini-Max Search - A type of heuristic search, the mini-max search technique is used when there exists an opponent whose actions restrict the attainment of a goal. Possible combinations of actions (or "moves") are examined and a best approach is chosen assuming that the decision maker wishes to maximize his own situation and minimize his opponent's situation. Mini-max search is used often in game-playing programs.
(9,18,28,65,75,80,81,91)

Mini-max Strategy - Mini-max strategy is a decision rule for use with decision (game) matrices. Select the lowest value in each column (opponent's choice) of the matrix. Choose the decision strategy (row) that has the highest of these values. That is, maximize the minimums.
(18,20,52,118,121)

Mode - The mode is that value in a set of numbers that occurs most frequently.
(7,13,53)

Monte Carlo Simulation - Monte carlo simulation is a name given by von Neumann and S.M. Ulam to a technique for solving problems that are too expensive for experimental solution or too difficult for analytic treatment. The technique involves the construction of a computational model of the problem and, through repeated execution, an approximate solution can be found by analysis of a large number of simulated outcomes.
(14,22,72,109)

Multi-Attribute Utility - Multi-attribute utility is a technique of decomposing a single utility measurement into its component characteristics or "attributes". Each attribute can then be evaluated separately with utility measures as well as measures of relative importance. Overall utility is obtained by a linear combination of the values for the component attributes.
(21,23,56,63,77,78,84,107)

MYCIN - The knowledge-based system called "MYCIN" was developed at Stanford University by B. Buchanan and S. Cohen for the purpose of expert consultation in the area of antimicrobial therapy for infectious blood diseases.

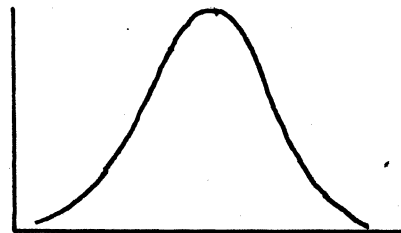
(6)

Non-Deterministic Classifiers - A non-deterministic (non-parametric) classifier is a pattern recognizer that relies upon a distance "metric" between observed objects in a class in order to categorize new objects. The "distance" from an object to a class of objects may be taken either to a representative object in the class or to a calculated class centroid.

(79,116)

Normal Distribution - The "bell" shaped curve that results when the number of trials of a binomial distribution becomes infinite is called a "normal distribution".

$$P_N = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left(\frac{-(x-\mu_x)^2}{2\sigma_x^2} \right)$$



where μ_x is the mean and σ_x is the standard deviation.

(7,13,42,53)

Operations Research - "Operational Research is the application of scientific methods, techniques, and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to the problems." Churchman, Ackoff, Arnoff. "Operations Research is the art of winning wars without actually fighting." Arthur C. Clarke.

(14,20,22,95,109)

Optimal Paths - The optimal path in a decision tree is determined by (1) the utilities placed at the end of each path from the root, (2) the internal node types, and (3) the probabilities placed on each event outcome. Every decision node has a value equal to the maximum of the values of the nodes succeeding it; every event node takes the expected value of the nodes succeeding it. The highest values determine the optimal paths.

(11,12,15,23,43,47,63,64,82,89,104,122)

Pareto Optimality - Pareto optimality is a decision option or strategy measured by a joint utility function from members of a decision group. The decision option is "Pareto optimal" if there is no alternative decision option that is at least as acceptable to all members and definitely preferred by some members. That is, a joint action is Pareto optimal if it is not possible (by changing strategy) to make one individual better off without also making another individual worse off.

(89)

Pattern Recognition - A mathematical technique, pattern recognition has the capability to classify objects into prescribed categories by trial and error after observing a number of samples without being provided with the decision rules. The classifier must be "trained" with a known set of objects before it can recognize new objects.

(79,116)

Payoff Matrices - The use of payoff matrices is a decision technique that does not involve uncertain events. A payoff matrix has rows corresponding to the possible decision alternatives (strategies), columns corresponding to the possible states of the world (unknown situations), and entries corresponding to the gain or loss (either money or utility) for every combination of decision choice and state of the world.

(3,10,29,55,57,117)

Perception - A branch of Cognitive Psychology, perception deals with an individual's understanding and interpretation of environmental stimuli and their effect on rational behavior.

(2,4,19,30,33,39,49,68,76,90,105,112,119,)

PERT Charts - The PERT chart is a statistical technique using networks that quantifies knowledge about the uncertainty faced in completing time-dependent projects and activities. Its use may aid the timely achievement of program deadlines by drawing attention to danger signals that could cause time delays in task completion.

(7,16,72)

PIP - The Probabilistic Information Processing (PIP) model was developed by W. Edwards at SSRI for the purpose of solving decision problems based on uncertain events. The model uses probability estimates for events which are decomposed into micro-events and outcomes.

(40)

Planning Models - While most decision models are concerned with one-time or "single-shot" decision problems, planning models aid in developing long range plans consisting of many actions in sequence. Sometimes "contingency plans" are developed which prescribe actions based on the outcomes of future events. As well as global strategy planning, such models may include probability estimation, cost-benefit analysis, resource allocation, etc.

(8,32,50,63,64,88,94,96,)

Probability Calibration - Probability calibration is a technique which can evaluate the ability of a particular person to estimate the probability of uncertain events. The result is a curve which can be used as a calibration standard to modify his estimates and obtain a more accurate measurement.

(66,67,69)

Probability Measurement - The measurement of probability can be formulated in a number of common ways: (1) a "probability" between 0 and 1, for example, a 1/5 or .2 chance; (2) a "chance", for example, 1 chance in 5; (3) a "percentage", for example, a 20% chance; and (4) as "odds", for example, 1 to 4 odds.

(26,38,44,102,)

Probability Models - Probability models are computer systems that aid decision making by the elicitation of subjective probabilities. Such systems do not usually deal with utilities.

(34,40,44,45,99,103)

Probability Theory - A branch of Mathematics, probability theory deals with the measurement of the likelihood of occurrence of uncertain events.

(7,13,26,38,42,44,53,93,101)

Problem Solving System - The Problem Solving System was developed at JPL and is a knowledge-based system for the purpose of aiding mission scientists in relaying commands to planetary spacecraft.

(6)

Production Rules - A production rule is a method of representing knowledge in a knowledge-based system. A "rule" is a specification of a conditional action and consists of 2 main parts: (1) a condition (or antecedent) which describes a situation and (2) an action (or consequent) which describes a process that may be performed if the condition is satisfied.

(6,71,106)

PROSPECTOR - The PROSPECTOR system is a knowledge-based model developed at SRI by R.O. Duda for the purpose of expert consultation on exploratory Geology.

(6)

Psychology - Psychology is the science of mind, mental states, and processes of a person or persons in order to explain actions, thought, emotions, and behavior.

(2,19,33,76,90,92,113)

Queueing Theory - Queueing (waiting line) problems occur when the capacity of a service system is inadequate to process all of the demand upon that system. Adjustments to the system to handle additional input must be weighed against additional costs. Queueing theory attempts to optimize system service while minimizing cost.

(7,22,72,95,109)

Regression Analysis - Regression analysis is the mathematical extension of past data relationships into the future for the purpose of prediction. A major portion of regression analysis is "curve fitting": the attempt to specify a mathematical function which closely matches observed data.

(22,42)

Resource Allocation Search - Resource allocation search is a type of heuristic search which does not involve an opponent. Most applicable to resource allocation problems, this type of search technique examines possible combinations of actions in order to select a best set for fulfilling a goal objective.

(80)

Revision of Prior Probabilities - Revising prior probabilities involves the use of Bayes' rule to obtain a better and more accurate estimate of marginal probabilities originally obtained by subjective judgment. The revision of prior probabilities is based on the outcome of a sample.

(53,89)

Risk Analysis - Risk analysis is the study of potential losses due to making non-optimal decisions and involves the characterization of acceptable risks and the quantification of risk in terms of utility.

(7,23,30,53,54,89)

Risk Sharing - Risk sharing is the diversification of potential losses among members of a group according to their individual utility functions.

(89)

RITA - RITA is a knowledge-based system developed at RAND Corp. by R. Anderson for the purpose of aiding terminal user agents.

(6)

Sampling - Sampling involves a random selection of items from a large population such that every item in the population has an equal chance of being included in the sample. Further, every possible combination of items that could make up a given size sample must have an equal chance of being selected.

(7,13,42,53,89)

Savage Regret Strategy - The Savage regret strategy is a decision rule for use with decision payoff matrices. From the original payoff matrix, make a new "regret" matrix by taking, for each outcome (column), the difference between the highest value and the other values. Rank each row by its greatest value (loss) and select the one with the least loss.

(55)

Scheduling - Scheduling problems occur when multiple tasks or jobs must be processed by a system that can handle only a few at a time. Optimal placement of jobs, each with a different completion time, is generally not easily solved.

(22,95,109)

Semantic Nets - A semantic net is a structure for representing knowledge in a knowledge-based system. It is built of knowledge "chunks" that are relations among relevant data items. For example, the following picture specifies a hierarchical relationship among members and classes.



(6)

Sensitivity Analysis - Sensitivity analysis involves the adjustment of system inputs in order to observe the effect on the outputs. In Decision Making, it is a technique applied to decision trees to determine the most "sensitive" node. This node has the most chance of affecting the total tree in a significant way and, thus, should be analyzed in more depth.

(34,64,88,122)

Standard Deviation - The standard deviation is a measure of the uniformity or dispersion within a set of numbers.

$$\sigma_X = \sqrt{\frac{\sum (X - \bar{X})^2}{n}}$$

where \bar{X} is the mean and n is the number of numbers in the set.
(7,13,42,53)

Statistical Decision Rules - A statistical decision rule is a procedure for testing a statistical hypothesis where the accept/reject criteria have been determined in advance for all possible sample outcomes. For example: "Take a random sample of 100 light bulbs from this shipment of 10,000. If 8 or more bulbs are defective, return the entire shipment, otherwise accept it."

(7,42,53)

Statistical Decision Theory - Statistical decision theory is the use of statistics to formulate decision rules and guidelines for the selection of beneficial courses of action based on information gained through sampling.

(53,101)

Statistical Inference - Statistical inference is the formulation of hypotheses and conclusions about a large collection of data based upon information gained through sampling.

(53,101)

Statistical Measurement - A single number that carries information about characteristics of a large group of numbers is a measurement in statistics.

(42)

Statistics - Statistics is that branch of Mathematics dealing with the science of collecting and classifying numerical facts in order to show their characteristics and significance.

(42)

Subjective Judgment - Numerical estimates that come from an individual are called "subjective" when they are based upon his knowledge, ability and experience and not upon mathematical computation.

(23,37,44,45,49,51,99,114)

Subjective Probability - An estimate is a subjective probability if it is the specification of the probability of a random event pronounced by a decision maker based on his own experience and expertise alone.

(44,45,49,89,99)

Subjective Utility - Subjective utility is the value or worth of a decision alternative to a decision maker based on his own expertise and value system.

(23,37,48,51,55,89,92,103,107,108)

Systems Analysis - Systems analysis is the study of the behavior of "systems": a set of objects together with relationships between their attributes. Systems analysis includes modeling, simulation, queueing, feedback, control, planning, management, dynamics, and experimentation.

(16,72,85,94)

Systems Simulation - Systems simulation involves the construction of a working mathematical, computer, or physical model containing similarity of properties or relations with the natural or technological system under study.

(2,14,16,71,72,85,91,101,106)

TREE - TREE is a decision aiding system developed at SRI which elicits a decision tree from an individual decision maker. The program uses sensitivity analysis to direct questioning and tree expansion.

(122)

Type I and Type II Errors - In Statistical Decision Theory, a Type I error occurs when a true hypothesis has been rejected; a Type II error occurs when a false hypothesis has been accepted.

<u>Decision</u>	<u>Hypothesis is in fact:</u>	
	<u>TRUE</u>	<u>FALSE</u>
Accept	Correct	Type II Error
Reject	Type I Error	Correct

(53)

Utility Models - A utility model is a computer system that aids decision making by the elicitation of subjective utilities. Such decision systems do not usually involve uncertain events.

(21,29,57,63,84,89,107,108)

Utility Theory - Utility theory is the study of human preferences as they relate to the selection of one alternative from a set of available alternatives. "Utility" is a numerical measure of these preferences.

(23,53,55,89,108)

Value of Information - In making a decision with less than perfect information, some expected loss will occur due to the uncertainty of event outcomes and states of the world. The reduction in loss given perfect information is the value or "worth" of the information.

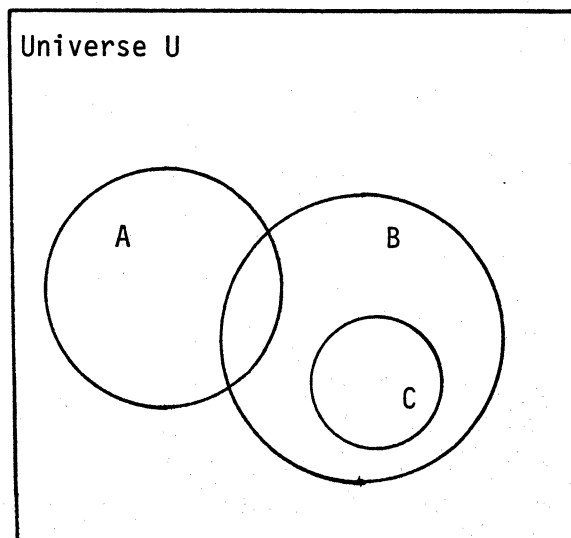
(7,53,89)

Variance - The variance is a statistical measure of the uniformity or dispersion within a group of numbers that uses the squared deviations from the mean.

$$\text{VAR}(X) = \frac{\sum (X - \bar{X})^2}{n}$$

where \bar{X} is the mean and n is the number of numbers in the set.
(7,42,53)

Venn Diagrams - A Venn diagram is a simple picture that describes the inclusion relationships among a number of sets.



4. REFERENCES

1. S. Andriole, "Progress Report on the Development of an Integrated Crisis Warning System", DDI/ARPA Report 76-17, Dec. 1976.
2. M.J. Apter, The Computer Simulation of Behavior, Hillary House, 1970.
3. S. Barclay, L.S. Randall, "Interactive Decision Analysis Aids for Intelligence Analysts", DDI/ARPA Report DT/TR 75-4, Dec. 1975.
4. R.E. Bellman, L.A. Zadeh, "Decision Making in a Fuzzy Environment", Management Science, Vol. 17, No. 4, Dec. 1970.
5. M. Ben-Bassat, F.A. Rothe, A. Freedy, "Pattern Recognition Applications to Political Crisis Prediction", Perceptrics, Inc. Report PFTR-1062-78-9/15, Sept. 1970.
6. J.A. Barnett, M.I. Bärnstein, "Knowledge-Based Systems: A Tutorial", SDC Report TM-(L)-5903/000/00, June 30, 1977.
7. H. Bierman Jr., Quantitative Analysis for Business Decisions, Irwin 1977.
8. M.M. Botvinnik, Computers, Chess and Long-Range Planning, Springer-Verlag, 1970.
9. J. Brown, "Heuristic Search Algorithm: Detailed Design", Perceptrics Report PR-1072-78-9, Sept. 29, 1978.
10. R. Brown, "Modeling Subsequent Acts for Decision Analysts", DDI/ARPA Report DT/TR 75-1, July 1975.
11. R. Brown, C.W. Kelly III, R.R. Stewart, J.W. Ulivila, "The Timeliness of a NATO Response to an Impending Warsaw Pact Attack", DDI/ARPA Report DT/TR 75-7, Dec. 1975.
12. R. Brown, J.W. Ulvila, "Selecting Analytic Approaches for Decision Situations", Volume I, II, III, DDI Report 77-7-25, Dec. 1977.
13. C.R. Carr, C.W. Howe, Quantitative Decision Procedures in Management and Economics, McGraw Hill, 1964.
14. E.D. Cashwell, C.J. Everett, Monte Carlo Methods, Pergamon, 1959.
15. R.L. Chang, T. Pavidis, "Fuzzy Decision Trees", Report 203, Computer Science Laboratory, Princeton Univ.

16. D.N. Chorafas, Systems and Simulation, Academic Press, 1965.
17. W.H. Crooks, M.A. Kuppin, A. Freedy, "Application of Computer Decision Aiding Systems to CAI: Adaptive Computerized Training System (ACTS)", Perceptronics Report PATR-1028-77-1, Jan. 1977.
18. J.M. Danskin, The Theory of Min-Max, Springer-Verlag, 1967.
19. A.D. DeGroot, Thought and Choice in Chess, Basic Books, 1965.
20. M. Dresher, Games of Strategy - Theory and Applications, Prentice Hall, 1961.
21. H. Dreyfus, S. Dreyfus, "Uses and Abuses of a Multi-Attribute and Multi-Aspect Models of Decision Making", Berkeley Report, 1975.
22. W.E. Duchworth, A Guide to Operational Research, Methuen, 1967.
23. W. Edwards, A. Tversky, Decision Making, Penguin Books, 1967.
24. D.R. Farris, A.P. Page, "Introduction and Survey of Group Decision Making with Applications to Worth Assessment", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-5, No. 3, May 1975.
25. A. Feinstein, Foundations of Information Theory, McGraw Hill, 1958.
26. W. Feller, An Introduction to Probability Theory and its Applications, Vol. 1, John Wiley, 1957.
27. J.A. Feldman, Y. Yakimovsky, "Decision Theory and Artificial Intelligence: A Semantics-Based Region Analyzer", Artificial Intelligence, Vol. 5, No. 4, Winter 1974.
28. N.V. Findler, B. Meltzer, Artificial Intelligence and Heuristic Programming, American Elsevier, 1971.
29. G.W. Fischer, W. Edwards, C.W. Kelly III, "Decision Theoretic Aids for Inference, Evaluation, and Decision Making: A Review of Research and Experience", DDI/ARPA Report TR/78 1-30, Feb. 1978.
30. B. Fischhoff, P. Slovic, S. Lichtenstein, "How Safe is Safe Enough? A Psychometric Study of Attitudes Toward Technological Risks and Benefits", Decision Research Report 76-1, 1976.

31. B. Fischhoff, "Decision Analysis: Clinical Art or Clinical Science?", Decision Research Report PTR-1042-77-5, May 1977.
32. B. Fischhoff, "The Art of Cost-Benefit Analysis", Decision Research Report PTR-1042-77-2/DR-76-10, Feb. 1977.
33. B. Fischhoff, P. Slovic, "On the Psychology of Experimental Surprizes", ORI/ARPA Report DDI-6, Aug. 1976.
34. B. Fischhoff, P. Slovic, S. Lichtenstein, "Fault Trees: Sensitivity of Estimated Failure Probabilities to Problem Representation", Decision Research Report PTR-1042-77-8, Aug. 1977.
35. A. Freedy, K.B. Davis, R. Steeb, M.G. Samet, P.C. Gardiner, "Adaptive Computer Aiding in Dynamic Decision Processes", Perceptrics Report PFTR-1016-76-8/30, Aug. 30, 1976.
36. A. Freedy, P.C. Gardiner, A. Leal, "Adaptive Decision Aiding in Tactical Operations: An Application to Airborne Anti-Submarine Warfare", Naval Research Reviews, Vol. XXXII, No. 2, Winter 1980.
37. A. Freedy, R.L. Weisbrod, R. Steeb, "A Pattern Recognition Approach to Subjective Value Estimation for Task Control Allocation", Journal of Cybernetics and Information Science, Vol. 1, No. 1, Spring 1976.
38. M.H. Foster, M.L. Martin (Ed.) Probability, Confirmation, and Simplicity, Odyssey Press, 1966.
39. L. Fox (Ed.) Advances in Programming and Non-Numerical Computation, Pergamon Press, 1966.
40. D.G. Fryback, W. Edwards, "Toward an Error Theory for PIP", Univ. of Michigan Report 011313-9-T, Nov. 1973.
41. K.S. Fu, "Syntactic (Linguistic) Pattern Recognition", Communications and Cybernetics 10, 1976.
42. N. Gilbert, Statistics, W.B. Saynders Co., 1976.
43. A.S. Ginsberg, F.L. Offensend, "An Application of Decision Theory to Medical Diagnosis-Treatment Problems", IEEE Transactions on Systems, Science, and Cybernetics, Vol. SSC-4, No. 3, Sept. 1968.
44. I.J. Good, The Estimation of Probabilities, M.I.T. Press, 1965.
45. B.C. Goodman, "Direct Estimation Procedures for Eliciting Judgments about Uncertain Events", Univ. of Michigan Report 011303-5-T, Nov. 1973.

46. L. Guild, The World's Greatest Gambling Systems, Holloway, 1970.
47. R.E. Hayes, J. Fain, G. Kenyon, B. Spector, "An Automated System for the Production and Sensitivity Analysis of Group Designed Decision Networks", CACI, Inc. Report, Aug. 31, 1977.
48. M.L. Hays, M.F. O'Connor, "Relating Promised Performance to Military Worth: An Evaluating Mechanism", Defense Management Journal, Oct. 1977.
49. R.M. Hogarth, "Cognitive Processes and the Assessment of Subjective Probability Distributions", Journal of the American Statistical Association, Vol. 70, No. 350, June 1975.
50. A. Hormann, "GAKU: An Artificial Student", Behavioral Science, Vol. 10, No. 1, Jan. 1965.
51. G. Huber, A. Delbecq, "Guidelines for Combining the Judgments of Individual Members in Decision Conferences", Academy of Management Journal, June 1972.
52. J.R. Jackson, "On Decision Theory Under Competition", Management Science, Vol. 15, No. 1, Sept. 1978.
53. P. Jedamus, R. Frame, Business Decision Theory, McGraw Hill, 1969.
54. D. Kahneman, A. Tversky, "Prospect Theory: An Analysis of Decision Making Under Risk", Decision Research Report PTR-1042-77-4, Apr. 1977.
55. S. Kassouf, Normative Decision Making, Prentice Hall, 1970.
56. T.W. Keelin III, "A Protocol and Procedure for Assessing Multi-Attribute Preference Functions", Stanford Univ. Report EES DA-77-2, Sept. 1976.
57. C.W. Kelly III, R.R. Stewart, "The Decision Template Concept", DDI Report, Dec. 1, 1977.
58. J.H. Kim, "A Graphic System for Evaluating Decision Aids", UCLA Engineering Systems Dept. Report, Winter 1979.
59. B. Kliemuntz (Ed.), Formal Representation of Human Judgment, John Wiley, 1968.
60. B. Kliemuntz (Ed.), Problem Solving: Research, Method, and Theory, John Wiley, 1966

61. E.B. Koffman, "Learning Through Pattern Recognition Applied to a Class of Games", Case Western Reserve Univ., DOD Report AD-666-673, May 1977.
62. A. Leal, E. Shaket, P.C. Gardiner, A. Freedy, "Studies and Application of Adaptive Decision Aiding in Anti-Submarine Warfare", Perceptronics Report PTR-1035-77-2, Feb. 1977.
63. A. Leal, S. Levin, S. Johnston, M. Agmon, G. Weltman, "An Interactive Computer Aiding System for Group Decision Making", Perceptronics Report PQTR-1046-78-2, Feb. 1978.
64. A. Leal, J. Pearl, "An Interactive Program for Conversational Elicitation of Decision Structures", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-7, No. 5, May 1977.
65. A. Leal, "Adaptive Decisions in Ballistic Missile Defense", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-7, No. 5, May 1977.
66. S. Lichtenstein, B. Fischhoff, "The Effect of Knowledge on the Calibration of Probability Assessments", ORI/ARPA Report DDI-4, Aug. 1976.
67. S. Lichtenstein, B. Fischhoff, L.D. Phillips, "Calibration of Probabilities", ORI/APRA Report DDI-3, Aug. 1976.
68. S. Lichtenstein, P. Slovic, B. Fischhoff, M. Layman, B. Combs, "Perceived Frequency of Recurrent Events", Decision Research Report PTR-1042-77-7, July 1977.
69. S. Lichtenstein, B. Fischhoff, "Calibration of Probabilities: The State of the Art", Proceedings of the 5th Research Conference on Subjective Probability, Utility, and Decision Making, 1976.
70. N.R.F. Maier, Problem Solving and Creativity, Brooks Cole, 1970.
71. D. May, E. Shaket, A. Leal, "Knowledgable Opponent Models for Enemy Submarine Tactics in Training Simulators", Report NAVTRAEQUIPCEN 78-C-0107-1, Naval Training Equipment Center, Orlando, Fla., Nov. 1978.
72. C. McMillan, R.F. Gonzalez, Systems Analysis, R.D. Irwin, 1965.
73. F. Mizoguchi, Y. Sayeki, "CAI Instructional Logic and Learner's Decision Strategies", Journal of the Informational Processing Society of Japan, Vol. 14, 1975.
74. P.A. Morris, R.D. Smallwood, "A Taskforce Decision Analysis", Xerox Research Center Report 78-11, Dec. 1978.
75. M. Newborn, Computer Chess, Academic Press, 1975.

76. A. Newell, "On the Analysis of Human Problem Solving Protocols", Carnegie Institute of Technology, June 27, 1966.
77. J.R. Newman, "Differential Weighting in Multi-Attribute Utility Measurement", SSRI/ARPA Report SSRI 76-6, Aug. 1976.
78. J.R. Newman, D. Seaver, W. Edwards, "Unit versus Differential Weighting Schemes for Decision Making", SSRI/ARPA Report SSRI 76-5, Aug. 1976.
79. N.J. Nilsson, Learning Machines, McGraw Hill, 1965.
80. N.J. Nilsson, Problem Solving Methods in Artificial Intelligence, McGraw Hill, 1971.
81. N.J. Nilsson, "Searching Problem Solving and Game Playing Trees for Minimal Cost Solutions", Proceedings IFIP Congress 68, Edinburgh, Aug. 1968.
82. D.W. North, "A Tutorial on Decision Theory", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SSC-4, No. 3, Sept. 1968.
83. N.F. O'Connor, W. Edwards, "On Using Scenarios in the Evaluation of Complex Alternatives", DDI/ARPA Report DT/TR 76-17, Dec. 1976.
84. N.F. O'Connor, T.R. Rhees, J.J. Allen, "A Multi-Attribute Utility Approach for Evaluating Alternative Naval Aviation Plans", DDI/ARPA Report 76-12, Oct. 1976.
85. S.L. Opter, Systems Analysis, Prentice Hall, 1968.
86. J.R. Payne, "A Brief Survey of Potential Decision Aids for the Task Force Commander and His Staff", SRI Report AD/A-016-627, Aug. 1975.
87. J. Pearl, "On Demonstrating the Effectiveness of Decision Analysis", UCLA Report ENG-1272, Sept. 1972.
88. J. Pearl, A. Leal, J. Saleh, "GODDESS: A Goal-Directed Decision Structuring System", UCLA Report UCLA-ENG-CSL-8034, June 1980.
89. H. Raiffa, Decision Analysis, Addison Wesley, 1970.
90. W.R. Reitman, Cognition and Thought, John Wiley, 1965.

91. H. Remus, "Simulation of a Learning Machine for Playing GO", Proceedings IFIP Congress 62, Amsterdam, 1962.
92. F. Restle, Psychology of Judgment and Choice, John Wiley, 1961.
93. W.W. Rosenboom, Foundations of the Theory of Prediction, Dorsey Press, 1966.
94. B.H. Rudwick, Systems Analysis for Effective Planning, John Wiley, 1969.
95. T.L. Saaty, Mathematical Methods of Operational Research, McGraw Hill, 1959.
96. H. Sackman, R.L. Citrenbaum (Ed.), Online Planning, Prentice Hall, 1972.
97. J. Saleh, A. Leal, "A Computerized Instructional Development Aid for Decision Tasks", Perceptronic Report P-77-155, Nov. 14, 1977.
98. J. Saleh, A. Leal, L. Lucaccini, P.C. Gardiner, R. Hopf-Weichel, "Analysis of Requirements and Methodology for Decision Training in Operational Systems", NTEC Report NAVTRAEQUIPCEN 77-C-0005-1, Feb. 1978.
99. R.K. Sarin, "Elicitation of Subjective Probabilities in the Context of Decision Making", Decision Sciences, Vol. 9, 1978.
100. M.G. Samet, G. Weltman, K.B. Davis, "Application of Adaptive Models to Information Selection in C3 Systems", Perceptronic Report PTR-1033-76-12, Dec. 31, 1976.
101. Y. Sawaragi, Y. Sunahara, T. Nakamizo, Statistical Decision Theory and Adaptive Control Systems, Academic Press, 1967.
102. J. Scarne, Scarne's Guide to Casino Gambling, Simon & Shuster, 1978.
103. D. Seaver, "Assessment of Group Preferences and Group Uncertainty for Decision Making", SSRI Report SSRI 76-4, June 1978.
104. J. Selvidge, "Rapid Screening of Decision Options", DDI/ARPA Report 76-12, Oct. 1976.
105. G.L.S. Shackle, Decision Order and Time, Cambridge Press, 1961.

106. E. Shaket, J. Saleh, A. Freedy, "Application of Rule-Based Computer Models to the Evaluation of Combat Training: A Feasibility Study", Perceptrics Report PFTR-1070-80-7-(2), July 1980.
107. T. Sheridan, A. Sicherman, "Estimation of a Group's Multi-Attribute Utility Function in Real Time by Anonymous Voting", IEEE Transactions on Systems, Man, and Cybernetics, May, 1977.
108. S. Siegel, Choice, Strategy and Utility, McGraw Hill, 1964.
109. J. Singh, Great Ideas of Operations Research, Dover, 1968.
110. J. Singh, Great Ideas in Information Theory, Language, and Cybernetics, Dover, 1966.
111. A. Smith, The Game of GO, C.E. Tuttle, 1961.
112. P. Slovic, B. Fischhoff, S. Lichtenstein, "The Uncertainty Illusion", ORI/ARPA Report DDI-2, Aug. 1976.
113. A. Tversky, "Applications of the Psychology of Decision", Proceedings Symposium on Computer Aids to Decision Making in Command and Control Systems, Haifa Univ., Mt. Carmel, Israel, Apr 1977.
114. A. Tversky, D. Kahneman, "Causal Schemata in Judgments Under Uncertainty", Decision Research Report PTR-1060-77-10, Oct. 1977.
115. L. Uhr, Pattern Recognition, Learning, and Thought, Prentice Hall, 1973.
116. L. Uhr, Pattern Recognition, John Wiley, 1966.
117. J.W. Ulvila, "A Pilot Survey of Computer Programs for Decision Analysis", DDI Report 75-2, Jan. 1975.
118. S. Vajda, Theory of Games and Linear Programming, Methuen, 1957.
119. M.D. Vernon, Perception Through Experience, Methuen, 1970.
120. A.R. Wagner, Crisis Decision Making, Prarger Press, 1974.
121. J.D. Williams, The Complete Strategyst, McGraw Hill, 1954.
122. R.M. Zamora, E.B. Leaf, "Tutorial on the Use of the SRI TREE Language System", SRI Draft Report, Dec. 1974.

APPENDIX - Abbreviations

ARI - Army Research Institute, Washington, D.C.
ARPA - Advanced Research Projects Agency, Washington, D.C.
DDI - Decision and Designs, Inc., McLean, Va.
JPL - Jet Propulsion Laboratory, Pasadena, Ca.
NTEC - Naval Training Equipment Laboratory, Orlando, Fla.
ORI - Oregon Research Institute, Eugene, Ore.
SDC - System Development Corp., Santa Monica, Ca.
SRI - Stanford Research Institute, Menlo Park, Ca.
SSRI - Social Sciences Research Institute, Los Angeles, Ca.
UCLA - University of California at Los Angeles

