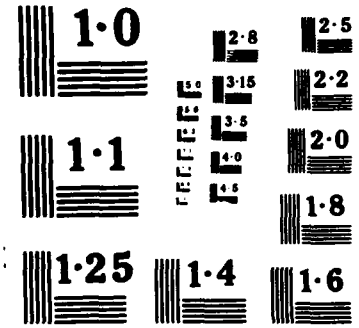
AD-A187 899 A GOAL PROGRAMMING R&D (RESEARCH AND DEVELOPMENT) PROJECT FUNDING MODEL Q (U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S M ANDERSON SEP 87 1/2

UNCLASSIFIED F/G 12/4 NL


1·0
2·8
2·5
3·15
2·2
3·5
2·0
4·0
1·1
4·5
1·8
1·25
1·4
1·6

DTIC FILE COPY

(2)

NAVAL POSTGRADUATE SCHOOL

Monterey, California

AD-A187 099

DTIC
ELECTE
OCT 2 3 1987
S D
D

THESIS

A GOAL PROGRAMMING R&D PROJECT FUNDING MODEL
OF THE U.S. ARMY STRATEGIC DEFENSE COMMAND
USING THE ANALYTIC HIERARCHY PROCESS

by

Steven M. Anderson

September 1987

Thesis Advisor: Dan C. Boger

Approved for public release; distribution is unlimited

87 14 447

AD-A187099

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) 55	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
A Goal Programming R&D Project Funding Model of the U.S. Army Strategic Defense Command Using the Analytic Hierarchy Process

12 PERSONAL AUTHOR(S)
ANDERSON, Steven M.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year Month Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1987 September	170

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Goal Programming, Analytic Hierarchy Process, R&D Project Funding Models

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

At present the US Army Strategic Defense Command (USASDC) relies on subjective judgments from key management personnel to make project funding decisions. In this thesis the Analytic Hierarchy Process (AHP) is used to convert subjective pairwise comparisons of thirty-five major USASDC projects, based on eleven key factors, into ratio-scaled numerical weights. The AHP coefficients are then used in a linear Goal Program (GP) in order to optimize the funding level for each project in Fiscal Year (FY) 1988 at several different USASDC total budget levels. An optimal priority list of projects is also determined. The model results are compared with the proposed funding levels and the present priority list, and a detailed examination of the impact of changes of the model parameters is conducted. This analysis of the model results and model sensitivity stimulates six funding recommendations for USASDC decision makers.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Prof. Dan C. Boger	22b TELEPHONE (Include Area Code) 408-646-2607 22c OFFICE SYMBOL 55Bo

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Approved for public release; distribution is unlimited

A Goal Programming R&D Project Funding Model of the US Army Strategic Defense Command Using the Analytic Hierarchy Process

by

Steven M. Anderson
Captain, United States Army
B.S., United States Military Academy, 1978

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1987

Author: _____
Steven M. Anderson

Approved by: _____
Dan C. Boger, Thesis Advisor

_____
Alvin F. Andrus, Second Reader

_____
Peter Purdue, Chairman,
Department of Operations Research

_____
Kneale T. Marshall
Dean of Information and Policy Science

ABSTRACT

At present the US Army Strategic Defense Command (USASDC) relies on subjective judgments from key management personnel to make project funding decisions. In this thesis the Analytic Hierarchy Process (AHP) is used to convert subjective pairwise comparisons of thirty-five major USASDC projects, based on eleven key factors, into ratio-scaled numerical weights. The AHP coefficients are then used in a linear Goal Program (GP) in order to optimize the funding level for each project in Fiscal Year ~~(FY)~~ 1988 at several different USASDC total budget levels. An optimal priority list of projects is also determined. The model results are compared with the proposed funding levels and the present priority list, and a detailed examination of the impact of changes of the model parameters is conducted. This analysis of the model results and model sensitivity stimulates six funding recommendations for USASDC decision makers. (Keywords: [illegible] research; Strategic Defense Initiative; [illegible] programs).

DTIC COPY INSPECTED 7

Accession For

A-1

TABLE OF CONTENTS

I. INTRODUCTION.....8
- A. SDI LONG AND SHORT RANGE GOALS.....8
- B. SDI ORGANIZATION AND FUNDING METHODS.....9
- C. STUDY OBJECTIVE AND ORGANIZATION.....9

II. BACKGROUND.....11
- A. SDI PROGRAM ELEMENTS.....11
- B. PROJECT DEVELOPMENT.....11
- C. PROJECT FUNDING GOALS.....13
  - 1. Maximize military effectiveness.....14
  - 2. Minimize project development risk.....15
  - 3. Minimize project development time.....16
  - 4. Maximize project development balance...17

III. LITERATURE REVIEW.....19
- A. SUBJECTIVE MODELS.....19
- B. RISK ASSESSMENT MODELS.....21
- C. FINANCIAL MODELS.....24
- D. MATHEMATICAL PROGRAMMING MODELS.....26
- E. PREFERRED MODEL.....31

IV. MODEL DEVELOPMENT.....32
- A. TRADITIONAL METHODS-SUBJECTIVE JUDGMENTS...32
  - 1. Numerical Rating Method.....33
  - 2. Categorical Judgement Method.....34
  - 3. Least Squares Method.....35
  - 4. Constant Sum Method.....38
- B. ANALYTIC HIERARCHY PROCESS.....41

V. GOAL PROGRAM FORMULATION.....49
- A. DECISION VARIABLES.....49
- B. SYSTEM CONSTRAINTS.....50
  - 1. Budget levels.....51
  - 2. Minimum funding levels.....52
  - 3. Maximum funding levels.....52

4. Non-negativity.....52
C. GOAL CONSTRAINTS.....53
1. Maximize military effectiveness.....53
2. Minimize project development risk.....54
3. Minimize project development time.....55
4. Maximize project development balance...55
D. ACHIEVEMENT FUNCTION.....56
E. THE GOAL PROGRAM FORMULATION.....57
F. MODEL ASSUMPTIONS.....57
VI. SOFTWARE SUPPORT AND MODEL RESULTS.....61
A. DATA COLLECTION AND SOFTWARE DEVELOPMENT...61
B. MODELS RESULTS.....62
1. AHP results.....63
2. GP results - optimal funding levels....64
3. GP results - optimal priority list.....73
VII. SENSITIVITY ANALYSIS.....78
A. CHANGES IN TOTAL USASDC BUDGET.....78
B. CHANGES IN MINIMUM AND MAXIMUM BOUNDS.....79
C. CHANGES IN GOAL CONSTRAINT COEFFICIENTS....80
D. CHANGES IN ACHIEVEMENT FN COEFFICIENTS.....85
VIII. CONCLUSIONS AND RECOMMENDATIONS.....89
A. CONCLUSIONS.....89
B. RECOMMENDATIONS.....91
APPENDIX A: PROGRAM ELEMENT DESCRIPTIONS.....93
APPENDIX B: PROPOSED PROJECT PRIORITY LIST.....98
APPENDIX C: AHP PROJECT SURVEYS.....100
APPENDIX D: AHP SOFTWARE SUPPORT.....108
APPENDIX E: GOAL PROGRAMMING SOFTWARE SUPPORT.....121
APPENDIX F: AHP OUTPUT.....131
APPENDIX G: GAMS OUTPUT.....140
APPENDIX H: AHP OUTPUT - SENSITIVITY ANALYSIS.....145
APPENDIX I: GAMS OUTPUT - SENSITIVITY ANALYSIS.....147
LIST OF REFERENCES.....164
INITIAL DISTRIBUTION LIST.....168

LIST OF TABLES

1. Balanced Technology Program.....18
2. Least Squares Method Scoring Procedure.....36
3. Least Squares Method Frequency Matrix.....36
4. Least Squares Method Probability Matrix.....37
5. Least Squares Method Standard Normal Matrix.....38
6. Constant Sum Method Comparison Matrices.....39
7. Constant Sum Method Average Comparison Matrix....39
8. Constant Sum Method W Matrix.....40
9. Constant Sum Method Scale Value Computations.....40
10. AHP Pairwise Comparison Scale.....44
11. AHP Example Comparison matrix.....44
12. AHP Example Eigenvector.....45
13. Random Consistency Index.....46
14. Car Buying Example Step 4 Demonstration.....47
15. Major USASDC projects.....50
16. Major projects FY 88 total budget levels.....51
17. AHP Consistency Ratio results.....63
18. AHP coefficient weights.....64
19. Achievement function AHP results.....65
20. Optimal project funding levels.....66
21. Optimal and proposed funding levels Kolmogorov-Smirnov two sample test results.....73
22. Optimal priority list of major projects.....74
23. Comparison of accurate and flawed matrix.....81
24. KEW projects - original comparison matrix.....82
25. KEW comparison matrix with minor changes.....82
26. KEW comparison matrix with major changes.....83
27. Achievement function eigenvalues Situations 1-4.....86
28. GP model results - Situations 1-4 compared with original.....87

LIST OF FIGURES

1. Numerical rating continuous line.....33
2. AHP Procedure.....42
3. Car buying hierarchical scheme.....43
4. Goal Program formulation.....58
5. Core budget strategy.....69
6. Basic budget strategy.....70
7. Enhanced budget strategy.....71
8. Extended budget strategy.....72
9. Difference vector of priority lists.....76

I. INTRODUCTION

In 1983 President Ronald Reagan announced the Strategic Defense Initiative (SDI), a program that called for an intensive research and development effort in space weapons technology. The primary objective of the initiative is to produce a system of defensive weapons capable of defending the United States and its allied countries from hostile ballistic missile infiltration; to create an impenetrable shield composed of high technology defensive weapons. President Reagan believed it was time to pursue such a program based on his assumption that the United States had the technological potential to bring his goal to reality.

A. SDI LONG AND SHORT RANGE GOALS

The President's initial SDI objective statement is now recognized as the long range goal of the SDI program [Ref. 1]. By conducting a vigorous research and development (R&D) program, it is hoped that the threat posed by ballistic missiles will be eliminated, thereby deterring aggression and promoting security and stability throughout the world.

The short range goal of the SDI has been established as well. Before proceeding with the full-scale production of the defensive system, an initial period of intensive R&D must be conducted. A target date of 1995 has been established for the completion of this initial phase to determine the physical and economic feasibility of the proposed system. The short range goal of the SDI is to provide the technical knowledge needed to support an informed decision by 1995 on whether or not to deploy a strategic space

defense against ballistic missiles. This decision is called the Full Scale Engineering Decision (FSED).

B. SDI ORGANIZATION AND PROJECT FUNDING METHODS

The SDI proposal led to the creation of the Strategic Defense Initiative Organization (SDIO) as the organization responsible for carrying out both objectives of the initiative. An Army unit was established to manage and direct Army activities in support of the SDI. This unit, the US Army Strategic Defense Command (USASDC), is headquartered in Washington, DC, and commanded by LTG John Wall. Additionally, the US Army Ballistic Missile Command in Huntsville, Alabama, was reorganized under the USASDC, since this command was responsible for many of the technological developments that stimulated the SDI.

As will be discussed in detail in the next chapter, the USASDC does not use a project funding model to assist in determining the funding levels for the many projects they manage. The budgeting methods presently used are almost entirely subjective, relying on expert opinion and informal prioritization techniques to determine project funding levels each year, depending on the approved budget from Congress.

C. STUDY OBJECTIVE AND ORGANIZATION

It is the primary objective of this study to develop an R&D project funding model of the presently funded major USASDC R&D projects. This model will determine optimum expenditure levels for each major project in FY 88, based on the long and short range goals of the SDI and the project development goals that will be generated in Chapter II. The model used to meet this objective should preferably have a wide range of flexibility and apply to each possible budget

strategy. Results from this model will be compared against presently forecasted FY 88 funding levels in order to test the validity of the subjective methods presently employed.

This paper is organized to logically discuss the modelling process and results. Chapter II is devoted to additional background information critical to the model selection and execution. The third chapter will consist of a search for the most appropriate project funding model among all such models currently used in the operations research literature. Chapters IV and V will examine the development and formulation of the model being implemented, and Chapter VI will present the computer programs written to perform the model. Additionally, the sixth chapter will tender model results and output. Chapter VII will be reserved for a deliberation on the model sensitivity and validity. The final chapter will present conclusions and recommendations.

II. BACKGROUND

This chapter is intended to discuss in detail those items of background information that are critical to the development of an R&D project funding model of the USASDC. This includes the SDI program element structure, the present project development process, and the specific project funding goals that have been established by key management personnel of the SDIO and USASDC.

A. SDI PROGRAM ELEMENTS

Given the structure reviewed in the previous chapter, a technical program has now been defined and implemented. R&D efforts are structured into five program elements, each element examining equally important SDI technology. Many of these programs have already been responsible for some outstanding experimental results. The five program elements are: (1) the Surveillance, Acquisition, Tracking and Kill Assessment (SATKA) program; (2) the Directed Energy Weapons (DEW) program; (3) the Kinetic Energy Weapons (KEW) program; (4) the Systems Analysis and Battle Management (SABM) program; and (5) the Survivability, Lethality and Key Technologies (SLKT) program. A complete description of each program element can by found in Appendix A.

B. PROJECT DEVELOPMENT

The USASDC has the responsibility of directing the research and development process for all Army-related SDI projects. Official funding for a particular project does not begin until a research objective is specified in a Work Package Directive (WPD). The WPD is a critical document that contains basic

administrative information and funding authority. There are presently over seventy WPDs being managed by the USASDC; thirty-five can be categorized as major WPDs, since they involve annual spending of over $5 million or are considered high priority (see Appendix B for a description of each). The focal point for project management at the USASDC headquarters is the Program Analysis and Evaluation (PAE) directorate.

The USASDC PAE shop is organized on program element lines: SATKA, SLKT, SABM, KEW, and DEW. Program element managers in these sections manage the WPDs, in conjunction with the program managers and technical personnel located at research facilities throughout the worldwide R&D community. PAE program element managers are highly educated and have broad technical and managerial backgrounds. They must understand the intricacies of the R&D process in the field in order to make correct recommendations to decision makers. The most difficult and important aspect of the program element managers job involves the allocation of funds to the projects in their respective program element areas.

Presently there is no formal project and funding model being used by the USASDC. Rather, project funding is based on a document [Ref. 2] that lists the WPDs in priority order and forecasts funding levels through 1994. The priority listing is put together by project management personnel at both the USASDC headquarters in Washington and Huntsville, and is based on subjective guidance, recommendations, and information from R&D personnel involved in SDI development worldwide. A key feature of the priority list is that it changes according to four different budgeting strategies. USASDC planners realize that

overall funding for the SDI is subject to congressional debate and approval, and it is difficult to predict the approved funding level for politically controversial programs. Therefore, budget planners have identified the following funding strategies:

1. Core - the level required to provide a high risk FSED in the late 1990's.
2. Basic - the level required to provide a reliable FSED in the late 1990's.
3. Enhanced - the level required to provide a reliable FSED in 1995.
4. Extended - the level required to provide a reliable FSED in the early 1990's.

Particularly noteworthy is the fact that the core and basic funding levels are not sufficient to meet the short term goal of an FSED in 1995; the enhanced and extended levels are the desired funding levels for the USASDC. A consistent long term funding strategy is not likely to be adopted by Congress in the near future, so USASDC planners must be flexible.

C. PROJECT FUNDING GOALS

As stated earlier in this chapter, the long range goal of the SDI is to ultimately develop a high technology defensive shield against hostile ballistic missile attack. The short range goal is to reach the FSED not later than 1995. Projects selected for development, or continued development, must support these two goals. Specifically, projects should exhibit the following characteristics in order to contribute to the attainment of short range and long range goals:

1. Maximize military effectiveness
2. Minimize project development risk
3. Minimize project development time
4. Maximize project development balance

The next four sections will discuss these desired sub-goals and the factors that influence the attainment of these goals.

1. Maximize military effectiveness

A project will not be selected for funding unless it contributes to the achievement of the overall military mission of the SDI. There are three ways in which a project can make such a contribution. The first is that the project can augment the achievement of the long range goal of the SDI; the project can assist in a defense against attacking ballistic missiles. This defense must be designed to destroy so many hostile missiles that an aggressor will be deterred from launching them. The degree to which a project aids the survivability, destructibility, supportability, and/or reliability of the SDI defensive system is a critical characteristic that must be evaluated prior to funding decisions.

The second manner in which a project can contribute to the military effectiveness of the SDI program concerns the SDI short-range goal; the project can support the achievement of an FSED by 1995. An informed FSED will require a great deal of technical and tactical information. Many projects perform R&D tasks that are designed to support the FSED, so a project's potential contribution in this area must be considered.

The final constituent of military effectiveness involves the potential generation of military spinoff technology. Military spinoff technology is a technological advance that benefits military objectives other than those associated with the SDI. For example, advances stimulated by an SDI research project on space target hardening would

certainly be carried over to ground and sky target hardening projects not be related to SDI. The space program of the 1960's and 1970's led to a great many technological breakthroughs that benefitted many other facets of the military world; one would expect the SDI program to similarly induce useful spinoff technology. The potential for generating additional military benefits is a project characteristic that must also be considered prior to funding decisions.

To summarize, the three components of the military effectiveness goal are: (1) maximize the potential contribution to the SDI long range goal of building a missile defense system; (2) maximize the potential contribution to the SDI short range goal of reaching an FSED by 1995; and (3) maximize the potential generation of military spinoff technology.

2. Minimize project development risk

Each project in SDI has a degree of risk associated with it; some projects are more likely to achieve success than others. It is advantageous to any financial strategy to fund projects that involve the least amount of risk. There are two separate types of risk that are associated with each project that must be considered during the funding process: technological risk and milestone risk.

Many projects require the development of radically new technology, whereas others involve established and proven scientific ideas. Technological risk addresses the technical or scientific uncertainty affiliated with each R&D project; the likelihood of failing to meet the ultimate technical objectives of the WPD. A venture that relies on the development of unproven technology in order to achieve its goal poses a risk to the SDI investment scheme. The technological

risk must be considered prior to making a funding decision regarding a project.

Milestone risk involves the milestone schedule that is listed in each WPD. Projects are given target dates in which to reach certain developmental plateaus. Milestone risk is the likelihood of failing to meet the target date schedule specified in the WPD; this risk is critical to the overall success of the SDI, since many projects are interrelated.

It is important to differentiate the two types of risk involved with SDI. A project might have a very low technological risk, but represent a high milestone risk if it depended on the performance of tasks that are technologically easy, but operationally difficult. The two components, therefore, of the goal to minimize risk are: (1) minimize technological risk; and (2) minimize milestone risk.

3. Minimize project development time

The third major desired characteristic of an SDI project is that it should minimize project development time. There are two constituents of project development time. The first concerns the time required to achieve ultimate project success. SDI projects demand varying lengths of time in order to accomplish the goals of the research. It is difficult to predict the time required for many projects, particularly those that involve new technology. Nonetheless, the estimation and minimization of this time is important, since the missile threat posed by Warsaw Pact countries is becoming increasingly sophisticated. It does not make sense to spend money on a project that would require an excessive amount of time to properly research and develop.

The second facet of project development time that should be considered in project funding decisions is the time required to achieve the project objectives needed for an FSED. The desire to reach an informed FSED by 1995 (the short range goal of the SDI) has already been discussed. The FSED requires information on the feasibility of each project. The time required to conduct the research needed to provide this information will vary. Many projects that involve proven technology can be expected to achieve the project objectives needed for an FSED very quickly, whereas other projects will contribute to the FSED slowly. Projects that need a short time to perform the required FSED research should be encouraged.

The two sub-goals of the minimize development time goal are as follows: (1) minimize ultimate project success time, and (2) minimize FSED contribution time.

4. Maximize project development balance

A balanced research and development SDI program is a theme that has been expressed repeatedly in the USASDC 1986 Report to Congress [Ref. 1] and by key leaders in the USASDC. The 1986 Budget Priorities briefing [Ref. 3] lists four elements of the Balanced Technology Program (BTP): technology base, concepts and designs, data collection and signature measurements, and function performance. It is desired that a proper balance of funding to these research elements be achieved and maintained.

Technology base scientific work encompasses work that is both basic and applied research. Some technology base efforts involve relatively straightforward extensions of existing technology; it also includes high risk, high payoff efforts. The technology base program is intended to foster the birth

of many innovative ideas. It is important that enough projects in this category are supported so that the SDI program continues to develop new technology and does not stagnate. The work done in the technology base phases are refined in the concepts and designs research phase. Specific ideas regarding problem solutions and equipment designs are formulated in writing and an experimental procedure is postulated. Data collection and signature requirements involve proof-of-feasibility experiments to support or refute the ideas stated in the concepts and design phase. Many projects in this category are critical to the goal of an informed FSED by 1995. The function performance phase involves experiments that demonstrate the capabilities of the project. This is the last phase prior to full-scale development, and deals with technology that has already been demonstrated as feasible and must now be integrated with other system requirements. Function performance experiments tend to be expensive and time consuming.

The goal of promoting project development balance will be achieved by maximizing adherence to the guidelines shown in Table 1.

TABLE 1

BALANCED TECHNOLOGY PROGRAM

Category	Guidance	FY 87
Technology base	35%	28%
Concepts and designs	5%	8%
Data collection	10%	7%
Function performance	50%	57%

III. LITERATURE REVIEW

The past twenty years has seen a great deal of analytic activity in the area of project management, and the aspect of research and development project funding has been modelled in a variety of ways. It is the intent of this chapter to provide a current assessment of the literature addressed to quantitative models of research and development project funding. The four general types of project funding models that will be discussed are subjective models, risk assessment models, financial models, and mathematical programming models.

A. SUBJECTIVE MODELS

The simplest form of formal R&D project evaluation involves subjective models. The subjective models that are used the most frequently are checklist and scoring models. Liberatore and Titus [Ref. 4], in their 1985 study of 29 Fortune 500 firms, found that almost half of the 29 firms had used checklist and scoring models to help manage the R&D project funding process.

The checklist involves the completion of a profile chart for each project being considered for funding. Criteria are listed on the checklist which are believed to be important factors in determining the eventual success or failure of the R&D effort. Each candidate project is rated according to a subjective scale such as yes/no or advantage/neutral/disadvantage. The opinions of several individuals can be summarized in a checklist by averaging their opinions.

Checklists are simple and easy to use while still providing some structure to the decision making process. This methodology lends itself readily to

types of information that are awkward or difficult to include in more formal model construction, such as social impacts and environmental concerns. Particular weaknesses of certain projects are identified quickly by their poor ratings on certain checklist criteria. The checklist procedure is particularly useful in time-constrained decision situations.

While the ease of the checklist model is desirable, it can also be dangerous since critical problems may be overlooked. Complicated relationships are not easily incorporated into such a model. Although many important factors may be included in the model, the relevance or weight of each individual factor or project is not captured.

The scoring model is an attempt remedy this problem by assigning weights to individual criteria and summarizing the results in a single project score. Decision makers are required to state their preferences in order to obtain a set of criteria weights.

Several methods have been developed for deriving these weights. These include simple rank-ordering of the criteria and various types of paired comparisons. Souder [Ref. 5] demonstrated that increasing the number of scoring intervals improves the accuracy of the model. However, psychometric testing has shown that nine is the maximum number of intervals that should be used.

In 1969, Moore and Baker [Ref. 6] conducted a study comparing scoring models with more sophisticated economic, risk analysis, and optimization models, and the scoring models fared well. Using standardized data, the scoring models they tested produced results that were 90 percent rank order consistent with economic and optimization models. The analysis was

limited to only five criteria, but it does suggest that a scoring model can be a useful tool when the complexity of more sophisticated approaches are not justified on the basis of time and cost.

Excellent examples of scoring model applications to R&D project funding have been presented by Moore and Baker [Ref. 6], Gargiulo and Hannoch [Ref. 7], Motley and Newton [Ref. 8], and Dean and Nishry [Ref. 9].

The major disadvantage with the scoring model is that it is dimensionless, thereby limiting its use to rank order comparisons. Such comparisons provide information on the ordinal scale, when often times R&D managers desire data concerning projects on a ratio or interval scale. Another problem is that there has been little analytic activity and very few applications of scoring models in recent years, indicative that other models of project funding are now more preferable than subjective models.

B. RISK ASSESSMENT MODELS

Many civilian firms have shown a proclivity towards using risk assessment techniques to make project funding decisions. Liberatore and Titus found that 35% of the respondents in their study were familiar with either decision tree models or Monte Carlo simulation models, the two risk assessment methods that are the most important and applicable.

Decision tree models attempt to focus on the fact that many R&D activities are actually a series of interrelated projects. The benefits that are gained via the successful completion of one project will affect the outcome of the other ventures. Decision trees have been used extensively to help in the characterization of project funding decisions.

The procedure is to establish decision points or nodes graphically and to determine branches emanating to and from each node. Each branch or path has a certain outcome and risk associated with it. For example, consider a project which might have two different funding strategies. If given strong support, the chances that the project might produce a highly successful outcome might be .8, and the chances of a moderate success are .2. However, if the project is given only weak support, these respective probabilities of high and moderate success might change to .6 and .4 respectively. The decision tree model is built by formalizing all such outcomes and probabilities. The optimum path is found by starting at the right-hand side, and by following an expected value algorithm, folding back to the starting point. At each node the expected value is calculated for all the branches leaving that point, and the path with the highest expected value is selected. Projects are then interrelated where appropriate and an entire network of decision trees are connected to model the complete project funding process.

This method is analytically simple and can be graphically represented, so the basic logic behind the tree structure can be easily communicated to high-level managers. It has been demonstrated as very useful in making decisions concerning projects when the number of projects being examined for funding are small and the interrelationships are not excessively complex [Ref. 10].

Raiffa [Ref. 11] and Jackson [Ref. 12] have both demonstrated that the decision tree model can be successfully applied to R&D project funding situations. The major drawback of this model concerns

the fact that outcomes at each node are represented by a few points rather than a continuous distribution of possible outcomes. Adding more branches to the nodes provides better representation of the underlying probability distribution, but the complexity of the calculations involved increase rapidly. Any user of this technique must be willing to accept the tradeoffs between accuracy and computational difficulty/expense.

The Monte Carlo simulation model is based on the decision tree model. Each of the nodes is replaced with a probability distribution and this produces a stochastic decision tree: This is analogous to adding an arbitrarily large number of branches to each decision point.

The Monte Carlo technique generally provides a more accurate description of the R&D decision process and offers a better basis for making project funding decisions than other methods. The complexity of the projects are displayed in a concise manner and the stochastic nature of the uncertain outcomes of R&D projects are recognized. Hespos and Strassman [Ref. 13] are responsible for the most renowned application of Monte Carlo to an R&D project selection and funding scenario.

The cost of the improvements bought by the Monte Carlo model is that there is a dramatic increase in information requirements. The probability distributions for each unknown research project outcome must be estimated, and this is difficult and costly in most instances.

Perhaps the most important methodological shortcoming of the two risk assessment models presented here is that neither method deals with resource constraints. These methods assess risk probabilities

but fail to allocate scarce resources among research activities. A user of a risk assessment model would most likely be someone more concerned with finding the combination of projects that offer the highest chance of ultimate R&D success, rather than optimizing the use of funds or project resources.

C. FINANCIAL MODELS

The Liberatore and Titus study concluded that financial models experience heavy use and have a high perceived impact in the business world today, as 62% of the firms they studied reported using financial project funding techniques. The major financial modelling technique used in the project funding process are Benefit Cost Ratio models (sometimes called Economic Index models).

Costs and benefits associated with each project are assessed in terms of dollars in the Benefit Cost Ratio model. Costs are the total resource costs of supporting the research project or group of projects, and benefits are the net earnings to be realized from the project once it is successful (or if it is successful). These costs and benefits are expressed as present values using an appropriate discount rate. If the ratio of benefits over costs is less than or equal to one, there is no reason to undertake the R&D project.

The benefit to cost ratio can be easily expanded to include probabilities of success of the project at various stages of development. Olsen [Ref. 14] used the following Benefit Cost Ratio calculation in a project funding study:

$$V = \frac{r * d * m * s * p * n}{\text{total project cost}} \qquad (3\text{-}1)$$

In equation 3-1, V represents the economic value of the project, s is the annual sales volume derived from the project if the project succeeds, and p is the profit per unit. The product's expected life span is represented by n, and r, d, and m are the probabilities of research, development, and marketing success, respectively.

The ratio in equation 3-1 captures the risks involved, and could be augmented to include noneconomic considerations. Social, environmental, and political costs or benefits can be added to either the numerator or denominator of the ratio, but they must be expressed in dollar units, as are the other factors.

Various project iterations can also be taken into account with this model. For example, successful completion of a project may result in a product which will perform the same function as an already existing project or another one under development. In such a case, one would reduce the project benefits by the expected loss in earnings from sales from the displaced product.

Benefit cost ratio models are desirable in many situations since they overcome the dimensionality problems of scoring models and checklist models. Decision makers are required to clearly quantify their evaluation of a project. The favorable result is that difficult issues cannot be avoided through the use of arbitrary scales, as the benefit cost ratio has an absolute interpretation. This allows project rejection decisions that do not involve unnecessary comparisons with other projects.

Gearing and Adams [Ref. 15] and Souder [Ref. 16] explain how the benefit cost ratio model might be applied to an R&D project funding model. Keefer [Ref.

17] and Costello [Ref. 18] are more recent proponents of the benefit cost model.

One problem with this type of financial model is that the information required is often times very difficult to obtain. The probabilities and cost and benefit estimations usually require a considerable degree of experience on the part of the analyst and/or historical precedent. It is also difficult to express many noneconomic effects in dollar terms, especially in military project funding efforts.

Another shortcoming with the benefit cost R&D project selection and funding technique is that benefit cost ratios are not useful when evaluating the consequences of alternative funding levels. Each element in the ratio must be reassessed if the funding level is increased or reduced. As with risk assessment models, benefit cost models do not recognize resource constraints. There is no way of quantitatively limiting a particular resource at a certain amount, or forcing the model to perform to a specific level.

D. MATHEMATICAL PROGRAMMING MODELS

Mathematical programming models have been used extensively during the last quarter of a century to solve many allocation and capital budgeting problems. Surprisingly, the Liberatore and Titus study found that there was no usage of mathematical programming for R&D project funding in the firms that they investigated. However, that fact has not precluded many optimization proponents researching new project selection and funding models. The branches of math programming that have seen the most activity in this area are linear programming, nonlinear programming, integer programming, and goal programming.

The technique of linear programming is a well known and useful one. Project funding models such as those proposed by Asher [Ref. 19] and Hanssman [Ref. 20] are formulated in the general form shown below:

$$\text{maximize} \quad \sum CX \qquad (3\text{-}2)$$

$$\text{subject to} \quad \sum AX <= B \qquad (3\text{-}3)$$

$$0 <= X <= 1 \qquad (3\text{-}4)$$

X is an n-component vector representing the funding levels of the projects, C is an n-component vector representing the contribution of the various projects, B is an m-component vector representing resource levels, and A is an m x n matrix representing resource usages of the projects.

The primary advantage of linear programming, and all mathematical programming models for project funding, is that modelled situations can be forced to meet resource constraints as the program seeks to maximize the objective function.

The linear programming formulation shown above allows the project to be funded at a maximum level when X = 1, or any level down to X = 0, where the project is not being funded. Of course, this model requires that a linear assumption be made concerning the resource constraints; the changes in X motivated by changes in B are assumed to be constant.

In many situations projects are either selected for development and full funding, or they are not selected at all. Many authors have proposed integer programming formulations in which the X's can only take on values of zero or one. Wiengartner [Ref. 21] was the first to propose the following formulation of integer programming project funding models:

Find $X = X_1, X_2, \ldots, X_n$ so as to maximize

$$\sum R_j X_j \qquad (3\text{-}5)$$

subject to:

$$\sum A_{ij} X_j <= B_i \quad = 1, \ldots, m \qquad (3\text{-}6)$$

where:

$$X_j = \begin{cases} 1 \text{ if the } j^{th} \text{ program is selected} \\ 0 \text{ is the } j^{th} \text{ program is not selected} \end{cases}$$

R_j = return of program j

A_{ij} = budget consumed in year i by project j

B_i = amount of total budget available for year i

The above formulation allows the decision maker to select a subset of projects from among a given, finite set. The objective is to maximize the return or benefit from these programs while continuing to satisfy budget limitations or any other resource constraints. The end result in this instance is that the decision maker will be provided the list of projects that he can support at the fully funded level, given the constraints that have been placed in the program.

While many functional relationships in a mathematical model of the project funding process may be linear in nature, others are more realistically described by nonlinear relationships. Numerous researchers began work on a project funding model thinking that a constant change of one variable in response to another was appropriate, only to discover that such an assumption was false.

Nonlinear programming models are very similar in structure to linear models; the only difference is that the constraint equations, objective function, or both are nonlinear. If the model builder has enough data to support nonlinear equations then there is no reason to make the standard linear assumption that the vast majority of project selection and funding models make.

An excellent example of a nonlinear approach was made by Taylor, Moore, and Clayton [Ref. 22]. They identified over twenty nonlinear relationships for inclusion in their model. For instance, they were able to state that the probability of success of a particular project increased according to the amount of money that was spent on it, but at a decreasing (rather than a constant) rate. A perfectly acceptable methodology is to initially make the model linear and make applicable nonlinear modifications as more information becomes available.

Linear, integer, and nonlinear project funding models all have weaknesses. Linear models are too simplistic for some project selection situations. Since resource utilization as well as the project funding level can be used as decision variables, a strictly 0-1 integer program can be overly restrictive. Nonlinear programs usually require considerably more information and research than linear models.

The most serious shortcoming of these mathematical models is that they are restricted to the consideration of only a single objective function. In most real-world situations, however, there are usually several objectives that are desirable to the decision maker. In 1961 Charnes and Cooper [Ref. 23] introduced the concept of goal programming as an attempt to rectify this problem.

Goal programming is a modification of linear programming that allows multiple goals or objectives to be optimized in the model. The decision maker is required to rank in an ordinal manner the goals established for the organization. In a linear program a single criterion is optimized directly, whereas in

goal programming the deviations from the exact satisfaction of the goals are minimized.

The formulation can be expressed as follows:

$$\text{Minimize:} \quad \sum d^- + d^+ \qquad (3\text{-}7)$$

$$\text{Subject to:} \quad \sum Gx + d^- - d^+ = g \qquad (3\text{-}8)$$

$$\sum Ax <= b \qquad (3\text{-}9)$$

$$d^-,\ d^+,\ x >= 0 \qquad (3\text{-}10)$$

The variables shown in equation 3-7, d^- and d^+, represent the negative and positive deviations from the goal constraints to be achieved (equation 3-8). These deviations are also referred to in goal programming literature as underachievement and overachievement variables. Equations 3-9 and 3-10 are typical linear programming constraints regarding resource availability and non-negativity. Note that equation 3-8 is not an inequality constraint but, contrary to most mathematical programming techniques, is an absolute equality statement. This is intended to place the deviations from the goal constraints into the deviation variables.

The goal programming project funding model has proven to be very flexible and popular. The basic methodology can be modified to include nonlinear and integer constraints. Charnes and Stedry [Ref. 24] wrote a linear goal programming model that broke the project selection process into short run and long run funding strategies. Salvia and Ludwig [Ref. 25] modelled the project funding process at the Lord Corporation using a goal program that optimized the attainment of ten goals involving 25 projects. Ignizio [Ref. 26] created an integer goal programming project funding model for the US Army Ballistic Missile Defense Agency, and a general integer model was written by

Winkofsky, Baker, and Sweeney in 1981 [Ref. 27]. Nonlinear programming was recently added to the list of successful modifications to the general goal programming algorithm when Taylor, Moore, and Clayton published their integer nonlinear goal program project funding model [Ref 22].

E. PREFERRED MODEL

In this chapter the four major model types for project funding have been discussed: subjective models, risk assessment models, financial models, and mathematical models. Though each model type is important and useful in many situations, the goal programming model for project funding in the mathematical model category is the most applicable to the project selection and funding scenario for the US Army Strategic Defense Command. This is true for several reasons. First, the goal programming algorithm allows the use of resource constraints, a very critical feature since the SDC is concerned with limited funding resources. Second, goal programming permits the decision maker to specify multiple objectives or targets to be achieved; as discussed in the previous chapter, there are several goals at issue here. Finally, in the last decade goal programming appears to have been established as the preferred method of solving the project funding problem. Numerous applications of goal programming have been made to scenarios not too dissimilar to the one facing the SDC; the articles written by other goal programmers will undoubtedly assist project selection efforts in this endeavor.

For the reasons just stated, goal programming will be the principle tool used in the project funding model to be discussed in the remainder of this thesis.

IV. MODEL DEVELOPMENT

The goal programming technique requires the development of mathematical equations to represent model goals and constraints. In the second chapter the four major project funding goals for the USASDC were introduced. These goals are reviewed below:

1. Maximize military effectiveness
2. Minimize project development risk
3. Minimize project development time
4. Maximize project development balance

It is the intent of this chapter to determine a methodology for converting subjective judgments of individual project contributions to the major SDI project goals into coefficient weights. These weights will represent the performance of each project regarding each goal or constraint equation in the GP model formulation.

A. TRADITIONAL METHODS OF QUANTIFYING SUBJECTIVE JUDGMENTS

A key problem in the project funding modelling process involves the quantification of subjective terms such as effectiveness, risk, time, and balance. The USASDC does not have a table or document that lists values of funded projects in such broad terms. The WPD for each project lists funding authorizations and milestone objectives, but it does not include a score for effectiveness, risk, time or balance. Project selection and funding decisions are largely based on the subjective opinions of key personnel involved with each project, especially the program element managers assigned to the USASDC headquarters. Operations research literature contains several traditional

methods for quantifying intangibles, a task that must be performed so that coefficient weights for the GP model can be determined.

1. Numerical Rating Method

A very simple method for quantifying subjective judgments is the numerical rating method (sometimes called the magnitude estimation method). This method was first proposed by Stevens [Ref. 28] as a method of eliciting comparative rankings in psychophysical experiments. Judges are given two reference points and asked to associate the rated items with these points. This can be done either by using numbers, or by plotting points on a continuous number line. When using two reference points, one can imply a constant interval scale. For example, in a project funding scenario, a program element manager might be asked to rate the potential technological payoff of two projects. The manager could perform this task by indicating where these projects fall on a continuous line, referenced by a prepositioned project with low payoff and another with high payoff, as demonstrated below in Figure 1.

```
-----X--------------X---------------X----------X---
     ^              ^               ^          ^
 low payoff       proj 1        high payoff  proj 2
  project
```

Figure 1 - Numerical Rating Continuous Line

The researcher could then use these intervals to determine the scale relationship of these four projects. Since this results in interval scale data, the points can then be linearly transformed to any

other scale desired; a common scale would be the 0-100 scale.

The primary advantage of this method is computational simplicity. Basic statistical work can be performed on the results, and one can easily test for significant differences. Unfortunately, problems often arise when determining the reference points; there is no natural origin and judges frequently disagree with the reference point positioning. Many researchers also have difficulty with the lack of bounds on the interval scale.

2. Categorical Judgement Method

A commonly used means of obtaining numerical results from subjective ratings is the categorical judgement method, wherein judges assign instances to ranked categories. For example, pollsters often ask people to rate political candidates as poor, fair, average, good, or outstanding. Program managers could similarly be asked to rate project milestone risk according to a scale of very low, low, average, high, or very high. Dyer, Mathews, Wright, and Yudowitch [Ref. 29] recommend that five categories be used for this technique.

The procedure begins by rating the items in question and then arranging the cumulative frequency data in a matrix of n row instances and m column categories. The elements of this matrix are treated as areas under a standard normal curve and are converted to the corresponding Z values. These values are then recorded in a Z_{ij} matrix consisting of n rows and m-1 columns, since the last column may be omitted for computational purposes. The row and column averages are computed, and called R_i and C_j respectively, and

the grand mean, G, is calculated. A row sum-of-squares term is computed as shown below:

$$SSC = \sum_j (C_j - G)^2 \qquad (4\text{-}1)$$

For each row, the following is computed:

$$SSR_i = \sum_i (Z_{ij} - R_i)^2 \qquad (4\text{-}2)$$

The scale values of the instances, S_i, are found by solving the following equation for each row:

$$S_i = G - Z_i * SQRT\ (SSC/SSR_i) \qquad (4\text{-}3)$$

In equation 4-3, S represents the interval scale value, G is the grand mean of the Z matrix, SQRT represents the square root mathematical operation, and SSC and SSR are the column and row sum-of-squares.

The categorical judgment method succeeds in obtaining an interval scale value that can be linearly transformed to any other scale. It is more sophisticated than the numerical rating method, but still computationally easy. Questionnaires employing this technique are straightforward and uncomplicated. The major drawback with the categorical method concerns the five-category limitation; this is not accurate enough for most serious efforts to quantify subjective evaluations.

3. Least Squares Method

A frequent procedure for eliciting expert opinion is that of asking judges to do some form of ordinal ranking of various instances of a designated property. The Least Squares Method was first proposed by Guilford [Ref. 30] as a means of obtaining scaled interval data from ordinal judgments. The procedure has proven very useful and relatively simple.

The method is initiated by soliciting the ordinal responses of the judges comparing several items on the basis of a particular factor or quality. For example, judges might be asked to rate several television shows as excellent, good, fair, or poor. Suppose that a judge feels program B is better than program C, which is better than program A. Tallies in the f_{ij} matrix would be made as shown in Table 2.

TABLE 2

LEAST SQUARES METHOD SCORING PROCEDURE

f_{ij}	A	B	C
A		1	1
B			
C		1	

Since B is the preferred show, one goes to the B column and makes entries in the columns that were rated inferior to B, which in this case were columns A and C. Likewise, an entry is make in the C column and A row. The responses from all the judges are tallied in this manner and collected in a f_{ij} frequency matrix like the one shown in Table 3.

TABLE 3

LEAST SQUARES METHOD FREQUENCY MATRIX

f_{ij}	A	B	C
A		28	46
B	72		65
C	54	35	

Note that the cross-diagonal elements each sum to the total number of judges; for this example there were 100. The next step is to convert the f_{ij} matrix to a probability matrix, p_{ij}. This is done according to the equation shown below.

$$p_{ij} = f_{ij} / (f_{ij} + f_{ji}) \qquad (4\text{-}4)$$

To continue with the example, the probability matrix in Table 4 was obtained.

TABLE 4

LEAST SQUARES METHOD PROBABILITY MATRIX

p_{ij}	A	B	C
A	.5	.28	.46
B	.72	.5	.65
C	.54	.35	.5

It is important to note that the diagonal constituents of this matrix are set equal to .5 and values in each column are added to obtain column sums. Probability matrix entries greater than .98 and less than .02 are omitted in order to avoid numerical bias. The p_{ij} matrix is then converted to a z_{ij} matrix of standard normal values. In our example, the z_{ij} matrix is shown in Table 5.

The sought-after scale values are equal to the column sums of the z_{ij} matrix. As in the categorical judgment method, these scale values are linearly transformable. The least square procedure has the advantage of requiring a relatively low level of ordinal assessments, so data collection surveys are simple. Judges are not asked to make lengthy pairwise

TABLE 5

LEAST SQUARE METHOD STANDARD NORMAL MATRIX

z_{ij}	A	B	C
A	0	-.583	-.100
B	.583	0	.385
C	.100	.385	0
Sums	.683	-.198	.285

comparisons; rather, they simply list the instances in what they believe is the correct order of importance regarding the compared factor. This method is not appropriate for use in the project funding model being developed here, however, because it requires a large number of judges. Many expert opinions must be collected gathered in order to make a probability matrix as described above. In the USASDC there are at most three experts in each program element management shop, and this is not sufficient to employ this method effectively.

4. Constant Sum Method

The Constant Sum Method is a technique developed by Comrey in 1950 [Ref. 31] that quantifies subjective ratings based on pairwise comparisons. Judges are asked to consider each possible pair of instances, and within each pair, split 100 points. Thus, for each judge with n instances to be scaled, n(n-1)/2 pairs must be considered and 100 points divided between each. The largest number is given to the member of the pair having the greatest amount of the property being considered. The computational procedure begins by creating a comparison matrix, with the cross diagonal elements summing to 100 points. This matrix is then averaged, depending on the number

of judges, and a W matrix is obtained by dividing each element by its respective cross-diagonal element. The column products are multiplied by the nth root, where n is the number of compared items. These values equal the desired scale quantities.

An example sheds further light on this method. Consider two judges evaluating three cheeses on the basis of taste. Their respective comparison matrices are shown in Table 6.

TABLE 6

CONSTANT SUM METHOD COMPARISON MATRICES

Judge 1

a_{ij}	A	B	C
A	50	20	40
B	80	50	60
C	60	40	50

Judge 2

a_{ij}	A	B	C
A	50	10	30
B	90	50	70
C	70	30	50

In both instances above, the judges indicate that each prefers cheese A to B, cheese A to C, and cheese C to B, but strength of these endorsements are different. The next step is to combine both matrices by averaging the a_{ij} values as shown in Table 7.

TABLE 7

CONSTANT SUM METHOD AVERAGE COMPARISON MATRIX

a_{ij}	A	B	C
A	50	15	35
B	85	50	65
C	65	35	50

The W_{ij} matrix is then computed using equation 4-5 shown below:

$$W_{ij} = a_{ij} / a_{ji} \qquad (4\text{-}5)$$

The W_{ij} matrix for this example is shown in Table 8.

TABLE 8
CONSTANT SUM METHOD W MATRIX

W_{ij}	A	B	C
A	1.00	.72	.54
B	5.67	1.00	1.86
C	1.86	.54	1.00

The scale values can be solved for now by taking each column product to its respective nth root. In our example, n, the number of cheeses being compared, is 3. The calculation is demonstrated in Table 9.

TABLE 9
CONSTANT SUM METHOD SCALE VALUE COMPUTATION

$$S_1 = [(1)(5.67)(1.86)]^{1/3} = 2.19$$
$$S_2 = [(.72)(1)(.54)]^{1/3} = .73$$
$$S_3 = [(.54)(1.86)(1)]^{1/3} = 1.00$$

A great advantage of this method over the others that have been discussed is that it provides quantitative values that are all on a similar ratio scale, rather than the interval scale. Ratio scales allow not only linear transformations, but all

arithmetic operations. For example, one can conclude that an instance with a value of 1.0 has twice the compared property of an instance with a .5 value. A problem with this method involves consistency; judges often contradict themselves (unintentionally), especially when the number of comparisons is large. Many judges find categorical comparisons much easier to make than numerical ones.

The traditional methods of quantifying subjective evaluations are not adequate for a project funding model. A method is needed that does not suffer from any of the major disadvantages prevalent in the procedures just discussed. In 1978 Saaty [Ref. 32] developed a method of quantifying subjective intangibles that is far superior to any of the traditional methods just described. He called this procedure the Analytic Hierarchy Process, and it will be the subject of the remainder of this chapter.

B. THE ANALYTIC HIERARCHY PROCESS (AHP)

In less than a decade, the AHP has found its way into many important decision-making models. Our investigation of the AHP will begin with a detailed discussion of the four-step AHP procedure that has been popularized by Saaty. These four critical steps in converting subjective judgments into numerical results are shown in Figure 2.

Step 1 involves hierarchic decomposition. The researcher must develop a logical representation of the factors and levels involved in problem scenario. For example, consider a person desiring to purchase a new automobile. The objective of buying a car is placed at the top of the hierarchy. Factors that influence the decision, such as price, comfort, and status are placed

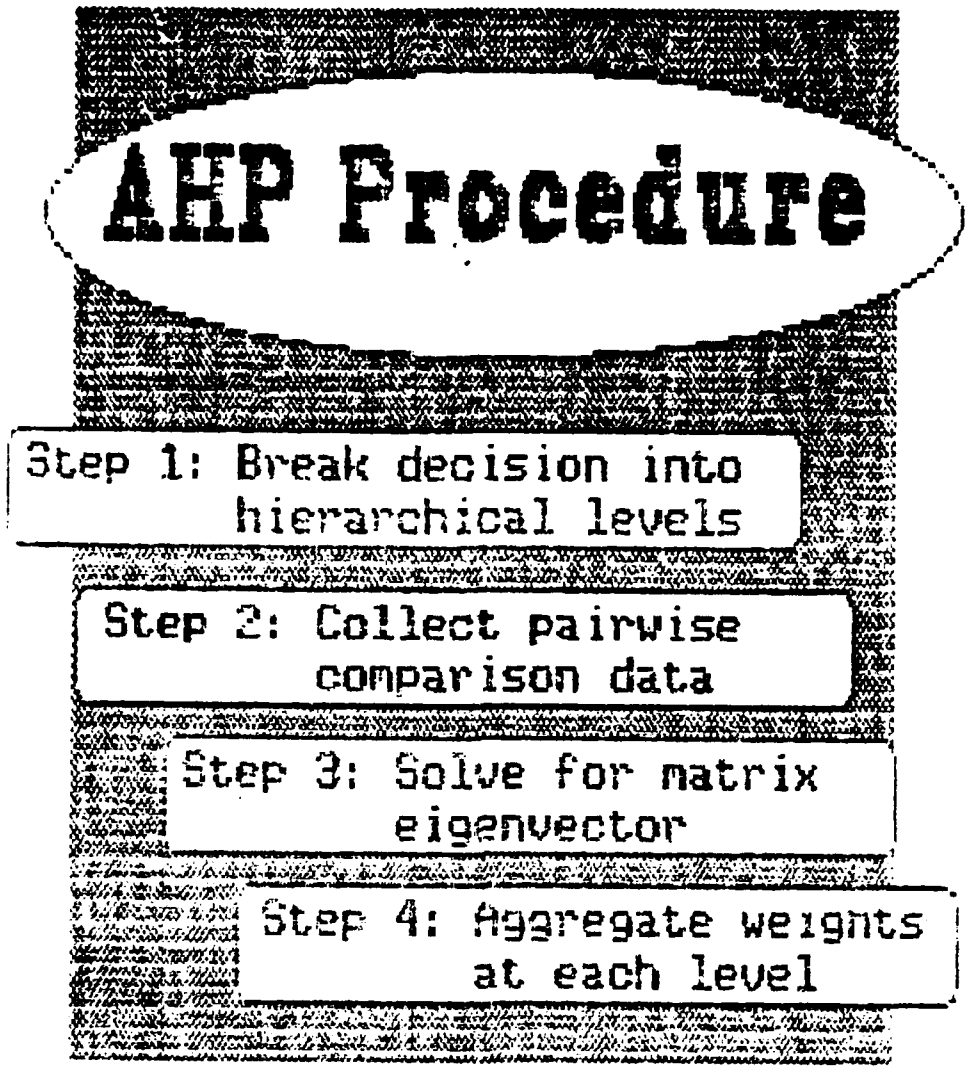


Figure 2 - AHP Procedure

in the next hierarchy level, and the various car alternatives are listed at level 3 of Figure 3.

In step 2, judges are asked to make pairwise comparisons of the factors at each level using the

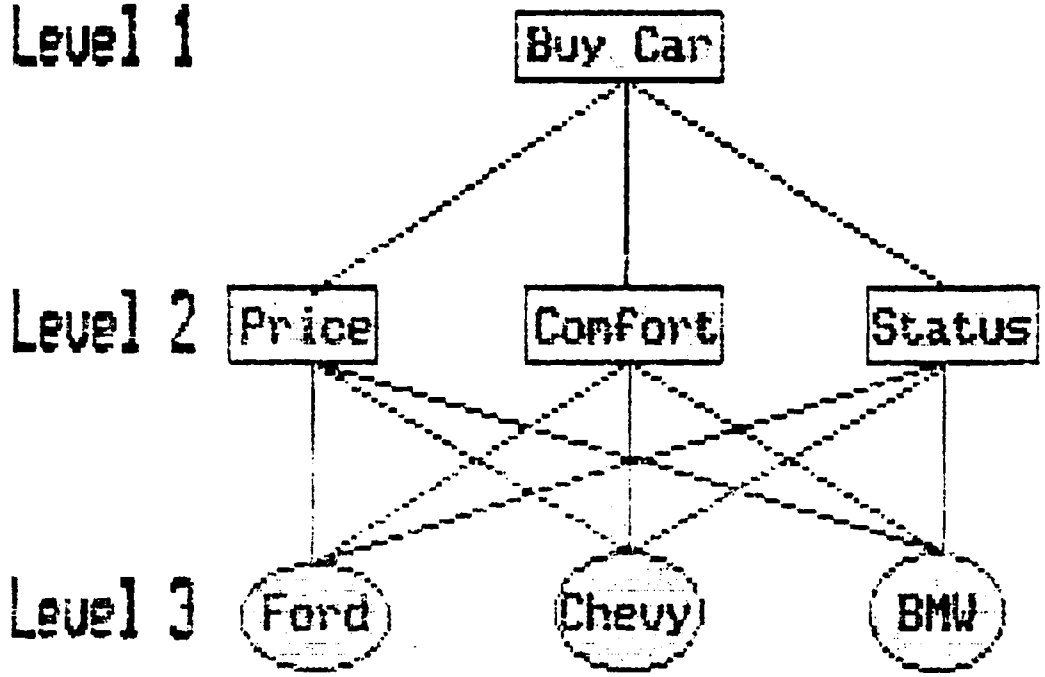


Figure 3 - Car Buying Hierarchical Scheme

pairwise comparison scale shown in Table 10. This table is the result of extensive psychological measurement studies. Saaty concluded that human sensory perception is capable of distinguishing only nine distinct subjective performance levels. As in the constant sum method, N(N-1)/2 pairwise comparisons must be made, and the results are placed in a comparison matrix. In the car buying example, a matrix like theone shown in Table 11 could be obtained.

In step 3, the eigenvalue solution technique is employed. As shown by Saaty and Vargas [Ref. 45], the procedure involves solving for the largest eigenvalue, Lambda Max. In the example we are concerned with,

TABLE 10

AHP PAIRWISE COMPARISON SCALE

Intensity of Importance	Definition
1	Equal contribution by both factors/alternatives to the property
3	One factor contributes slightly more to the property than the other
5	One factor is strongly favored over the other
7	One factor is very strongly favored over the other
9	The evidence favoring one factor over the other is of the highest possible order of affirmation
2,4,6,8	Intermediate values
Reciprocals	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal value when compared to i

TABLE 11

AHP EXAMPLE COMPARISON MATRIX

Comfort	Ford	Chevy	BMW
Ford	1	1/2	1/4
Chevy	2	1	1/2
BMW	4	2	1

Lambda Max was found to be 3.0. The normalized eigenvector is then computed and is as shown in Table 12.

The AHP interprets the eigenvector as clear evidence that the BMW will contribute the most to your comfort while operating a car, since the BMW comfort factor is twice the size of the Chevy comfort factor, and three times as large as the Ford value.

TABLE 12

AHP EXAMPLE EIGENVECTOR

Comfort	Ford	Chevy	BMW
Ford	1	1/2	1/4
Chevy	2	1	1/2
BMW	4	2	1
EIGENVECTOR:	.143	.286	.571

Ford comfort value: .143
Chevy comfort value: .286
BMW comfort value: .571

In the simple example just described, it was apparent that the responses of the judges were not contradictory or conflicting. However, in many instances the number and complexity of subjective judgments involved in the AHP make it necessary to compute a consistency ratio (CR). It is fortunate that the AHP provides a method for computing the CR, for this affords the user the opportunity to evaluate the quality of the data that has been input in the comparison matrices. Respondents, despite their best efforts to the contrary, are often inconsistent and intransitive in making pairwise comparisons.

The calculation of a consistency ratio (CR) can be demonstrating by continuing with our car buying example. Suppose a judge felt the Ford was more comfortable than the Chevy, and the Chevy more comfortable than the BMW. The judge would be inconsistent if he rated the BMW more comfortable than the Ford; such a response would stimulate a high CR. The CR is found by first finding the consistency index (CI). The consistency index (CI) is determined using equation 4-3, where N is the number of items being compared.

$$CI = \frac{\text{Lambda Max} - N}{N - 1} \qquad (4\text{-}3)$$

The CI is compared to the corresponding random consistency index (RI) shown in Table 13. The RI are average consistency indices for matrices whose reciprocal entries were drawn at random from the values 1/9, 1/8, ..., 1, 2, ...,8 , 9.

TABLE 13

RANDOM CONSISTENCY INDEX

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	.58	.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio can then be found, since CR is equal to the ratio CI/RI. The value of CR should be 10 percent or less. If it is more than 10 percent, the judgments are considered inconsistent; the problem should be studied again and the comparison matrix revised.

Step 4 aggregates relative weights of various levels obtained from the third step in order to produce a vector of composite weights. This vector constitutes the scaled rankings of the various alternatives with respect to the factor being studied. The procedure is to start at the highest level hierarchy and determine the weights of the factors at that level. These weights are then multiplied by the eigenvector at the next level, and new vectors are obtained. This process continues until the last level.

To continue with our car example, in this step the eigenvectors of price, comfort, and status would be combined. Suppose the buyer felt price was the most important factor, followed by status and then comfort.

This would then be placed in a comparison matrix and an eigenvector determined. The procedure involved in step 4 is demonstrated in Table 14.

TABLE 14

CAR BUYING EXAMPLE STEP 4 DEMONSTRATION

Level 2 eigenvalues: Price =.5
Comfort =.2
Status =.3

Level 3 eigenvalues:

Factor	Ford	Chevy	BMW
Price	.4	.4	.2
Comfort	.2	.3	.5
Status	.2	.1	.7

Ford weight = (.5)(.4)+(.2)(.2)+(.3)(.2) = .30
Chevy weight = (.5)(.4)+(.2)(.3)+(.3)(.1) = .29
BMW weight = (.5)(.2)+(.2)(.5)+(.3)(.7) = .41

Step 4 informs us that on the basis of the data in this example concerning the buyers vehicle preferences regarding price, comfort, and status, the BMW should be purchased. The Ford and Chevy are rated too closely to distinguish between them.

The AHP affords several advantages over the traditional methods discussed earlier in this chapter. Use of the AHP allows the researcher to quantify weights at more than just one hierarchy level. The AHP gives scaled values that are on a ratio scale, and the AHP is the only method that provides a mechanism for checking on the consistency of the input data. The AHP is more accurate than the traditional methods, since it has its roots in psychological testing and human sensory perception capabilities. The only disadvantage of this method is that it is considerably more complex. However, the benefits gained from using the AHP far

exceed this drawback, since a computer program can be written to overcome computational difficulty.

The choice of AHP to quantify subjective evaluations has become quite common during the last five years. The areas in which the AHP has been applied are diverse and numerous. In a 1984 book review, Gray [Ref. 33] noted that "...you have to actually try the method in some simple situations to understand its remarkable power". Zahedi recently [Ref. 34] surveyed the AHP and over fifty published applications of AHP in twenty-seven topic areas. These instances included the project funding model developed by Johnston and Hihn [Ref. 35], and the budget allocation models of Sinuany-Stern [Ref. 36] and Arbel [Ref. 37].

The AHP is superior to the traditional methods of quantifying subjective evaluations discussed in this chapter, and it has been successfully applied to similar projects. These two facts lead to the conclusion that the AHP is the preferred technique to use in deriving the coefficient weights for the linear equations in the GP model being developed.

V. GOAL PROGRAM FORMULATION

In this chapter, mathematical expressions of the goals and constraints for the GP model will be developed. Discussions of model constituents such as the decision variables, system constraints, goal constraints, and the achievement function, will be included in order to formulate the GP model.

A. DECISION VARIABLES

The first step in the construction of a mathematical decision model is the determination of the decision variables. Decision variables are parameters that may be controlled and are sometimes referred to as "control" variables. These variables represent the items that will be optimized when solving the model.

The USASDC presently manages thirty-five WPDs that were categorized as "major projects" in Chapter II. These are projects that in FY 86 were funded at levels exceeding $5 million or are deemed important enough to warrant special attention. The major projects will be the focus of the model and are listed in Table 15. Funding for the major projects constitute 89.8% of the total USASDC core budget level, a clear indication of the prominence of these projects in the overall SDI program.

The decision variables in the formulated model are the costs associated with each major project in FY 88. Xj is the notation used to indicate the funding level in dollars of the jth project. The ultimate purpose of the model development is to determine the optimal values of these decision variables.

TABLE 15

MAJOR USASDC PROJECTS

Program Element	WPD #	WPD Title
SABM	B122	Theater Missile Def Architecture
	B142	Architecture Support Analysis
	B412	Battle Mgmt/C3 Technology
	B532	Battle Mgmt/C3 Experimental Sys
	B612	National Test Bed
SLKT	L008	Ground Sys Passive Survival Tech
	L212	Army Power Technology
	L503	Advanced Materials
	L721	CM Technology Base
	L723	Ballistic Range Expt
DEW	D044	AFOCAL Technology
	D076	Free Electron Laser Demonstration
	D080	Free Electron Laser Site Dev
	D047	NPB Accelerator Technology
	D112	Interactive Discrimination
	D114	DEW Concept Development Defn
	D083	NPB Test Facility
KEW	K222	Exoatmospheric Interceptor Expt
	K623	Invite, Show, and Test Forum
	K624	ERINT Program
	K225	G&C Missile Electronics
	K323	Seeker/Windows/Avionics
	K325	Propulsion Integration
	K524	SDI Targets
	K321	Endoatmospheric Interceptor Expt
SATKA	S271	Airborne Optical Adjunct Expt
	S051	Optical Airborne Measurement Pgm
	S011	Cobra Judy
	S052	Queen Match
	S053	Optical Discrimination Algorithms
	S243	LWIR Probe
	S402	SATKA Targets
	S091	Optics Technology
	S102	LG Radar Technology
	S281	Terminal Imaging Radar Expt

B. SYSTEM CONSTRAINTS

There are two types of constraints present in most GP formulations, system constraints and goal constraints. System constraints are "absolute" constraints; they define the feasible solution space that must be adhered to before an optimal or satisfactory solution can be considered. Goal

constraints are "nonabsolute" in that the program seeks to satisfy such equations to the highest level possible; goal programming attempts to minimize the deviation from a prespecified level, rather than attempt to satisfy any level completely. This section is concerned with the system constraints involving USASDC budget levels, minimum and maximum project funding levels, and non-negativity requirements.

1. Budget Levels

The first system constraint is concerned with the total amount of money available for all of the thirty-five major programs in FY 88. As discussed in Chapter II, four different funding strategies exist, each one motivated by a different FSED completion date. Since the funding strategy for FY 88 has not been decided, each of the possible appropriation levels will be run on separate iterations of the model. Table 16 shows the funds that have been tentatively appropriated to the sum total of all major WPDs for each funding strategy.

TABLE 16

MAJOR PROJECTS FY 88 TOTAL BUDGET LEVELS

Funding Strategy	Budget ($M)
Core	882.6
Basic	1029.1
Enhanced	1255.4
Extended	1383.4

An equation representing the budget constraint will be included in each iteration of the model. The equation mathematically states that the sum of the project funding levels must be less than or equal to the total budget, and are as follows:

Iteration 1: X1 + X2 + X3 + . . . + X35 <= 992.6
Iteration 2: X1 + X2 + X3 + . . . + X35 <= 1029.1
Iteration 3: X1 + X2 + X3 + . . . + X35 <= 1255.4
Iteration 4: X1 + X2 + X3 + . . . + X35 <= 1383.4

2. Minimum Funding Levels

There is a minimum amount of money that must be spent on each project and, for many of the major projects being modelled, this amount is substantial. Spending on any project cannot simply cease; at least some money must be spent in each project, if only to shut the program down. Most programs are committed to minimal funding levels in order to cover a variety of prior obligations such as equipment purchases, facility rentals, and labor contracts.

Equations for the minimum funding levels will be entered in the model as shown below:

X1 >= Minimum Funding Level for Project 1
X2 >= Minimum Funding Level for Project 2
.
.
X35 >= Minimum Funding Level for Project 35

3. Maximum Funding Levels

Similarly, there is a maximum amount of money that can be spent on each project. Upper bounds on spending exist because USASDC program element managers realize that there is a practical limit to the amount of money that can be devoted to single project; at a certain point additional funds could not be reasonably or effectively spent on the project in question.

The maximum funding level equations are as follows:

X1 <= Maximum Funding Level for Project 1
X2 <= Maximum Funding Level for Project 2
.
.
X35 <= Maximum Funding Level for Project 35

4. Non-negativity

A goal program model requires that all decision variables be greater than or equal to zero. The positive and negative deviation variables and all other variables used in the goal constraints must be non-negative. This requirement adds the following relations:

X1,.., X35, PPOS, PNEG, RPOS, RNEG, TPOS, TNEG,
BPOS, BNEG, WTPNEG, WTRPOS, WTTPOS, WTBNEG >= 0

C. GOAL CONSTRAINTS

Goal constraints are mathematical equations that represent the objectives of the scenario being modelled. In a model of the thirty-five major projects of the USASDC, the goal constraints will parallel the four major project goals. The performance of each project with respect to each of these goals will be determined using the AHP as discussed in the previous chapter. Goal constraint equations do not have inequalities as do system constraints. Rather, the left hand side (LHS) of the equation is set equal to the right hand side (RHS), thereby forcing residual values into either the positive or negative deviation variable.

1. Maximize Military Payoff

Military payoff is based on individual project contributions to the following: (1) the SDI long range goal of building a missile defense; (2) the short range goal of reaching an FSED by 1995; and (3) the potential generation of military spinoff technology. The AHP will determine a military payoff score for each project (P1 through P35), and this score will be multiplied by its respective decision variable (X1 through X35). The sum of these products is compared to the RHS of the goal constraint by using positive and negative

deviation variables (PPOS and PNEG). The RHS is intended to provide an unobtainable objective for the LHS of the equation; the sum of the products of the military payoff scores and the maximum funding level for each project (MAX1 through MAX35) provides such an objective. The goal constraint attempts to get the LHS as close to this unobtainable level on the RHS as possible by minimizing the negative deviation variable. Since the RHS level cannot be reached, the positive deviation variable will be zero. The final goal constraint equation representing the maximization of military payoff is as stated in equation 5-1:

$$(P1 * X1) + \ldots + (P35 * X35) - PPOS + PNEG = (P1 * MAX1) + \ldots + (P35 * MAX35) \qquad (5\text{-}1)$$

2. Minimize Project Development Risk

The second nonabsolute constraint that will be formulated concerns project development risk. There are two types of risk to be modelled. As discussed in Chapter II, the first is technological risk, which refers to the likelihood of failing to meet the ultimate technical objectives of the WPD. The second, milestone risk, accounts for the possibility that the target milestones in the WPD may be violated. The AHP will be once again used to assimilate these two risks into a single goal constraint. The equation will be very similar to the other goal constraints. The LHS is a summation of the risk score from the AHP (R1 through R35) multiplied by the amount of money to be spent on each program (X1 through X35); the RHS is this same risk value multiplied by the minimum funding level (MIN1 through MIN35). Since the RHS represents an unobtainable goal, the residual will driven into RPOS,

the positive deviation variable of the formulated risk equation shown in equation 5-2:

$$(R1 * X1) + \ldots + (R35 * X35) - RPOS + RNEG = (R1 * MIN1) + \ldots + (R35 * MIN35) \qquad (5\text{-}2)$$

3. Minimize Project Development Time

The minimization of project development time is the third goal to be modelled by the GP. The two constituents of project development time are the time required to achieve ultimate project success and the time needed to meet the FSED requirements. The AHP program will be used to develop a time factor for each project (T1 through T35). This value is multiplied by the decision variables and these products summed so that they may be compared to the unachieveable objective. Since the desire is to minimize, the RHS should be an artificially low value derived from the multiplication of the time values and the minimum funding levels. The deviation from the goal will be driven into TPOS and the end result is a time goal equation as shown below:

$$(T1 * X1) + \ldots + (T35 * X35) - TPOS + TNEG = (T1 * MIN1) + \ldots + (T35 * MIN35) \qquad (5\text{-}3)$$

4. Maximize project development balance

The fourth goal to be modelled is to maximize project development balance. The AHP will assist in modelling this objective by combining the following four elements of project balance into one number between 0 and 1: technology base, concepts and designs, data collection, and signature measurements. Contrary to the other goal constraints, the second level AHP hierarchical values will not be equal. Rather, the eigenvalues calculated for each balance sub-factor will

be multiplied by the BTP guidance values shown in Table 1. This will ensure that each element of balance is given priority according to the goals expressed by the 1986 Budget Priorities briefing [Ref. 3]. This will generate balance values (B1 through B35) that can then be used as shown above in the other goal constraints. The RHS side number will be the same unobtainable maximum value that was used in the other maximizing goal constraint, payoff. The value of BPOS will be zero, and the deviation from the goal will be captured by BNEG. The final goal constraint for the model formulation is as displayed in equation 5-4:

$$(B1 * X1) + \ldots + (B35 * X35) - BPOS + BNEG = (B1 * MAX1) + \ldots + (B35 * MAX35) \qquad (5\text{-}4)$$

D. ACHIEVEMENT FUNCTION

The final step in the model development is the establishment of the achievement function. Given that there is some solution to the multiple objective model as represented by the goal formulations described above, the critical task of finding the optimal solution still remains. The achievement function is designed to perform such a task by minimizing the goal deviation variables.

There are eight deviation variables that are included in the GP model, a positive and negative deviation variable for each of the four goal constraints. Goals one and four are maximizing goals, so variables PNEG and BNEG will retain the goal deviations that are to be minimized. Likewise, goals two and three are minimization equations, so RPOS and TPOS are included in the achievement function.

If the four goals were considered equal in rank or importance, the LHS of the achievement function would

consist of a summation of the four deviations. However, the goal constraints for this model of the thirty-five major SDI projects are not equal in priority. Maximizing payoff is the most important goal, and maximizing balance is the lowest priority objective. The AHP will determine the magnitude of the differences between the four goal constraints; this magnitude will be reflected in weight values for each goal equation between 0 and 1. The LHS consists of the sum of the product of each weight value (WTPNEG, WTRPOS, WTTPOS, WTBNEG) multiplied by its respective deviation variable. The LHS is set equal to a single variable, DEVIATION, and minimization of the RHS value will determine the optimal solution. The achievement function is as displayed in equation 5-5.

$$(WTPNEG * PNEG) + (WTRPOS * RPOS) + (WTTPOS * TPOS) + (WTBNEG * BNEG) = DEVIATION \quad (5\text{-}5)$$

E. THE GOAL PROGRAM FORMULATION

The final formulated GP model encompasses all of the equations described above and is as shown on the next page in Figure 4.

F. MODEL ASSUMPTIONS

There are several assumptions that are being made for this model, situations that are assumed to be true in order to simplify the model and make it solvable. The negation of any of these assumptions invalidates the model developed above.

The first model assumption is that all equations in the GP model are linear. This is the most important assumption, since it allows a great simplification of the data collection process and model formulation. Linearity is assumed because there is not enough

Achievement Function

Minimize:

(WTPNEG * PNEG) + (WTRPOS * RPOS) +
(WTTPOS * TPOS) + (WTBNEG * BNEG) = DEVIATION

Goal Constraints

Subject to:

(P1 * X1) + . . . + (P35 * X35) - PPOS + PNEG
= (P1 * MAX1) + . . . + (P35 * MAX35)
(R1 * X1) + . . . + (R35 * X35) - RPOS + RNEG
= (R1 * MIN1) + . . . + (R35 * MIN35
(T1 * X1) + . . . + (T35 * X35) - TPOS + TNEG
= (T1 * MIN1) + . . . + (T35 * MIN35)
(B1 * X1) + . . . + (B35 * X35) - BPOS + BNEG
= (B1 * MAX1) + . . . + (B35 * MAX35)

System Constraints

X1 + . . . + X35 <= BUDGET
X1 >= MIN 1
X2 >= MIN 2
.
X35 >= MIN 35
X1 <= MAX1
X2 <= MAX2
.
X35 <= MAX35

X1,.., X35, PPOS, PNEG, RPOS, RNEG, TPOS, TNEG,
BPOS, BNEG, WTPNEG, WTRPOS, WTTPOS, WTBNEG >= 0

Figure 4 - Goal Program Formulation

information to postulate any other functional form. One can be quite certain that none of the equations above in reality are exactly linear, but in the absence of

data to the contrary, linearity is assumed to be a close approximation to the actual curves. This is especially true since the solution space is being bounded by upper and lower funding levels, which should constrain the model to the region where the linear assumption is particularly accurate.

The second assumption is that all variables in the mathematical model are continuous. This is a common assumption in models such as the one presented here. The capability of doing integer or noncontinuous programming exists and could be implemented, but this would only add needless complexity to the solution process. Assuming that all variables are continuous poses no major practical obstacles.

In Chapter II, the four project goals regarding payoff, risk, time, and balance were developed. Each of these goals had various components that made up these goals, and the AHP will determine an overall payoff, risk, time and balance weight factor based on these sub-goals. The third major model assumption is that these sub-goals are equal in priority. For example, under the risk goal, milestone risk and technological risk are assumed to be the same in importance. The AHP has the capability of handling a situation in which this assumption was not true, but there is not sufficient information concerning the sub-goals to conclude or assume differently.

Another key assumption is that the program element managers are the best individuals to respond to the AHP survey. Much has already been said about the vast expertise that they possess, and it was the overwhelming consensus of the chain of command at the USASDC that program element managers were best suited to make the subjective judgments upon which the AHP

model, and the subsequent GP model, is based. If this assumption was not true, than the model developed in this chapter would not be valid.

The final major assumption to be discussed is that the total funding level for the major USASDC projects in FY 88 is not known, and that the four funding strategies (core, basic, enhanced, and extended) are the only alternatives. The model could be easily changed to handle any funding strategy, but it will be assumed that only the four strategies mentioned in the USASDC Budget Priorities Briefing [Ref. 3] are of concern. This assumption is most important in simplifying the data analysis of Chapter VI.

VI. SOFTWARE SUPPORT AND MODEL RESULTS

As stated in Chapter II, the primary objective of this study is to develop a research and development project funding model of the major USASDC projects, and to use this model to determine optimum expenditure levels for each project in FY 88. Such a model has now been completely developed, and this chapter is intended to present both the computer programs written to solve the model and the model results. Specifically, this entails a discussion of the data collection and software development process, the numerical output acquired from the various model iterations, and the consequences of the data produced.

A. DATA COLLECTION AND SOFTWARE DEVELOPMENT

The process of collecting data and designing software to support the GP model formulation is an essential step in determining the optimum expenditure levels for each major project in FY 88. As discussed earlier, the GP model requires that the coefficient weights for the goal and system constraints be determined by the AHP, in addition to the achievement function weights. Program element managers were selected to respond to a pairwise comparison survey that was designed to subjectively evaluate the major projects being studied on the basis of the eleven key factors discussed earlier. A detailed description of this data collection effort and a copy of the actual surveys that were written can be found in Appendix C.

Computer software was written that would perform the necessary AHP calculations and determine the coefficient weights for the GP model. APL [Ref. 38] was the computer language chosen to perform the AHP

calculations, since APL is particularly powerful when performing array computations. An APL workspace called "AHP", consisting of nine APL functions, was written on an IBM PC using "APL Plus 5.0", an APL program compiler produced by STSC. The workspace was intended to be easy to use and have a broad range of applicability. All programs were generalized, so that the AHP can be used on any subjective data array, not just the USASDC data set presented here. The programs were also designed to be interactive, so that a user is prompted for the information needed as the program progresses, a feature that helps avoid confusion. Appendix D contains the complete program listings of all nine APL functions, as well as detailed information on how to use the workspace.

The Generalized Algebraic Modelling System (GAMS) [Ref. 41] was selected to solve the GP model. GAMS is significant because it is the first optimizing program that uses the special notation called the Backus-Nauer Form (BNF). This notation enables the user to write constraint equations in precise mathematical form, greatly enhancing the flexibility and simplicity of the program code. A GAMS program was written for each of the four possible funding strategies based on the GP model of the major projects of the USASDC. Appendix E contains the complete listing of the GAMS program for the core funding strategy, and it also includes a more detailed discussion of how the program was constructed.

B. MODEL RESULTS

The output from the AHP procedure and the GP model will be surveyed in this section. This evaluation will include an analysis of the optimal funding levels for each major project and the optimal funding priorities at each budget strategy (core, basic, enhanced,

extended). The optimal funding levels and priority lists obtained by the model will be compared with those that have been proposed for FY 88.

1. AHP RESULTS

The AHP surveys were collected and the pairwise comparison data from these surveys was entered into the APL "AHP" workspace. A complete iteration of the AHP program involves 55 matrices, derived from comparisons of projects within each program element. As stated in the second chapter, these comparisons are based on eleven components. Each component contributes to either the payoff, risk, time, or balance factor. The initial run of the AHP program was not successful, since several of the 55 compared matrices were determined to be inconsistent, ie, the consistency ratio for these matrices was above 10%. Respondents liable for the survey completion were contacted, informed of the problem, and asked to make corrections in their responses that would reduce the CR for each inconsistent matrix to an acceptable level. The second iteration of the AHP was successful in resolving this issue, as is demonstrated in Table 17 below.

TABLE 17

AHP CONSISTENCY RATIO RESULTS

	FACTOR				
	PAYOFF	RISK	TIME	BALANCE	TOTAL
# MTXS	15	10	10	20	55
MEAN	.048	.047	.045	.004	.031
STD DEV	.029	.028	.033	.007	.031
RANGE	.097	.082	.089	.021	.097

Each of the factors had an average CR value well under 10%, and not one of the 55 matrices was

found to be inconsistent. It is critical to the GP model that the standard for consistency not be violated, since inconsistency will adversely affect the accuracy and credibility of the model.

TABLE 18

AHP COEFFICIENT WEIGHTS

Project	Factor			
	Payoff	Risk	Time	Balance
B122	.024	.048	.049	.025
B142	.048	.007	.006	.025
B412	.02	.048	.049	.027
B532	.044	.007	.006	.033
B612	.006	.033	.033	.033
L008	.03	.028	.035	.029
L212	.032	.028	.035	.029
L503	.037	.041	.028	.029
L721	.022	.023	.023	.029
L723	.022	.023	.023	.029
D044	.06	.009	.007	.03
D076	.06	.009	.015	.027
D080	.015	.029	.035	.027
D047	.032	.01	.008	.027
D112	.005	.064	.065	.03
D114	.004	.075	.065	.03
D083	.024	.005	.005	.027
K222	.067	.013	.021	.036
K623	.005	.082	.021	.036
K624	.024	.026	.049	.021
K225	.027	.011	.031	.021
K323	.027	.01	.031	.021
K325	.027	.01	.031	.021
K524	.007	.066	.025	.036
K321	.045	.01	.018	.036
S271	.045	.019	.019	.033
S051	.023	.04	.027	.03
S011	.02	.104	.081	.03
S052	.025	.034	.027	.03
S053	.03	.012	.011	.028
S243	.049	.007	.008	.024
S402	.019	.02	.033	.024
S091	.036	.011	.016	.034
S102	.02	.018	.032	.028
S281	.018	.022	.031	.024

The objective of the AHP was to produce coefficient weights for the goal constraints and the achievement function. The AHP workspace gave values for these weights, rounded to three decimal places, as displayed in Table 18. A more complete collection of

the output from the AHP workspace can be found in Appendix F. The payoff factor eigenvector and the 15 matrices that contributed to its calculation is included in this appendix.

The determination of the four factor weights in the achievement function was also found via the AHP workspace. These weights are extremely important, as they represent the relative priorities of the payoff, risk, time, and balance goal constraints in the GP model. The comparison matrix, consistency information, and weight eigenvector regarding the achievement function is shown in Table 19.

TABLE 19

ACHIEVEMENT FUNCTION AHP RESULTS

Comparison Matrix

	Payoff	Risk	Time	Balance
Payoff	1	2	5	7
Risk	1/2	1	3	5
Time	1/5	1/3	1	2
Balance	1/7	1/5	1/2	1

Lambda: 4.020
Consistency Index: .007
Consistency Ratio: .007

Payoff weight: .527
Risk weight: .301
Time weight: .110
Balance weight: .063

2. GP Results - Optimal Funding Levels

The coefficient weights for the goal constraints and the achievement function determined above were incorporated in the GAMS program. The optimal funding levels for each project are displayed in Table 20.

TABLE 20

OPTIMAL PROJECT FUNDING LEVELS ($M)

Project	Funding Strategy			
	Core	Basic	Enhanced	Extended
B122	6	6	6	6
B142	15	15	15	15
B412	9	9	9	9
B532	95	95	95	95
B612	2	2	2	2
L008	5	5	5	30
L212	2	2	2	12
L503	5	5	5	24
L721	2	2	2	12
L723	2	2	2	10
D044	15	15	15	15
D076	260	260	260	260
D080	5	5	5	5
D047	15	15	55	55
D112	1	1	1	1
D114	6	6	6	6
D083	12	12	80	80
K222	187	187	187	187
K623	5	5	5	5
K624	10	10	10	10
K225	6	6	20	20
K323	3	3	10.7	50
K325	4	4	25	25
K524	4	4	4	4
K321	108.6	204	204	204
S271	25	76.1	105	105
S051	15	15	15	15
S011	3	3	3	3
S052	15	15	15	15
S053	3	3	19.2	19.2
S243	15	15	15	15
S402	3	3	3	3
S091	5	5	35.5	35.5
S102	2	2	2	18.7
S281	12	12	12	12

Table 20 shows AHP results from each model iteration. The only change between runs was that the budget level system constraint RHS was increased for each successive repetition. For example, the core iteration used a budget figure of $882.6 million; this was altered to $1029.1 million for the basic run. Appendix G contains the solution summary and several additional reports from each of the four budget strategy model repetitions.

A significant observation is that almost all projects, regardless of the funding strategy, are funded at a level equal to either the minimum or maximum bound of that project. The GP optimizer selects projects that contribute the most to the achievement function for funding above the minimum level. Once an "efficient" project such as this is identified, the optimizer adds to the decision variable until the project reaches its upper bound, or the budget is exhausted.

Only projects that provide the most payoff and/or balance while costing little in risk and/or time are deemed efficient, and these projects can be identified by observing the marginal values. The marginal values for the individual projects at each model run (see Appendix G) indicate the rate at which the objective function value improves as the RHS increases a small amount. Since the GP model attempts to minimize the deviation variable in the achievement function, only the projects with a negative marginal value are funded above the minimum bound.

The budget increases 56.7% from the core to the extended strategy, so it was expected that many projects would demonstrate a dramatic increase in funding. The number of projects funded at the minimum level in the core strategy was 28, a figure that dropped to 14 at the extended budget strategy level. The optimization program does not increment each program a small amount when given additional budget money. Rather, it finds additional projects that enhance the achievement function and then uses these projects to the fullest extent possible.

Another critical aspect of the GP model results concerns the difference between the optimal

funding levels, as determined by the model, and the proposed funding levels. The FY 88 proposed levels were discussed in Chapter II and can be found in Appendix B. The optimal and the proposed funding levels for each of the four budget strategies are plotted against each other in Figures 5 through 8 on the following pages. The funding levels for the various projects are on the y-axis and the projects (represented in order and numbered 1 through 35) are displayed on the x-axis. In viewing these graphs, the optimal and proposed funding levels appear closely related. The y-axis scale accentuates the difference between the two levels, but one cannot be certain that this difference is substantial. A statistical test is needed to make this important determination.

The nonparametric Kolmogorov-Smirnov two-sample goodness of fit (K-S) test was used to decide if the proposed and optimal distribution functions are identical. The K-S test calculates the maximum distance between the cumulative distribution functions of the two samples. If the deviation is large enough, the null hypothesis that the distributions are the same is rejected. A deviation figure, DN, is calculated and compared against the critical deviation figure found in a K-S test table, a number based on the sample size and significance level. The PC statistical graphics program "Statgraphics", published by STSC [Ref. 44], was used to determined DN and an associated P-value. Small DN and large P-values support the null hypothesis that the two distributions are the same. With a .05 level of significance, the null hypothesis cannot be rejected if the P-value is greater than .05 [Ref. 43].

The K-S procedure is generally more efficient that the Chi-square test for goodness of fit, and is

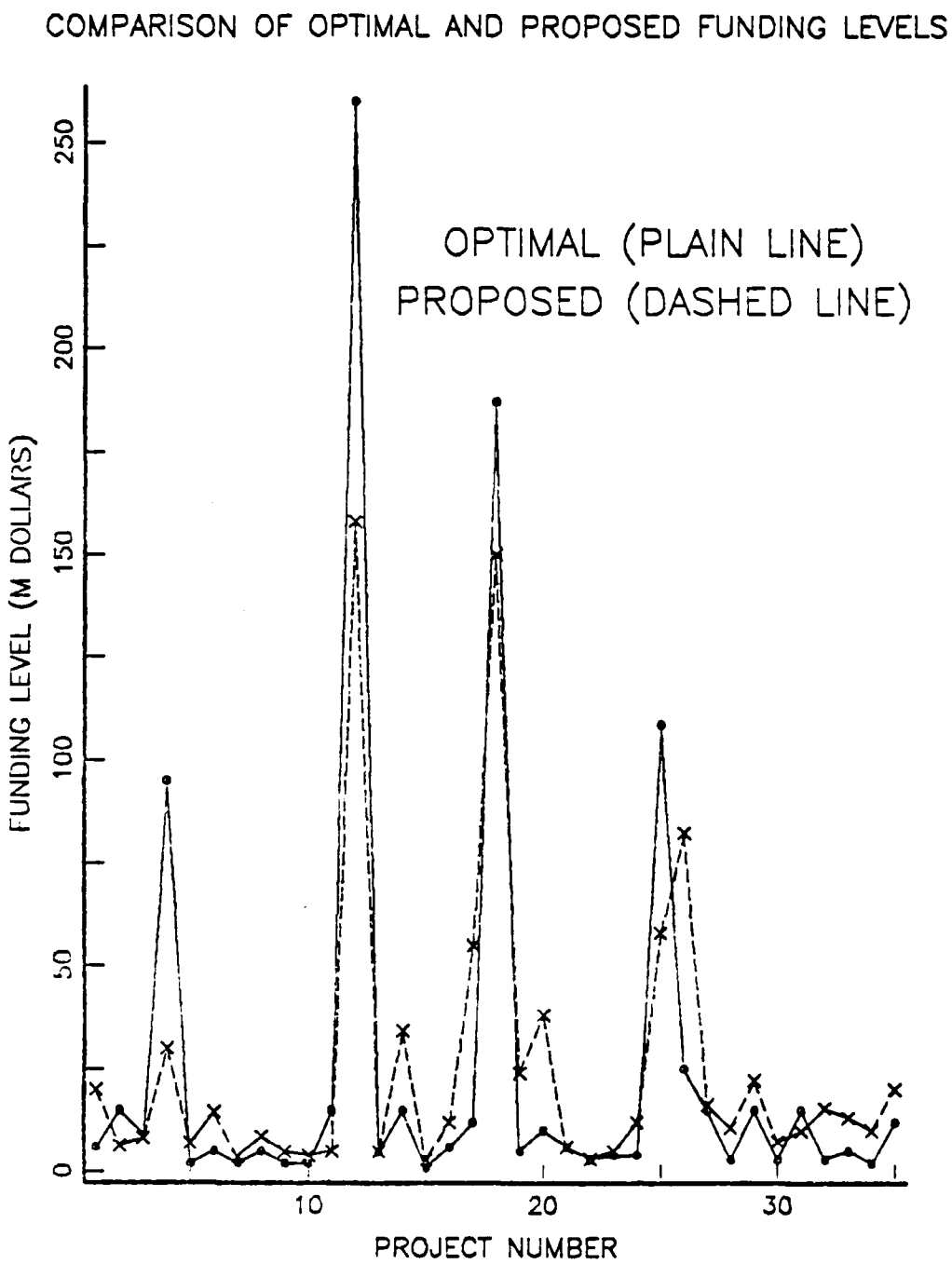


Figure 5 - Core Budget Strategy

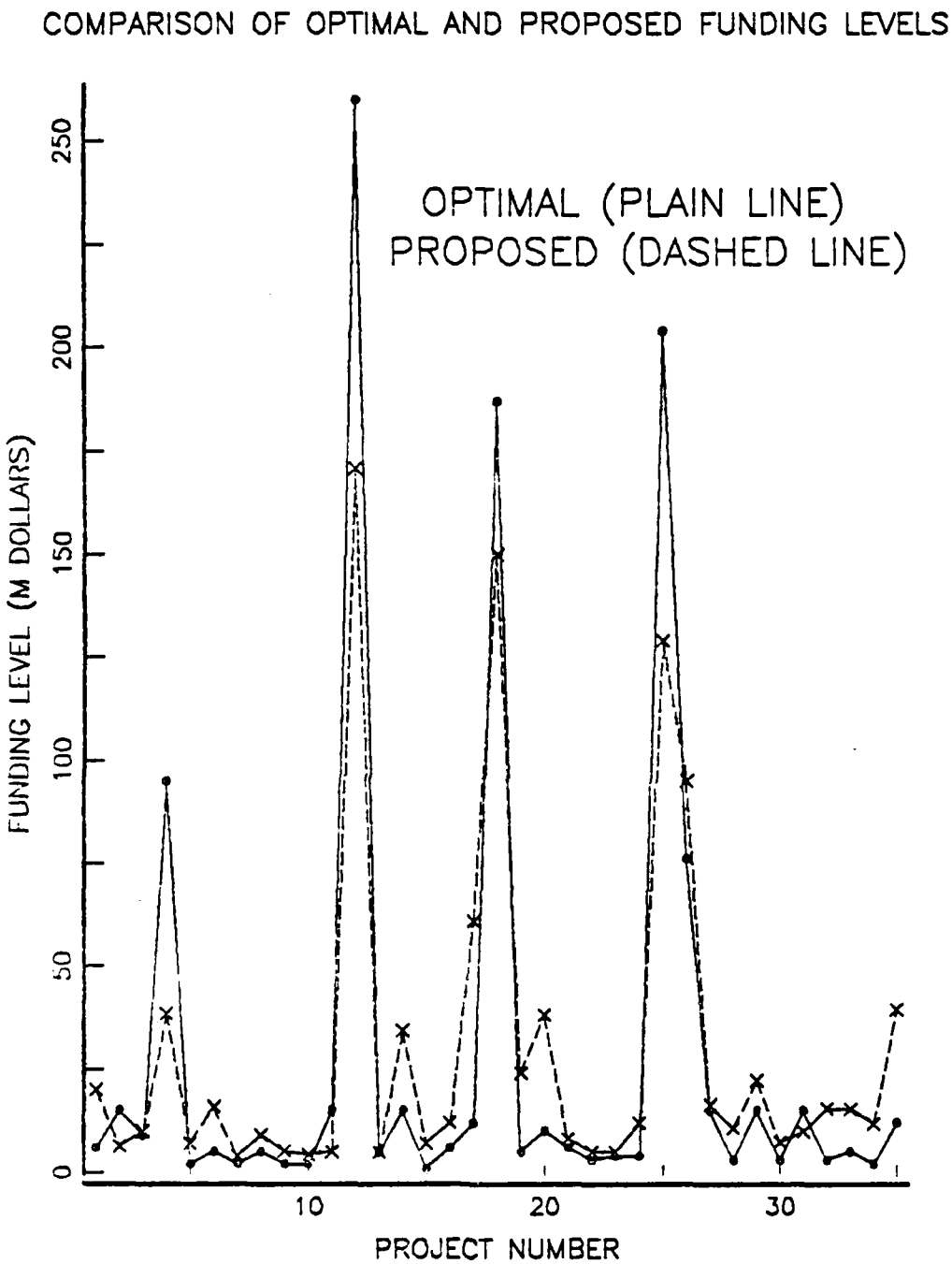


Figure 6 - Basic Budget Strategy

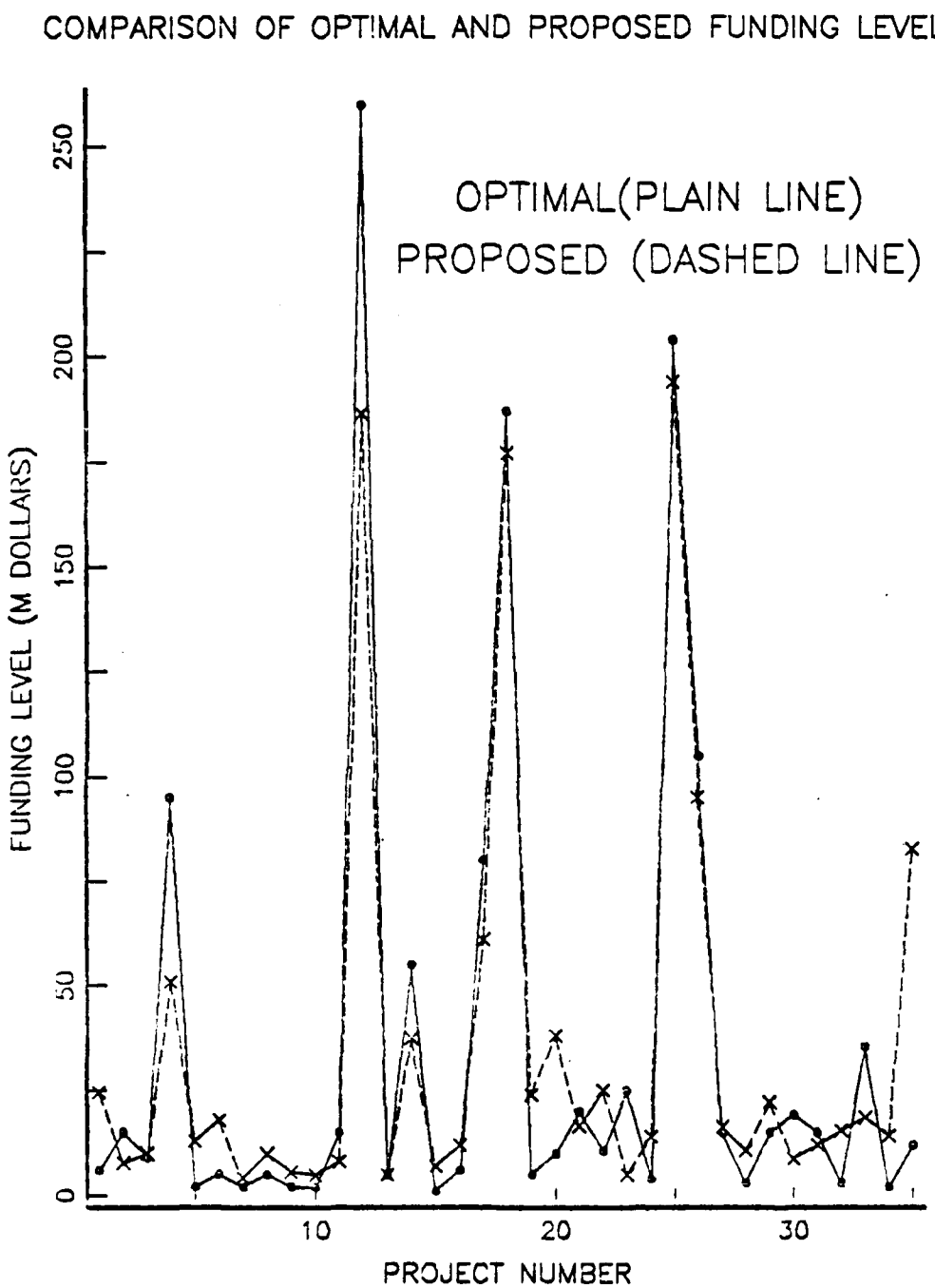


Figure 7 - Enhanced Budget Strategy

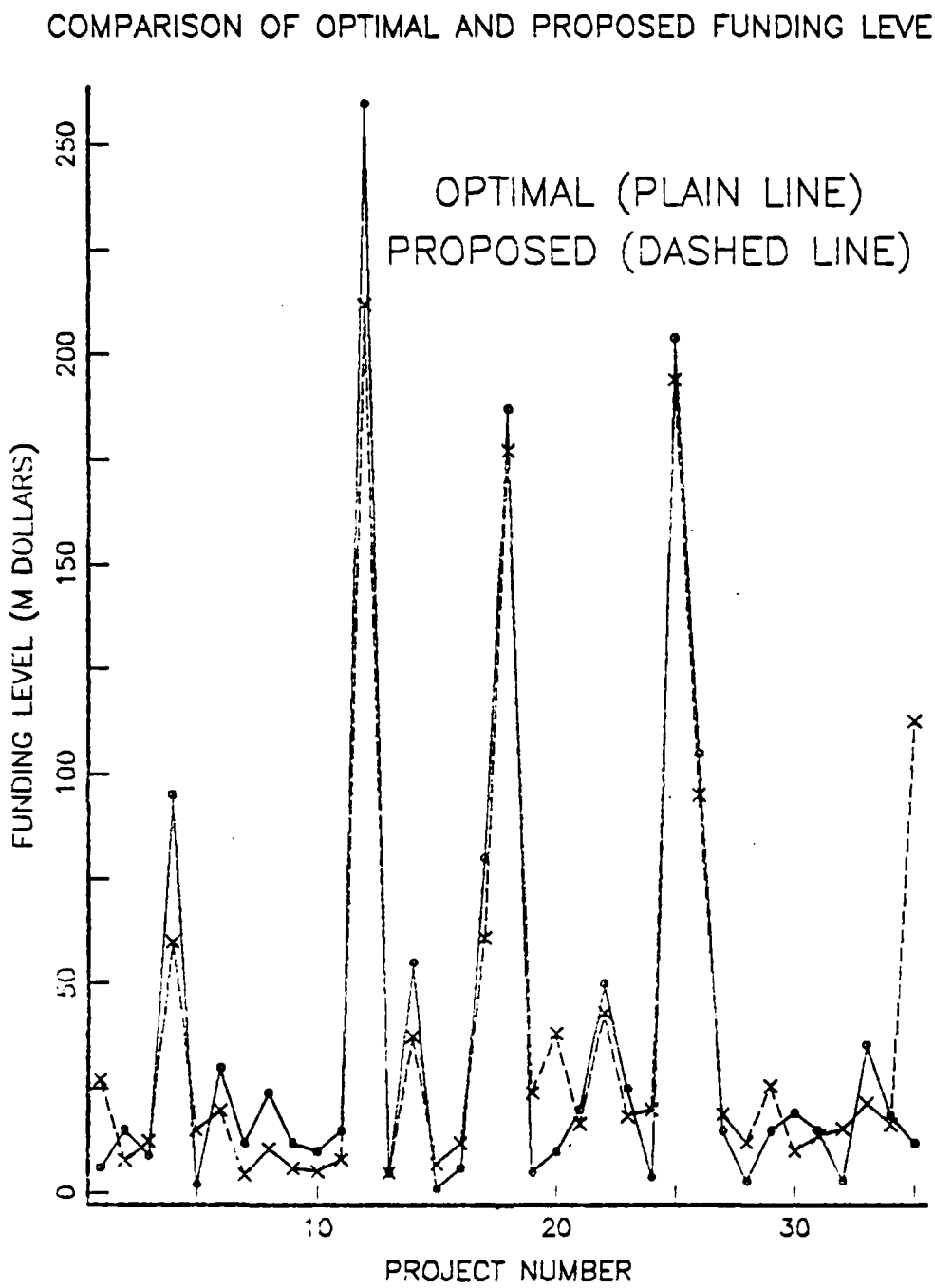


Figure 8 - Extended Budget Strategy

highly sensitive to population differences with respect to location, dispersion, or skewness. The K-S test was performed on the optimal and proposed funding levels for each budget strategy, and the results are summarized below in Table 21.

TABLE 21

OPTIMAL AND PROPOSED FUNDING LEVELS

Kolmogorov-Smirnov Two Sample Test Results

Strategy	DN	Sig Level
Core	.3142	.0630
Basic	.3714	.0160
Enhanced	.2857	.1148
Extended	.2000	.4858

A review of these results leads to the deduction that the optimal and proposed funding levels are very similar. The null hypothesis can be rejected at only the basic funding strategy, and the association between the two is particular strong at the enhanced and extended levels. These results support the intuitive inference of Figures 5-8; they show satisfactory correlation between the two distributions, particularly at the upper spending stages. However, it is clear that several projects at each strategy level exhibit substantial differences that demand attention.

3. GP Results - Optimal Priority List

The marginal values from the GP model output that were mentioned above provide information that makes possible a determination of project priority at each budget strategy. Appendix B contains the priority list of projects presently used by the USASDC. A comparison of the present USASDC priority list with the

optimal one derived from the GP model would provide additional insight.

The marginal values indicate the order in which the projects are selected for funding above the minimum bound. Projects that have the smallest marginal values are those that are valued by the optimizer the most. For example, a project with a marginal value of -.025 was given additional funds by the optimizing program prior to a project with a marginal value of -.005.

TABLE 22

OPTIMAL PRIORITY LIST OF MAJOR PROJECTS

Number	Project	Marg	Number	Project	Marg
1	K222	-.0313	19	L721	-.0034
2	D044	-.0294	20	L723	-.0037
3	D076	-.0285	21	S102	-.0038
4	S243	-.0242	22	S402	-.0010
5	B142	-.0232	23	S052	-.0013
6	B532	-.0221	24	S281	-.0002
7	K321	-.0204	25	K624	-1.6E-3
8	S271	-.0178	26	D080	-1.3E-3
9	S091	-.0150	27	D412	-0.4E-3
10	D047	-.0141	28	S051	.0023
11	S053	-.0120	29	B122	.0061
12	D083	-.0129	30	B612	.0090
13	K325	-.0082	31	K524	.0172
14	K225	-.0083	32	D112	.0233
15	K323	-.0083	33	K623	.0235
16	L212	-.0064	34	D114	.0264
17	L503	-.0051	35	S011	.0297
18	L008	-.0057			

The priority list shown in Table 22 was determined by simply rank ordering the various project marginal marginal values. A noteworthy observation is that the priority list does not change for any of the budget strategy model iterations, or any other budget level selected. The marginal values change, but the rank ordering does not, so the optimal priority list of preferred projects can be determined at any budget

level in the feasible region of the model solution. Table 22 displays the priority list and marginal values derived at a budget level of $1615.1 million.

The $1615.1 million funding level is significant because at this level the achievement function reaches its lowest value. At funding levels greater than $1615.1 million the objective value does not decrease, despite the infusion of additional funds into the model. This demonstrates that the bottom eight projects on the priority list of Table 22 will not contribute to the achievement function at any budget level, since the marginal values are always positive. The $1615.1 million funding level identifies those projects that do not contribute to the goals of the USASDC, no matter how much research and development money is available. In these unfortunate instances the payoff and/or balance benefits are exceeded by the risk and/or time drawbacks and money spent on them, according to the model, is wasted.

Similarly, the top seven projects are identified by the priority list. These are all projects that have highly favorable marginal values, ie, less than -.20. It should also be noted that each of these projects is optimally funded at their respective maximum levels at even the lowest budget levels. These top seven projects contribute the most to minimizing the goal constraint equations and optimizing the achievement function.

A comparison between the proposed and the optimal priority lists was made graphically in Figure 9. The plot of the difference vector makes it obvious that there is little similarity between the two priority lists. This supposition was verified by using Kendall's test for rank correlation, a nonparametric

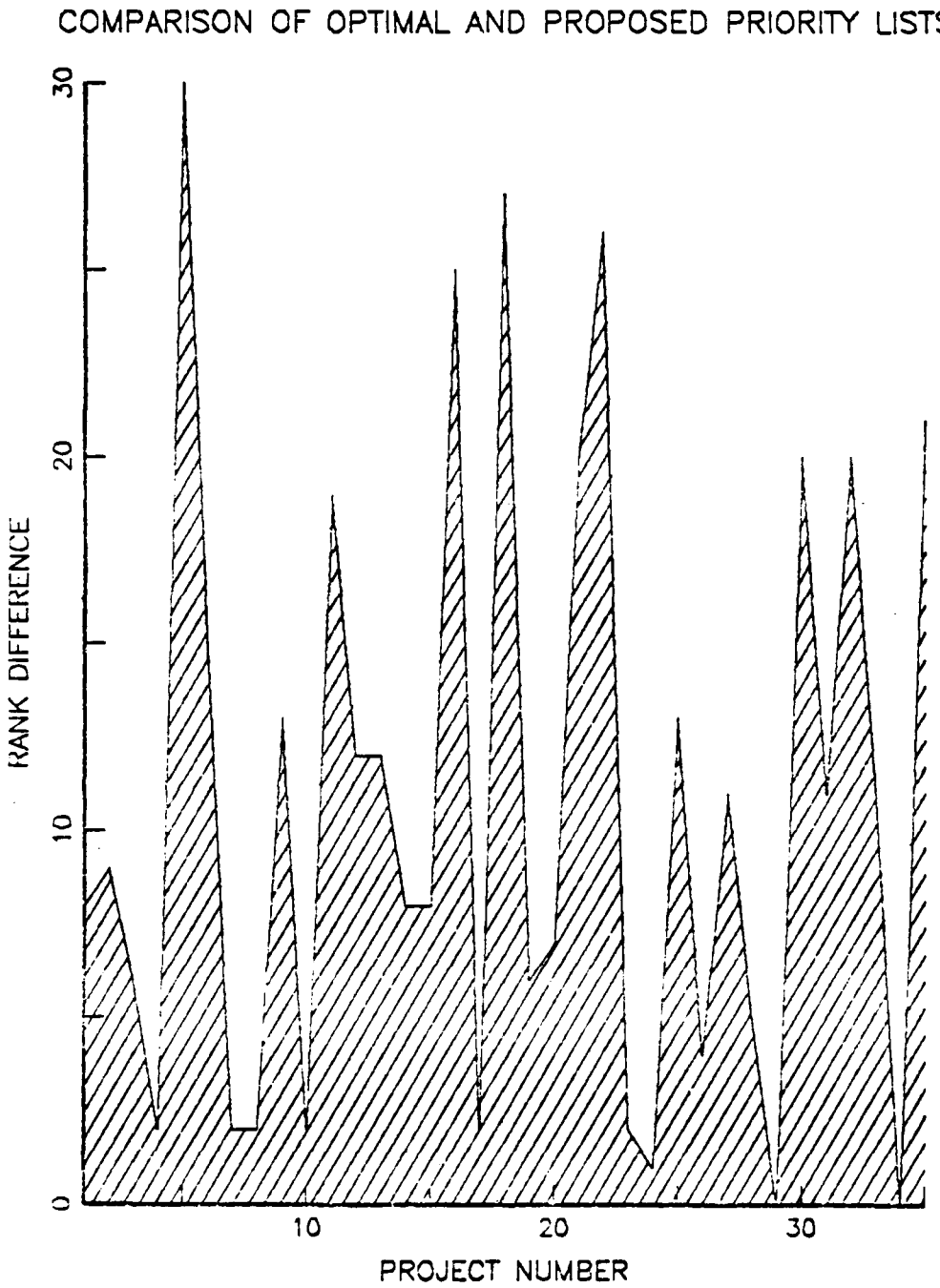


Figure 9 - Difference Vector of Priority Lists

procedure for determining a correlation coefficient, called Kendall's Tau, based on rank. A Kendall's Tau coefficient close to 1.0 demonstrates a high degree of agreement between the two vectors. In this case, the tau statistic was computed using Statgraphics and found to be .1193. This low correlation coefficient supports the hypothesis that the two priority lists are significantly different.

VII. SENSITIVITY ANALYSIS

In previous chapters, a model was developed based on several key elements of data that were obtained from surveys regarding the major projects presently being funded by the USASDC. It is obvious, however, that responses to these surveys may not be perfect; the data used may be subject to error, and resource availabilities and subjective evaluations can change with time. It is the purpose of this chapter to analyze the impact of changes in the goal programming model. Specifically, this entails determining the sensitivity of the model to changes of the following: (1) total USASDC budget; (2) minimum and maximum project funding levels; (3) goal constraint coefficients; and (4) achievement function coefficients.

A. CHANGES IN TOTAL USASDC BUDGET

The model was designed to handle changes in the total USASDC budget with ease, and five different budget levels iterations were discussed in the last chapter. The possible budget levels that can be run on the model are infinitely many, as long as the budget figure is within the bounds established by summing the various project minimum and maximum funding levels, $348 million and $1788.9 million respectively. However, possible as it is to run model iterations with a budget figure of $1788.9 million, it really is not practical to exceed $1615.1 million. This was the budget level identified in the Chapter VI as the point where the achievement function is minimized; budget levels above this do not enhance model performance.

Each total budget will yield different funding levels for each project. However, the optimal priority list, as discussed in Chapter VI, does not fluctuate with budget variations. This fact enables the use of the optimal priority list as a predictive tool that greatly enhances the validity of the model. For example, consider budget variations in the vicinity of the core strategy level, $882.9 million. At this level the first seven projects on the priority list were funded at the maximum level and the eighth project, S271, was optimized at a level higher than its minimum, but less than its maximum. If additional R&D funds are somehow made available, the priority list indicates that the model will initially spend this money on S271 until it reaches its maximum level. If still more funds are accessible, the model will allocate the money to the ninth project on the priority list. Likewise, if the budget is reduced from the basic strategy, the model will reduce the funds devoted to S271 before it takes money away from the number seven project. By increasing the flexibility and applicability of the model regarding changes in the total USASDC budget, the determination of a priority list in Chapter VI can now be seen as an important contribution to the sensitivity of the model.

B. CHANGES IN MINIMUM AND MAXIMUM PROJECT BOUNDS

Program element managers provided estimates for the minimum and maximum funding levels for each project, as discussed in Chapter IV, and it is possible that some of these approximations may change. Deviations in the upper and/or lower bounds can have a profound bearing on the optimal funding levels computed by the GP model, but once again the optimal priority list can be used to help predict the impact.

The minimum funding levels must first be satisfied before the model begins allocating money to other projects. Consider a project that, at a given budget level, is being funded at its maximum level. A change in the minimum funding level of this project will have absolutely no effect on the model results. Likewise, a change in the upper bound of a project being funded below that level will not alter model output. However, any other situation will vary the model results. If a project funded at the minimum has its lower bound reduced, then the additional money will be directed to the next available project on the optimal priority list that has not yet been maximized. The same result will occur if a project funded at its maximum level experiences a reduction in this upper bound.

In a similar manner the GP model will take money away from projects according to the priority list. This will occur if projects not being maximized have their lower bounds increased, or maximized projects have their upper bounds increased. Of course, the number of projects that will be affected by the changes in the bounds depends on the number and size of these modifications. Nonetheless, the impact of even large changes can be anticipated by using the optimal priority list, a feature that ensures that the GP model is sufficiently responsive to changes in the minimum and maximum funding levels of individual projects.

C. CHANGES IN GOAL CONSTRAINT COEFFICIENTS

Survey results were converted, using the AHP, into 135 goal constraint coefficients. The surveys were based on subjective judgments that can possibly vary for a number of reasons. In this section an analysis of the impact of changes in the subjective evaluations will be conducted.

The first situation to investigate is the impact of a mistake in completing a survey or transcribing data from a survey. One of the advantages in using the AHP procedure to generate weights from subjective evaluations is that it has a built-in mechanism to detect errors of this type. This feature is illustrated in Table 23, a table that displays an actual matrix taken from the AHP output in Appendix F and a "flawed" matrix that contains an input error.

TABLE 23

COMPARISON OF ACCURATE MATRIX WITH FLAWED MATRIX

Accurate Matrix					Flawed Matrix				
1	1	2	1	5	1	1	2	1	1
1	1	2	1	5	1	1	2	1	5
1/2	1/2	1	1	5	1/2	1/2	1	1	5
1	1	1	1	5	1	1	1	1	5
1/5	1/5	1/5	1/5	1	1	1/5	1/5	1/5	1
CONSISTENCY RATIO: .017					CONSISTENCY RATIO: .117				

The only change that was made in the flawed matrix is that the upper right-hand number was changed from 5 to 1, representative of a common typographical error. The consistency ratio (CR) computation turns this simple mistake into a glaring error by raising the CR to above 10%. Since a CR this high is unacceptable, the matrix data input would have to be examined and the error corrected. This example demonstrates the sensitivity of the GP model in responding to minor lapses, a feature that makes the model results more credible.

The GP model might also be subjected to a change of opinion. A respondent to a survey could decide that a project was judged inappropriately. Once again it is illuminating to look at an example of such a situation.

Consider the comparison matrix of KEW projects according to milestone risk shown in Table 24.

TABLE 24

KEW/MILESTONE RISK - ORIGINAL COMPARISON MATRIX

	K222	K623	K624	K225	K323	K325	K524	K321
K222	1	1/5	1	1	1	1	1/5	1
K623	5	1	5	5	5	5	1	5
K624	1	1/5	1	2	2	2	1	2
K225	1	1/5	1/2	1	1	1	1/5	1
K323	1	1/5	1/2	1	1	1	1/5	1
K325	1	1/5	1/2	1	1	1	1/9	1
K524	5	1	1	5	5	9	1	9
K321	1	1/5	1/2	1	1	1	1/9	1

Consistency Ratio: .031

Eigenvector: .062 .308 .116 .055 .055 .051 .302 .051

Suppose the KEW program element manager receives information implying that he overestimated the milestone risk of K623. The program element manager might then change the original comparison matrix to one as shown in Table 25.

TABLE 25

KEW COMPARISON MATRIX WITH MINOR CHANGES

	K222	K623	K624	K225	K323	K325	K524	K321
K222	1	1/2	1	1	1	1	1/2	1
K623	2	1	2	2	2	2	1	2
K624	1	1/2	1	2	2	2	1	2
K225	1	1/2	1/2	1	1	1	1/5	1
K323	1	1/2	1/2	1	1	1	1/5	1
K325	1	1/2	1/2	1	1	1	1/9	1
K524	5	1	1	5	5	9	1	9
K321	1	1/2	1/2	1	1	1	1/9	1

Consistency Ratio: .042

Eigenvector: .089 .178 .140 .069 .069 .066 .321 .066

The only numbers changed in the this new matrix are those in the second row and second column, values corresponding to project K623. The numbers in the original matrix were larger, signifying that K624 involves a high degree of milestone risk. The lower numbers in the new matrix denote that the milestone risk for K623 is not as substantial as the first matrix claimed. This is also reflected by the coefficient eigenvector. The largest coefficient change occurred in the K623 value, which dropped from .308 to .178, but the other project coefficient weights increased only slightly. A K-S test was performed comparing the two different eigenvectors. The computed P-value was .27, a high value signifying that the minor changes in the comparison matrix did not significantly alter the matrix output.

TABLE 26

KEW COMPARISON MATRIX WITH MAJOR CHANGES

	K222	K623	K624	K225	K323	K325	K524	K321
K222	1	1/5	1	1	1	1	1/5	1
K623	5	1	1/5	1/5	1/5	1/5	1	1/5
K624	1	5	1	2	2	2	1	2
K225	1	5	1/2	1	1	1	1/5	1
K323	1	5	1/2	1	1	1	1/5	1
K325	1	5	1/2	1	1	1	1/9	1
K524	5	9	1	5	5	9	1	9
K321	1	5	1/2	1	1	1	1/9	1

Consistency Ratio: .031

Eigenvector: .091 .022 .167 .081 .081 .077 .406 .077

To continue with the KEW example, Table 26 displays the results of a major change in the program element manager's opinion of K623. Now the knowledge available is such that the manager feels K624 has the least amount of milestone risk of any of the KEW projects.

The second column and second row feature very small numbers, changes that have a big effect on the eigenvector of coefficient weights. Not only has the K623 coefficient has decreased considerably from .308 to .022, but the other coefficients have all increased approximately 50%. The K-S test statistic when this latest eigenvector is compared with the original one is .038, indicative that the two eigenvectors are considerably different.

The example above demonstrates the sensitivity of the model to major subjective changes in the responses to the AHP surveys. Despite the fact that the KEW milestone risk eigenvector has been altered by the changes, it remains to be determined if this will have an impact on the overall risk eigenvector. As discussed in Chapters II and IV, each of the four major factors (payoff, risk, time, and balance) are comprised of several sub-factors. In the case of risk, the sub-factors are technological risk and milestone risk.

The complete AHP program was run with the modified matrix and a new risk eigenvector was computed. This eigenvector was compared with the original by means of the K-S test. The K-S P-value was computed as .4858, so it is evident that much of the deviation that had been stimulated by the major changes in the KEW milestone risk matrix has been suppressed at this higher level in the model.

The new risk eigenvector was substituted into the GP model. The GAMS model was run at the core strategy level and the results proved notable. Only two projects were affected by the new eigenvector, so the calculated P-value of .9830 comparing the new with the original optimal funding levels was not surprising. However, the fact that the funding level for K623 was

not altered by the changes was surprising. The model took $13 million from B142 and gave it to K321. The new optimal priority list was computed, and it shows a drop of several places in rank order of B142. K321 retains its place on the list and since it is the next project that is not funded to its maximum level, the funds taken from B142 are given to K321.

The discussion above should point out the inability of the model to predict the impact of major changes in subjective evaluations. What began as a change in the opinion of a program element manager regarding project K623 ended up affecting the funding levels of two other projects. This result demonstrates the complex interrelationships of the goal coefficients and the difficulty in anticipating the repercussions of major opinion alterations. The model responds very well to simple errors and minor changes involving the subjective evaluations, but major changes unfortunately demand a complete reiteration of the model.

D. CHANGES IN ACHIEVEMENT FUNCTION COEFFICIENTS

The most important comparison matrix used in the model is the one that determines the achievement function coefficient weights, and a matrix that was displayed and discussed at length in the last chapter. This section is concerned with the impact of changes to the achievement function coefficients.

The original weights for the achievement function were based on the perception that maximizing payoff was the most important goal of the GP program, and minimizing risk was a close second priority. Minimizing time was important, but not as critical as the goals involving payoff and risk. Maximizing balance was considered the least important objective in the achievement function, but a goal nonetheless. In

mathematical notation, this situation can be represented as shown below in equation 7-1.

Original Ach Fn: Payoff > Risk > Time > Balance (7-1)

It is recognized that the original goal priorities used in the model might change someday, since organizational priorities often change. Keeping such a possibility in mind, the following four achievement function situations were envisioned:

Situation 1: Payoff = Risk > Time > Balance (7-2)
Situation 2: Risk > Payoff > Time > Balance (7-3)
Situation 3: Time > Payoff > Risk > Balance (7-4)
Situation 4: Payoff = Risk = Time = Balance (7-5)

There are many possible priority relationships, but these were selected as likely scenarios that could satisfactorily demonstrate the impact of achievement function changes on the model results. The four situations were converted into AHP comparison matrices according to the procedure discussed in Chapters IV and VI, and the complete results of these AHP iteration can be found in Appendix H. The weight eigenvalues obtained from the AHP workspace depicting each achievement function situation are shown in Table 27.

TABLE 27

ACHIEVEMENT FUNCTION EIGENVALUES - SITUATIONS 1-4

Situation	Payoff	Risk	Time	Balance
Original	.527	.301	.110	.063
1	.425	.425	.093	.056
2	.330	.542	.079	.048
3	.250	.152	.557	.041
4	.250	.250	.250	.250

The achievement function coefficients from Table 27 were each programmed into the GAMS GP model in the same way that the original weights were. The four different situations were run on the GP model at each funding strategy budget level. The output from this endeavor is contained in Appendix I. Listed in Table 28 are the results of numerous tests comparing the funding vectors and optimal priority lists derived from the original and supplemental model iterations.

TABLE 28

GP RESULTS - SITUATIONS 1-4 COMPARED W/ ORIGINAL

	Sit 1	Sit 2	Sit 3	Sit 4
Core Budget				
K-S Deviation:	.0000	.0000	.2286	.0000
P-value:	1.0000	1.0000	.3199	1.0000
Basic Budget				
K-S Deviation:	.0000	.2286	.2286	.2286
P-value:	1.0000	.3199	.3199	.3199
Enhanced Budget				
K-S Deviation:	.0000	.2876	.3143	.2876
P-value:	1.0000	.1242	.0630	.1242
Extended Budget				
K-S Deviation:	.1677	.3143	.4285	.3143
P-value:	.5632	.0630	.0032	.0630
Priority List				
Kendall's Tau:	.6336	.5462	-.0017	.2539

The data contained in Table 28 demonstrates the extremely wide range of validity that the GP model possesses. Situation 1 involves slight changes in the coefficient weights, and the optimal funding levels selected at the three lowest budget levels are identical with those of the original model. The P-value at the extended level indicates that there is only slight deviation from the original extended funding levels, and the optimal priority list

correlation is high. In Situation 2, risk has been established as a higher priority than payoff, but only at the extended funding level do the model results from this iteration differ significantly from the original model output. The Kendell Tau figure is still quite high and is testimony to the similarity between the original and Situation 2's optimal priority list. Situation 4 represents a substantial departure from the goal priorities established for the original model, yet the Table 28 data shows that only at the extended budget level can one reject the hypothesis that the two funding levels are the same. However, the Situation 4 optimal priority list does differ notably from the original. Situation 3 involves a radical digression from the original in that the payoff coefficient has been decreased to .152 from .527 and the time coefficient raised from .11 to .557. Nevertheless, the funding levels at the core and basic budget strategies are not statistically different, further confirmation of the excellent flexibility and applicability of the GP model that has been developed.

VIII. CONCLUSIONS AND RECOMMENDATIONS

This final chapter is intended to briefly discuss the conclusions that can be drawn from the results and analysis of the GP model, as well as state the recommendations that this study has motivated.

A. CONCLUSIONS

1. Presently proposed project funding levels are valid; model funding levels are optimal.

The proposed funding levels for the 35 major USASDC projects do not vary significantly from the optimal levels determined by the model for three of the budget strategy levels. However, there is substantial variation from optimality at the basic strategy budget level. The similarity between the optimal and proposed levels are acceptable for the core and enhanced strategy, but their respective significance levels are low enough to cause some concern. The best course of action is to make the minor funding corrections needed to convert the proposed levels to the optimal ones suggested by the model.

2. The present priority list in use is not valid; the model priority list is optimal.

The project priority list presently in use by the USASDC differs significantly from the optimal priority list. An accurate priority list has been demonstrated in Chapter VII as an excellent predictive device, enabling managers to speculate appropriate responses to changes in budget level and individual project bounds. The optimal project priority list calculated from the model should replace the present priority list so that an accurate and effective tool is at the disposal of key management personnel.

3. <u>The bottom eight projects on the priority list are not productive.</u>

In Chapter VI it was discovered that the last eight projects on the optimal project priority list had non-negative marginal values at every funding level in the feasible region. This indicates that these projects do not make any positive contributions to the model goals. In these unfavorable instances the advantages afforded by spending money on the projects are exceeded by the disadvantages they accrue, so funding for these projects should be terminated as soon as possible. If these projects are reduced from their present level of funding to their respective minimum funding levels, a savings of $63.1 million dollars will be realized.

4. <u>The top seven projects on the priority list are particularly productive.</u>

The top seven projects in the priority list demonstrated highly productive characteristics, as was explained in Chapter VI. At the $1615.1 million funding level, each of these projects had a marginal value under -.20, and each project was optimized at its respective maximum funding level for every model iteration. Funding priority should be given to these very favorable projects.

5. <u>A total USASDC budget for the major project of over $1615.1 million is not productive.</u>

The $1615.1 million funding level for the 35 major projects was determined as the point where the achievement function was minimized. Money spent in excess of this amount does not decrease the objective value any further, since these additional funds can only be spent on the ten unproductive projects; at $1615.1 million all projects that make favorable

contributions to the model are at their respective maximum funding levels. Total budget endowments greater than $1615.1 million should be diverted to more productive research and development endeavors.

6. <u>The GP model developed is flexible and has a wide range of validity.</u>

The GP model developed has been successful in meeting all the objectives of this study. The AHP has been used to convert previously vague subjective evaluations into the precise mathematical coefficients needed for a reliable solution. The GP model has been analyzed as very adaptable to changes in the model parameters and the R&D environment. Simple and versatile personal computer software has been written to support all computational aspects of the model. A user with a properly organized data base can perform a completely new iteration of the model in less than an hour. These characteristics help describe a model worthy of wide dissemination and use.

B. RECOMMENDATIONS

1. R&D funds in FY 88 should be provided to each major project as shown in Table 20 of Chapter VI according to the budget strategy that is approved for the USASDC.
2. The optimal project priority list displayed in Table 22 of Chapter VI should immediately replace the present priority list used at the USASDC.
3. Steps should be taken save $63.1 million by eliminating the following eight projects as soon as possible (listed in order of elimination priority):
   a. S011 - Cobra Judy
   b. D114 - DEW Concept Development Defn
   c. K623 - Invite, Show, and Test Forum

d. D112 - Interactive Discrimination
e. K524 - SDI Targets
f. B612 - National Test Bed
g. B122 - Theater Missile Def Architecture
h. S051 - Optical Airborne Measurement Pgm

4. Steps should to taken to ensure the following seven projects receive maximum priority and funding support:
   a. K222 - Exoatmospheric Interceptor Expt
   b. D044 - AFOCAL Technology
   c. D076 - Free Electron Laser Demonstration
   d. S243 - LWIR Probe
   e. B142 - Architecture Support Analysis
   f. B532 - Battle Mgmt/C3 Experimental Sys
   g. K321 - Endoatmospheric Interceptor Expt
5. Total funding for the major USASDC projects should not be allowed to exceed $1615.1 million. Excess funds should be diverted to more promising R&D efforts.
6. The GP model developed in this paper, and the associated software designed to support it, should be implemented as soon as possible as a management and planning tool in the USASDC Program Analysis and Evaluation Directorate.

APPENDIX A

PROGRAM ELEMENT DESCRIPTIONS

USASDC technical efforts are structured into five program elements, each element examining important SDI technology. Program element managers are assigned to each program element, and they monitor and coordinate the funding and conduct of the research efforts in each area. Many of these projects in the program elements have already been responsible for some outstanding experimental results. A discussion of the focus of each of these program elements follows.

A. SURVEILLANCE, ACQUISITION, TRACKING AND KILL ASSESSMENT (SATKA) PROGRAM

The SATKA program provides sensor research efforts involved in performing surveillance, acquisition, tracking, discrimination and kill assessment of hostile ballistic missiles. The SATKA program is critical to the overall success of the SDI, since a target must be identified and tracked before it can be destroyed. There are three basic sensor types involved in the accomplishment of this important mission:

1. Rocket launch detection sensors - used to detect the the initiation of an attack.
2. Midcourse sensors - employed to track atmospheric reentry vehicles and decoys in midcourse.
3. Terminal phase sensors - utilized to track attacking warheads in the last seconds prior to impact.

Key components of the SATKA program are technology development experiments and data collection efforts. This program element has the largest number of R&D

projects being managed by the USASDC and accounts for over 35% of the Fiscal Year 1987 budget. Research efforts are being concentrated in the following areas: radars, laser radars, infra-red sensors, interactive discrimination, and signal processing.

B. DIRECTED ENERGY WEAPONS (DEW) PROGRAM

The DEW program identifies and validates the technology supporting directed energy systems; it is hoped that these systems will be able to discriminate decoys from warheads, and then destroy large numbers of enemy vehicles in split seconds. This discrimination and intercept mission is key to achieving high levels of ballistic missile defense effectiveness.

To achieve the DEW goal, research has been directed towards technologies that perform the functions of (1) generating a high energy destruction beam; (2) conditioning the beam and delivering it for propagation toward the target; (3) focusing the beam at the target along a prescribed path; and (4) hitting the target and reinitiating the sequence quickly in order to engage a new target. Thus, the DEW program includes work on laser devices at various wavelengths; laser beam control and optics; particle beam technology; pointing and fire control; and nuclear directed energy weapons.

The DEW program has funded R&D in two major new technologies, the Ground Based Free Electron Laser (GBL) and the Neutral Particle Beam (NPB). Several DEW projects involve GBL and NPB proof-of-feasibility and data collection experiments.

C. KINETIC ENERGY WEAPONS (KEW) PROGRAM

R&D efforts in the KEW program support all options involved in kinetic energy guided projectiles. As a

relatively mature set of technologies, these endeavors are expected to provide the intercept and kill functions for initially deployed ballistic missile defenses. KEW weapons are also very useful in the defense of space platforms.

Kinetic energy projectiles rely on nonnuclear kill mechanisms. They are accelerated by chemically propelled boosters or hypervelocity electromagnets. Chemical rockets are in a more advanced technological state, but hypervelocity weapons are considered preferable in engagements that involve very large numbers of engagements in short periods of time. Hypervelocity guns are also attractive because of their ability to achieve rapid target kills with minimal system weight impact.

The KEW program is developing technology in four major R&D areas. These include: (1) space-based kinetic kill vehicles; (2) ground-launched interceptors; (3) advanced hypervelocity rail guns; and (4) fire control support items.

D. SYSTEM ANALYSIS AND BATTLE MANAGEMENT (SABM) PROGRAM

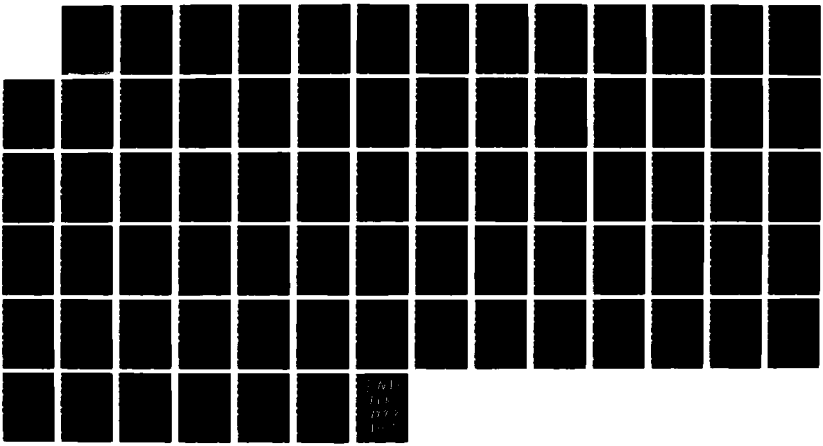
The SABM program is concerned with the management of activity on two diverse, but related fronts. Systems analysis efforts define the performance requirements of systems that will constitute the strategic defense. Battle management research will define the operational environment of decisions and rules involved in the collective deployment of many individual systems.

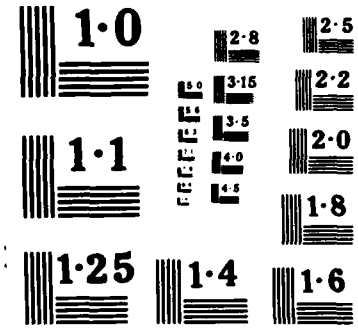
Specific tasks within the systems analysis framework include the following:

1. Architecture - defining system organization, concepts, and parametric trade-offs that allow

AD-A187 899 A GOAL PROGRAMMING R&D (RESEARCH AND DEVELOPMENT) PROJECT FUNDING MODEL O (U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S M ANDERSON SEP 87 2/2

UNCLASSIFIED F/G 12/4 NL




1·0
2·8
2·5
3·15
2·2
3·5
2·0
4·0
1·1
4·5
1·8
1·25
1·4
1·6

assessment of key technologies and system functions.

2. Threat analysis - projection of possible threat structures and scenarios that will help define appropriate US responses.
3. Logistic integration - addresses logistic supportability issues across the entire SDI program.

Key elements of battle management research are listed below:

1. Situation assessment - concerned with a wide variety of algorithms that perform damage assessment, defensive firing strategies, and network management.
2. Command, control, and communication - involves projects investigating the rapid passing of critical battlefield information and directives.
3. Battle management software - addresses the development of some of the most complex computer programming ever attempted; software that can make instant and appropriate battlefield decisions according to programmed instructions.

E. SURVIVABILITY, LETHALITY AND KEY TECHNOLOGIES (SLKT) PROGRAM

Critical factors in the development of a strategic defense include effectiveness, affordability and survivability. The SLKT program performs research in the key technologies involving these factors. Specifically, the SLKT program manages research intended to:

1. Develop tactics to enhance the survivability of defensive components in hostile environments.
2. Reduce uncertainties that exist in the US capability to predict enemy target vulnerability;

3. Coordinate and stimulate the development of energy generation, conversion, and power conditioning subsystems.
4. Develop technologies to improve space transportation, repair, and resupply.
5. Identify and manage research into the development of high technology materials and structures.
6. Develop tactical and technical countermeasures in order to negate the effectiveness of defensive strategies.

The SLKT program is organized into the following five projects: (1) System Survivability; (2) Lethality and Target Hardening; (3) Space Power and Power Conditioning; (4) Space Transportation and Support; (5) Materials and Structures Development; and (6) Countermeasures.

APPENDIX B

PROPOSED PROJECT FUNDING LEVELS AND PRIORITY LIST

The funding levels shown in the table below represent the presently forecasted funding levels for each of the 35 major USASDC projects in FY 88. The major projects are listed in rank order corresponding to priority. The data for this table was collected from the USASDC-Huntsville Resource Management Office priority listing, dated 3 Dec 1986.

PROPOSED FUNDING LEVELS AND PRIORITY LIST

		Budget Strategy			
Rank	Project	Core	Basic	Enhanced	Extended
1	S271	82.3	95.0	95.0	95.0
2	B142	6.2	6.2	7.7	7.7
3	K222	150.0	150.0	177.0	177.0
4	B532	30.0	38.5	51.1	59.9
5	B122	20.0	20.0	24.5	27.1
6	K623	24.0	24.0	24.0	24.0
7	S051	16.4	16.4	16.4	18.9
8	S011	10.7	10.7	10.7	12.3
9	K624	38.0	38.0	38.0	38.0
10	D076	158.0	170.6	186.5	211.9
11	D044	5.0	5.0	8.0	8.0
12	S052	22.2	22.2	22.2	25.6
13	L721	4.8	5.1	5.6	6.0
14	S053	7.3	7.3	8.8	10.2
15	S243	9.8	9.8	12.0	13.8
16	S402	15.4	15.4	15.4	15.4
17	L723	4.0	4.3	4.8	5.2
18	S091	13.1	15.3	18.6	21.5
19	D112	3.0	7.0	7.0	7.0
20	D083	55.0	61.0	61.0	61.0

Rank	Project	Core	Basic	Enhanced	Extended
21	D047	34.4	34.4	37.4	37.4
22	S081	5.0	5.0	5.0	5.0
23	S102	10.0	11.7	14.2	16.4
24	K225	6.0	8.0	16.6	16.6
25	K323	3.0	5.0	25.0	43.0
26	K325	5.0	5.0	5.0	18.4
27	K524	12.0	12.0	14.0	20.0
28	L008	14.6	16.0	18.0	19.8
29	B412	8.1	10.0	10.0	12.4
30	K321	58.0	129.0	194.0	194.0
31	S281	20.1	39.4	82.8	112.7
32	B612	7.0	7.0	12.9	15.1
33	L503	8.5	9.0	10.0	10.6
34	D114	12.0	12.0	12.0	12.0
35	L212	3.7	3.9	4.2	4.5

APPENDIX C

AHP MAJOR PROJECT SURVEYS

The process of collecting data in support of the GP model developed in Chapter V is an essential step in determining the optimum expenditure levels for each major project. This appendix is intended to provide information on the AHP surveys that were designed and implemented to achieve this end.

The GP model requires that the following data be collected regarding each of the thirty-five major projects being modelled:

1) Military payoff weight factor
2) Development risk weight factor
3) Development time weight factor
4) Development balance weight factor
5) Minimum funding level
6) Maximum funding level

The data collection effort is complicated by the fact that each of the first four items are motivated by several subjective evaluations. As discussed in Chapter III, the AHP has been determined as the most accurate method of converting subjective evaluations into the numerical weights required for the model.

The personnel selected to respond to the AHP project survey were the program element managers for each of the five program elements: SATKA, DEW, KEW, SABM, and SLKT. These individuals have the most project management experience and are assumed to be best suited to make reliable pairwise comparisons of the projects, as discussed in the last chapter. They continually report on and monitor the progress of all projects in their respective program elements, giving them a sufficiently broad perspective. Program element

managers are not likely to be prejudiced towards one particular project, as a project manager or research scientist might. They also have extensive technical backgrounds in their particular fields, giving them the expertise to make precise comparative judgments.

The project survey requested the program element managers to estimate the minimum and maximum funding levels for each major project. Additionally, the questionnaire required respondents to make subjective comparisons between each program element project regarding each of the following factors:

1) Potential contribution to SDI long range goal
2) Potential contribution to SDI short range goal
3) Potential generation of spinoff technology
4) Technological risk
5) Milestone risk
6) Ultimate project success time
7) FSED contribution time
8) Concepts and designs balance
9) Signature requirements/data collection balance
10) Function performance balance
11) Technological base balance

The survey was designed according to the principles of AHP discussed in Chapter IV. The program managers compared each major program with all the other programs in that same program element on the basis of the factors shown above. Respondents were briefed in person and in writing on the AHP comparison scale, and a definition of each comparison factor was provided. The program element managers were given over two months (18 Dec 86 - 28 Feb 87) to work on and complete the survey.

MAJOR PROJECT SURVEY

WPD:_____ POC:_____

This survey is designed to obtain pairwise comparison data on all of the WPDs in your program element. The projects will be compared on the basis of eleven key issues. You have already been briefed on the purpose of this survey and it's theoretical foundations.

Please use the following numerical scale to help describe the relationships of the WPDs on the following pages:

1 - same/equal
2
3 - moderate
4
5 - strong
6
7 - very strong
8
9 - extremely strong

2, 4, 6, 8 - intermediate values

Please also ensure that you circle either "advantage" or "disadvantage" when each comparison is made. Questions made be directed to MAJ Donnellon, USASDC Program Analysis and Evaluation Directorate, or CPT Anderson, Naval Postgraduate School.

Comparison 1: Potential contribution to long range goal

Definition: Potential for benefiting the overall technological goals of the SDI or strategic defensive system.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

Comparison 2: Potential contribution to FSED decision

Definition: Potential for helping to achieve an FSED decision not later than 1995.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

Comparison 3: Potential generation of military spinoff technology

Definition: Potential benefit to the generation of military technology; assistance to the military in ways external to the SDI R&D program.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

Comparison 4: Technological risk

Definition: Likelihood of failing to meet the ultimate technical objectives of the program/WPD; probability of not achieving technological success.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

Comparison 5: Milestone risk

Definition: Likelihood of failing to meet the milestone schedule needed for an FSED decision in 1995; probability of not achieving the milestones specified by the WPD.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

Comparison 6: Time required to achieve ultimate technological project success

Definition: Time needed to achieve the ultimate technical objectives of the WPD, provided that all resources needed (money, facilities, etc.) are made available.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

Comparison 7: Time required to achieve objective required for FSED decision in 1995.

Definition: Time needed to achieve only those objectives needed in order to make an informed FSED decision by 1995.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

Comparison 8: Concepts and designs balance

Definition: Propensity of the project to be in the concepts and designs developmental phase.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.
_____ gives a ___ advantage/disadvantage over_____.

Comparison 9: Signature requirements/data collection balance.

Definition: Propensity of the project to be in the signature requirements/data collection developmental phase.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

Comparison 10: Function performance balance

Definition: Propensity of the project to be in the function performance developmental phase.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

Comparison 11: Technological base balance

Definition: Propensity of the project to be in the technological base developmental phase.

In regards to the above comparison,

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

_____ gives a ___ advantage/disadvantage over_____.

This completes the survey. Thank you for your time.

Please return, using the pre-addressed envelope that has been provided, to:

CPT Steven M. Anderson
1242 Spruance Road
Monterey, CA 93940
NPS phone: (AV) 878-2786
(COMM) 408-646-2786

APPENDIX D

AHP SOFTWARE SUPPORT

This appendix is intended to provide information on the software that was written in order to support the GP Model and perform the AHP process, a tedious procedure if performed by hand.

Once the project surveys had been collected, the next step was to utilize the AHP to determine the required coefficient weights for the GP model. The calculations required to implement the AHP are numerous and difficult. APL [Ref. 38] was the computer language chosen to perform the AHP calculations, since APL is particularly powerful when performing linear algebra computations; APL has the capability to directly manipulate aggregates of data in the form of arrays or matrices.

An APL workspace called "AHP" was written, consisting of nine APL functions that perform the AHP mathematical procedure outlined in Chapter IV. The workspace was written on an IBM Personal Computer using APL Plus Version 5.0, Statistical Graphics Corporation. The workspace was intended to be easy to use and have a broad range of applicability, and is printed out in its entirety at the end of this appendix. All programs were generalized, so that the AHP can be used on any subjective data array, not just the USASDC data set presented here. The programs were also designed to be interactive, so that a user is prompted for the information needed at the appropriate time, a feature that helps avoid confusion and needless repetition. The programs are also relatively fast, so that changes in the data can be made and analyzed quickly, a needed characteristic for sensitivity analyses. Additionally,

the function DESCRIBE gives the utilizer an overview of the workspace and the functions contained within, and INPUTHOW is a function created to demonstrate the proper method for entering pairwise comparison data into the other routines.

The workspace has several key subroutines that serve as building blocks for the other routines. The main function AHP utilizes four APL functions. MATRIX takes given pairwise comparison data and manipulates it into the matrix needed by the other workspace functions. Additionally, this matrix is printed on the terminal screen so that the user can verify that the correct data was entered into the routine. EIGENVECTOR performs the linear algebra calculations in order to produce an eigenvector of ratio scale coefficient weights. Consistency Index (CI) and Consistency Ratio (CR) values are also calculated and displayed by the EIGENVECTOR program. AHPBASE collects all the eigenvectors calculated from comparison matrices at each particular hierarchical level and for each factor. AHPSTAND determines the overall standardized eigenvector for the main factor (ie, payoff, risk, time, or balance) being analyzed based on the AHPBASE eigenvectors at each hierarchical level. For example, AHPSTAND made one overall standardized eigenvector for risk from the milestone risk and technological risk arrays. The main workspace function, AHP, serves principally to call up these subroutines the correct number of times and formats the output.

Two additional functions are included in the workspace that are noteworthy. SINGLE is a function designed to perform the AHP procedure when only one comparison matrix is being studied. AHPCHECK allows the user to ensure that the AHP is functioning

correctly. It is identical to the AHP function, except that it prints the computations made at each step, enabling the user can check for accuracy and logic.

A summary of the functions contained in this workspace is shown below:

1. INPUTHOW - Recommended reading for the first time user; demonstrates how to enter matrix data.
2. AHP - Determines a weight eigenvector for several factors at various hierarchical levels.
3. AHPCHECK - A checking function to ensure that AHP is calculating eigenvalues and CRs properly.
4. AHPSTAND (subroutine) - Determines standardized weight eigenvector for elements in comparison matrix.
5. AHPBASE (subroutine) - Collects basic comparison matrix data for AHPSTAND subroutine.
6. SINGLE - Computes a weight eigenvector for elements in a single comparison matrix.
7. EIGENVECTOR (subroutine) - Ascertains matrix eigenvector and calculates consistency ratio data.
8. MATRIX (subroutine) - Creates matrix from input values for use by eigenvector.

The completed surveys were converted into data arrays and entered into the AHP function as input. The AHP program was used four times, once for each factor. The comparison matrices, their respective CIs and CRs, as well as the intermediate and final eigenvector for each factor was printed in an output file (see Appendix F). This concluded the procedure for determining weight values for each project in regards to payoff, risk, time, and balance.

```
[1]  ⍝*********************************************************************
[2]  ⍝
[3]  ⍝   FUNCTION:  AHP                          WORKSPACE:  AHP
[4]  ⍝
[5]  ⍝   PROGRAMMER:  STEVEN M. ANDERSON         DATE:  25 JAN 1987
[6]  ⍝
[7]  ⍝   PURPOSE:  THIS IS THE MOST IMPORTANT FUNCTION CONTAINED IN THIS
[8]  ⍝   WORKSPACE.  THE AHP FUNCTION USES THE OTHER FUNCTIONS IN THE WORK-
[9]  ⍝   SPACE TO EXECUTE THE ANALYTIC HIERARCHY PROCESS.  THE ULTIMATE GOAL
[10] ⍝   OF THIS PROCESS IS TO ANALYZE NUMEROUS ELEMENTS ON THE BASIS OF
[11] ⍝   SEVERAL FACTORS AT THE SAME HIERARCHICAL (OR PRIORITY) LEVEL.  IT
[12] ⍝   IS ASSUMED THAT THE USER HAS COMPARITIVE DATA IN THE FORM OF MATRICES
[13] ⍝   REPRESENTING COMPARISONS OF MANY ELEMENTS; THESE ELEMENTS ARE
[14] ⍝   COMPARED ON THE BASIS OF THE FACTORS EXISTING AT THE HIERARCHICAL
[15] ⍝   LEVEL BEING ANALYZED.  ULTIMATELY, WHEN THE AHP IS COMPLETED, ALL
[16] ⍝   THE ABOVE-MENTIONED DATA IS REPRESENTED BY A SINGLE EIGENVECTOR.
[17] ⍝   IT IS ALSO IMPORTANT TO NOTE THAT CONSISTENCY CALCULATIONS ARE ALSO
[18] ⍝   PROVIDED, WHICH ENABLE THE USER TO DRAW CONCLUSIONS CONCERNING THE
[19] ⍝   QUALITY OF DATA BEING INPUT INTO THE PROGRAM.
[20] ⍝
[21] ⍝*********************************************************************
[22]  '  WELCOME TO AHP.  THIS FUNCTION WILL PERFORM THE ANALYTIC HIERARCHY'
[23]  'PROCESS ON SEVERAL FACTORS AND MANY COMPARED ELEMENTS AT THE SAME'
[24]  'HIERARCHICAL LEVEL.  IT IS ASSUMED THAT THE USER IS FAMILIAR WITH THE'
[25]  'AHP AND HAS DATA GROUPED IN COMPARISON MATRICES.  IF YOU ARE NOT'
[26]  'FAMILIAR WITH THE PROPER WAY OF ENTERING MATRIX DATA INTO THE PROGRAM,'
[27]  'PLEASE SEE THE FUNCTION INPUTHOW BEFORE CONTINUING ANY FURTHER.'
[28]  '  PLEASE BEGIN BY ENTERING THE NAME/TITLE OF THE HIERARCHICAL LEVEL'
[29]  'BEING ANALYZED (ENCLOSE IN APOSTROPHES):'
[30]  BIGTITLE←⎕
[31]  'PLEASE ENTER THE NUMBER OF FACTORS YOU WISH TO CALCULATE EIGENVECTORS'
[32]  'FOR AT THIS HIERARCHICAL LEVEL:'
[33]  X←⎕
[34]  BIGVEC←0
[35]  BIGVEC←1↓BIGVEC
[36]  ONEVEC←0
[37]  ONEVEC←1↓ONEVEC
[38]  TWOVEC←0
[39]  TWOVEC←1↓TWOVEC
[40]  THREEVEC←0
[41]  THREEVEC←1↓THREEVEC
-42-  FOURVEC-0
[43]  FOURVEC←1↓FOURVEC
[44]  TVEC←0
[45]  TVEC←1↓TVEC
```

```
[46]   A←0
[47]  L1:A←A+1
[48]   AHPSTAND
[49]   →(A<X)/L1
[50]   Z←(⍴BIGVEC)↑X
[51]   ONEVEC←(Z↑BIGVEC)↑X
[52]   →(X=4)/L3
[53]   →(X=3)/L2
[54]   TWOVEC←(Z↓BIGVEC)↑X
[55]   TVEC←ONEVEC+TWOVEC
[56]   →L4
[57]  L2:BIGVEC←Z↓BIGVEC
[58]   TWOVEC←(Z↑BIGVEC)↑X
[59]   THREEVEC←(Z↓BIGVEC)↑X
[60]   TVEC←ONEVEC+TWOVEC+THREEVEC
[61]   →L4
[62]  L3:BIGVEC←Z↓BIGVEC
[63]   TWOVEC←(Z↑BIGVEC)↑X
[64]   BIGVEC←Z↓BIGVEC
[65]   THREEVEC←(Z↑BIGVEC)↑X
[66]   FOURVEC←(Z↓BIGVEC)↑X
[67]   TVEC←ONEVEC+TWOVEC+THREEVEC+FOURVEC
[68]  L4:'  '
[69]   '  '
[70]   '*************************************************************************'
[71]   '*************************************************************************'
[72]   '  '
[73]   '                    F I N A L   A H P   D A T A'
[74]   '  '
[75]   '*************************************************************************'
[76]   '*************************************************************************'
[77]   '  '
[78]   '                HIERARCHICAL LEVEL: ',(BIGTITLE)
[79]   '  '
[80]   '                       NUMBER OF FACTORS:  ',(2 0 ⍕X)
[81]   '  '
[82]   '                STANDARDIZED_EIGENVECTOR_=_ALL_ELEMENTS'
[83]   '
[84]   (5 3 ⍕TVEC)
[85]   '  '
[86]   '          CHECK_=_SUM_OF_VECTOR_ELEMENTS_SHOULD_EQUAL_1.0'
[87]   '
[88]   '                              SUM = ',(6 4 ⍕(+/TVEC))
[89]   '  '
```

```
[90]  '*****************************************************************'
[91]  '  '
[92]  ⍝************************ END OF PROGRAM ******************************
[93]  →0
      ∇


[1]   ⍝*****************************************************************
[2]   ⍝
[3]   ⍝    FUNCTION:  AHPCHECK                    WORKSPACE:  AHP
[4]   ⍝
[5]   ⍝    PROGRAMMER:  STEVEN M. ANDERSON        DATE:  25 JAN 1987
[6]   ⍝
[7]   ⍝    PURPOSE:  THIS PROGRAM IS INTENDED PERFORM THE SAME TASKS AS THE
[8]   ⍝    MAIN PROGRAM AHP AND PROVIDE ADDITIONAL OUTPUT WHICH CAN BE USED
[9]   ⍝    BY THE PROGRAMMER TO CHECK BASIC COMPUTATIONS AND VECTOR
[10]  ⍝    MANIPULATIONS.
[11]  ⍝
[12]  ⍝*****************************************************************
[13]   '  WELCOME TO AHPCHECK.  THIS PROGRAM IS INTENDED TO CHECK THE BASIC'
[14]   'COMPUTATIONS INVOLVED IN THE MAIN AHP FUNCTION.  PLEASE BEGIN BY'
[15]   'STATING THE TITLE OF THE COMBINED FACTORS AT THIS HIERARCHICAL LEVEL:'
[16]   BIGTITLE←⎕
[17]   'PLEASE ENTER THE NUMBER OF FACTORS YOU WISH TO CALCULATE EIGENVECTORS'
[18]   'FOR AT THIS HIERARCHICAL LEVEL:'
[19]   X←⎕
[20]   BIGVEC←0
[21]   BIGVEC←1↓BIGVEC
[22]   ONEVEC←0
[23]   ONEVEC←1↓ONEVEC
[24]   TWOVEC←0
[25]   TWOVEC←1↓TWOVEC
[26]   THREEVEC←0
[27]   THREEVEC←1↓THREEVEC
[28]   TVEC←0
[29]   TVEC←1↓TVEC
[30]   A←0
[31]  L1:A←A+1
[32]   AHPSTAND
[33]   →(A<X)/L1
[34]   Z←(⍴BIGVEC)⍕X
[35]   ONEVEC←(Z↑BIGVEC)⍕X
[36]   →(X=3)/L2
```

```
[37]  TWOVEC←(Z↓BIGVEC)⌽X
[38]  TVEC←ONEVEC+TWOVEC
[39]  '  '
[40]  '=================================================================='
[41]  'Z'
[42]  Z
[43]  '++++++++++++++++++++++++++++ LOOP FOR 2 ++++++++++++++++'
[44]  'BIGVEC'
[45]  BIGVEC
[46]  'BIGVEC SUM:',(7 5 ⍕(+/BIGVEC))
[47]  '1VEC'
[48]  ONEVEC
[49]  'ONEVEC SUM:',(7 5 ⍕(+/ONEVEC))
[50]  '2VEC'
[51]  TWOVEC
[52]  'TWOVEC SUM:',(7 5 ⍕(+/TWOVEC))
[53]  'TVEC'
[54]  TVEC
[55]  'TVEC SUM:',(7 5 ⍕(+/TVEC))
[56]  →L3
[57] L2:'--------------------------  LOOP FOR 3 --------------------'
[58]  'BIGVEC BEFORE DROP'
[59]  BIGVEC
[60]  'BIGVEC SUM:',(7 5 ⍕(+/BIGVEC))
[61]  BIGVEC←Z↓BIGVEC
[62]  'BIGVEC NEW'
[63]  BIGVEC
[64]  'BIGVEC SUM NOW:',(7 5 ⍕(+/BIGVEC))
[65]  TWOVEC←(Z↑BIGVEC)⌽X
[66]  THREEVEC←(Z↓BIGVEC)⌽X
[67]  TVEC←ONEVEC+TWOVEC+THREEVEC
[68]  'ONEVEC'
[69]  ONEVEC
[70]  'ONEVEC SUM:',(7 5 ⍕(+/ONEVEC))
[71]  'TWOVEC'
[72]  TWOVEC
[73]  'TWOVEC SUM:',(7 5 ⍕(+/TWOVEC))
[74]  'THREEVEC'
[75]  THREEVEC
[76]  'THREEVEC SUM:',(7 5 ⍕(+/THREEVEC))
[77]  'TVEC'
[78]  TVEC
[79]  'TVEC SUM:',(7 5 ⍕(+/TVEC))
[80] L3:→0
```

```
[81] ⍝
[82] ⍝************************* END OF PROGRAM ******************************
      ∇


[1]  ⍝*********************************************************************
[2]  ⍝
[3]  ⍝   FUNCTION:  AHPBASE                    WORKSPACE:  AHP
[4]  ⍝
[5]  ⍝   PROGRAMMER:  STEVEN M. ANDERSON       DATE:  23 JAN 1987
[6]  ⍝
[7]  ⍝   PURPOSE:  THIS PROGRAM IS DESIGNED TO UTILIZE OTHER SUBROUTINES
[8]  ⍝   FOUND IN THIS WORKSPACE AND OBTAIN A STANDARDIZED EIGENVECTOR OF
[9]  ⍝   VALUES CONTAINED IN A SINGLE COMPARISON MATRIX.  THIS PROGRAM
[10] ⍝   ENABLES THE USER TO COMPARE MANY DIFFERENT ELEMENTS OR PROGRAMS
[11] ⍝   THAT ARE BEING COMPARED TO A SINGLE FACTOR.  ADDITIONALLY,
[12] ⍝   CRITICAL CONSISTENCY DATA IS CALCULATED CONCERNING THE QUALITY OF
[13] ⍝   DATA ENTERED IN THE INPUT COMPARISON MATRIX.  WHEN USED IN
[14] ⍝   CONJUCTION WITH AHP, THIS FUNCTION WILL CALCULATE DATA ON A STRING
[15] ⍝   OF MATRICES.
[16] ⍝
[17] ⍝*********************************************************************
[18]  '  '
[19]  '=================================================================='
[20]  '                          MATRIX NUMBER',(2 0 ⍕K)
[21]  '=================================================================='
[22]  '  '
[23]  'PLEASE ENTER THE GROUP NAME ASSOCIATED WITH THE ELEMENTS IN THIS'
[24]  'MATRIX (USE APOSTROPHES TO ENCLOSE):'
[25]  GROUP←⎕
[26]  'PLEASE ENTER THE NUMBER OF ELEMENTS BEING COMPARED IN THIS MATRIX:'
[27]  NUM←⎕
[28]  'PLEASE ENTER THE UPPER TRIANGULAR PART OF THE MATRIX:'
[29]  V←⎕
[30]  '  '
[31]  '            ----------------------------'
[32]  '            AHP DATA FOR MATRIX NUMBER',(2 0 ⍕K)
[33]  '            ----------------------------'
[34]  '  '
[35]  '            FACTOR:   ',(TITLE)
[36]  '  '
[37]  '            GROUP:    ',(GROUP)
[38]  RATIO←NUM÷TOTAL
```

```
[39]  R←0.5×1+(1+8×⍴V)*0.5
[40]  WEIGHTVEC←EIGENVECTOR R MATRIX V
[41]  STANDVEC←RATIO×WEIGHTVEC
[42]  ⍞⍞
[43]  ⍞WEIGHT EIGENVECTOR:  ⍞,(5 3 ⍕WEIGHTVEC)
[44]  ⍞⍞
[45]  ⍞STANDARDIZED WEIGHTS:⍞,(5 3 ⍕STANDVEC)
[46]  ⍝
[47]  ⍝************************ END OF PROGRAM ********************************
[48]  →0
      ∇


[1]   ⍝*********************************************************************
[2]   ⍝
[3]   ⍝   FUNCTION:  AHP                          WORKSPACE:  AHP
[4]   ⍝
[5]   ⍝   PROGRAMMER:  STEVEN M. ANDERSON         DATE:  24 JAN 1987
[6]   ⍝
[7]   ⍝   PURPOSE:  THIS PROGRAM IS DESIGNED TO UTILIZE OTHER SUBROUTINES
[8]   ⍝   FOUND IN THIS WORKSPACE AND OBTAIN A STANDARDIZED EIGENVECTOR OF
[9]   ⍝   VALUES BASED ON MORE THAN ONE COMPARISON MATRIX.  THIS FUNCTION
[10]  ⍝   ENABLES THE USER TO COMPARE MANY DIFFERENT ELEMENTS CONTAINED IN
[11]  ⍝   SEVERAL DIFFERENT MATRICES BY REPEATEDLY CALLING THE AHPBASE
[12]  ⍝   FUNCTION.
[13]  ⍝
[14]  ⍝*********************************************************************
[15]  ⍞⍞
[16]  ⍞⍞
[17]  ⍞*********************************************************************⍞
[18]  ⍞                          FACTOR NUMBER⍞,(2 0 ⍕A)
[19]  ⍞*********************************************************************⍞
[20]  ⍞⍞
[21]  ⍞PLEASE ENTER THE NAME OF THE FACTOR YOU NOW WISH TO ANALYZE:⍞
[22]  TITLE←⎕
[23]  ⍞NOW ENTER THE NUMBER OF MATRICES BEING COMPARED TO THIS FACTOR:⍞
[24]  N←⎕
[25]  ⍞NOW ENTER THE TOTAL NUMBER OF ELEMENTS THAT ARE BEING COMPARED TO THIS⍞
[26]  ⍞FACTOR.  FOR EXAMPLE, IF YOU HAVE 3 MATRICES WITH 5 ELEMENTS IN EACH⍞
[27]  ⍞MATRIX BEING COMPARED ON THE BASIS OF THE ABOVE-STATED FACTOR, THEN⍞
[28]  ⍞YOU WOULD ENTER 15 AT THIS TIME:⍞
[29]  TOTAL←⎕
[30]  TOTALVEC←0
```

```
[31]  TOTALVEC←1↓TOTALVEC
[32]  K←0
[33] L1:K←K+1
[34]  ⍝   ⍝
[35]  AHPBASE
[36]  TOTALVEC←TOTALVEC,STANDVEC
[37]  →(K<N)/L1
[38]  BIGVEC←BIGVEC,TOTALVEC
[39]  ⍝   ⍝
[40]  ⍝   ⍝
[41]  ⍝       ==================================================⍝
[42]  ⍝       EIGENVECTOR FOR ELEMENTS IN ALL MATRICES OF FACTOR',(2 0 ⍕A)
[43]  ⍝       ==================================================⍝
[44]  ⍝   ⍝
[45]  ⍝             HIERARCHICAL LEVEL: ',(BIGTITLE)
[46]  ⍝   ⍝
[47]  ⍝                  FACTOR: ',(TITLE)
[48]  ⍝   ⍝
[49]  ⍝EIGENVECTOR: ',(5 3 ⍕TOTALVEC)
[50]  ⍝  ⍝
[51]  ⍝         CHECK--SUM OF VECTORS ELEMENTS SHOULD EQUAL 1.0⍝
[52]  ⍝         ----------------------------------------------⍝
[53]  ⍝                        SUM = ',(6 4 ⍕(+/TOTALVEC))
[54]  ⍝       ==================================================⍝
[55]  →0
      ∇
```

```
[1]  ⍝*********************************************************************
[2]  ⍝
[3]  ⍝   FUNCTION:  EIGENVECTOR                  WORKSPACE:  AHP
[4]  ⍝
[5]  ⍝   PROGRAMMER:  STEVEN M. ANDERSON         DATE:  20 JAN 1987
[6]  ⍝
[7]  ⍝   PURPOSE:  THIS FUNCTION IS DESIGNED AS A SUBROUTINE OF THE MAIN
[8]  ⍝   AHP PROGRAM.  IT TAKES THE MATRIX FROM THE MATRIX FUNCTION AND
[9]  ⍝   PERFORMS THE CALCULATIONS INVOLVED IN THE AHP IN ORDER TO PRODUCE
[10] ⍝   AN EIGENVECTOR OF WEIGHTS CORRESPONDING TO THE PRIORITY OF THE
[11] ⍝   ELEMENTS BEING COMPARED.  ADDITIONALLY, THE CONSISTENCY CALCULATIONS
[12] ⍝   ARE MADE IN THIS SUBROUTINE.  THE PRINT STATEMENTS ASSOCIATED WITH
[13] ⍝   THIS DATA ARE ALSO CONTAINED IN THIS FUNCTION.
[14] ⍝
[15] ⍝*********************************************************************
```

```
[16]  B←A+(⍳P)∘.=⍳P←1↑⍴A
[17]  R←R÷+/(R←+/B)
[18] L:P←R
[19]  R←R÷+/(R←B+.×R)
[20]  →L×⍳1E¯15<+/|R-P
[21]  X←1↑(A+.×R)÷R
[22]  '  '
[23]  '              LAMBDA(MAXIMUM): ',(7 3 ⍕X)
[24]  D←((1↑(A+.×R)÷R)-1↑⍴A)÷(1↑⍴A)-1
[25]  '  '
[26]  '              CONSISTENCY INDEX: ',(5 3 ⍕D)
[27]  C←100⍴((0 0 0.58 0.9 1.12 1.24 1.32 1.41 1.45 1.49),(90⍴1.49))
[28]  '  '
[29]  '              CONSISTENCY RATIO: ',(5 3 ⍕(D÷C[⍴R]))
[30] ⍝
[31] ⍝************************* END OF PROGRAM ********************************
      ∇
```

```
[1]  ⍝*************************************************************************
[2]  ⍝
[3]  ⍝   FUNCTION:  INPUTHOW                    WORKSPACE:  AHP
[4]  ⍝
[5]  ⍝   PROGRAMMER:  STEVEN M. ANDERSON        DATE:  19 JAN 1987
[6]  ⍝
[7]  ⍝   PURPOSE:  THIS FUNCTION IS DESIGNED TO EXPLAIN AND DEMONSTATE THE
[8]  ⍝   PROPER WAY OF ENTERING MATRIX DATA INTO THE FUNCTIONS CONTAINED IN
[9]  ⍝   THIS WORKSPACE.
[10] ⍝
[11] ⍝*************************************************************************
[12]  '  WELCOME TO INPUTHOW, A FUNCTION DESIGNED TO SHOW YOU HOW TO INPUT'
[13]  'MATRIX DATA INTO THE OTHER FUNCTIONS CONTAINED IN THIS WORKSPACE.'
[14]  'SHOWN BELOW IS AN EXAMPLE 5×5 MATRIX:'
[15]  '  '
[16]  '                                A     B     C     D     E'
[17]  '                              ------------------------------'
[18]  '                          A  |  1    1/4    3     2    1/3'
[19]  '                          B  |  4     1     1    1/3    5 '
[20]  '                          C  |  1/3   1     1     7    1/4'
[21]  '                          D  |  1/2   3    1/7    1     3 '
[22]  '                          E  |  3    1/5    4    1/3    1 '
[23]  '  '
[24]  'THE ACTUAL DATA THAT IS ENTERED IS ONLY THE UPPER TRIANGULAR PART OF'
```

```
[25]   'THE MATRIX, SINCE THE REST OF THE DATA IS REDUNDANT.  THEREFORE, WE'
[26]   'ARE ONLY CONCERNED WITH THE NUMBERS ABOVE AND TO THE RIGHT OF THE'
[27]   'MATRIX DIAGONAL.'
[28]   '   FIRST, ALL FRACTIONS/RECIPROCALS ARE ENTERED AS NEGATIVE NUMBERS.'
[29]   'THEREFORE, 1/4 IS ENTERED AS  ¯4.'
[30]   '   NEXT, DATA IS ENTERED BY MOVING LEFT TO RIGHT, COLUMN BY COLUMN.'
[31]   'ONCE IN A COLUMN, DATA IS ENTERED FROM THE TOP DOWN.'
[32]   '   THEREFORE, THE STRING OF NUMBERS THAT WOULD BE ENTERED IN THE ABOVE'
[33]   'EXAMPLE IS AS FOLLOWS:'
[34]   '  '
[35]   '                SOLUTION:  ¯4 3 1 2 ¯3 7 ¯3 5 ¯4 3 '
[36]   '  '
[37]   '   THATS ALL THERE IS TO IT......GOOD LUCK.......'
[38]  ⍝
[39]  ⍝************************ END OF PROGRAM ******************************
[40]   →0
       ∇
```

```
[1]   ⍝*********************************************************************
[2]   ⍝
[3]   ⍝    FUNCTION:  MATRIX                        WORKSPACE:  AHP
[4]   ⍝
[5]   ⍝    PROGRAMMER:  STEVEN M. ANDERSON          DATE:  20 JAN 1987
[6]   ⍝
[7]   ⍝    PURPOSE:  THIS PROGRAM IS DESIGNED AS A SUBROUTINE TO THE AHP AND
[8]   ⍝    SINGLE FUNCTIONS.  IT TAKES THE INPUT COMPARISON MATRIX VALUES AND
[9]   ⍝    MANIPULATES THEM INTO A FORM THAT CAN BE USED BY THE EIGENVECTOR
[10]  ⍝    FUNCTION, AS WELL AS PRINT THE COMPARISON MATRIX SO THAT A VISUAL
[11]  ⍝    CHECK CAN BE MADE BY THE USER THAT THE CORRECT DATA HAS BEEN ENTERED.
[12]  ⍝
[13]  ⍝*********************************************************************
[14]   A←(N,N)⍴0
[15]   A[1;1]←1
[16]   K←0
[17]   I←1
[18]   V←((V>0)×V)-(V<0)⍟V
[19]  L1:A[⍳J;I]←1⍟A[I;⍳J]←V[K+⍳J←I-1]
[20]   K←K+J
[21]   A[I;I]←1
[22]   →(N≥I←I+1)/L1
[23]   A←⍉A
[24]   '  '
```

```
[25]  '                    COMPARISON MATRIX'
[26]  '                    -----------------'
[27]   8 3 ⍕A
[28] ⍝
[29] ⍝************************ END OF PROGRAM ********************************
      ∇


[1]  ⍝*********************************************************************
[2]  ⍝
[3]  ⍝   FUNCTION:  SINGLE                          WORKSPACE:  AHP
[4]  ⍝
[5]  ⍝   PROGRAMMER:  STEVEN M. ANDERSON            DATE:  22 JAN 1987
[6]  ⍝
[7]  ⍝   PURPOSE:  THIS PROGRAM IS INTENDED TO PERFORM THE SAME FUNCTION
[8]  ⍝   AS THE MAIN AHP FUNCTION FOR USERS WITH ONLY ONE COMPARISON MATRIX
[9]  ⍝   TO ANALYZE.  THE LENGTHLY INTRODUCTION CONTAINED IN AHP IS NOT USED
[10] ⍝   IN THIS PROGRAM, AS USER FAMILIARITY WITH THE AHP PROGRAM IS ASSUMED.
[11] ⍝
[12] ⍝*********************************************************************
[13]  'ENTER THE UPPER TRIANGULAR PART OF THE MATRIX PLEASE:'
[14]  V←⎕
[15]  R←0.5×1+(1+8×⍴V)*0.5
[16]  WEIGHTVEC←EIGENVECTOR R MATRIX V
[17]  ' '
[18]  'WEIGHT EIGENVECTOR: ',(5 3 ⍕WEIGHTVEC)
[19] ⍝
[20] ⍝************************ END OF PROGRAM ********************************
      ∇
```

APPENDIX E

GOAL PROGRAMMING SOFTWARE SUPPORT

This appendix includes a discussion of the software that was used and developed in order to determine the optimal funding level for each of the major project in the SDI program being studied.

The final steps in the GP model solution process entailed finding and using a suitable optimizing program. Several excellent linear and non-linear programming packages are available, such as the Linear Interactive Discrete Optimizer (LINDO) [Ref. 39] or the General Interactive Optimizer (GINO) [Ref. 40]. Both programs are simple and can be used on an IBM PC, but they lack the tremendous power and flexibility of the recently developed General Algebraic Modelling System (GAMS) [Ref. 41].

GAMS was written by Brooke, Drud, and Meeraus of the Development Research Department, World Bank. It is the first optimizing program that uses the special mathematical notation called the Backus-Nauer Form (BNF). This notation enables the user to write constraint equations in a more generalized and compact style than other packages. GAMS also has the capability to handle nonlinear and integer programming problems. Additionally, since program coding is very terse, changes are extremely easy to make, an advantage that will be exploited in the next chapter. Dr. Richard Rosenthal of the Naval Postgraduate School has referred to GAMS as "perhaps the most significant development in the field of operations research in the last five years" [Ref. 42].

A GAMS program was written (see Appendix E) based on the GP model of the major projects of the USASDC.

For the reader unfamiliar with GAMS procedures, a short discussion of this program is appropriate. The SET command establishes a set i, consisting of the WPD numbers of the thirty-five projects being modelled. There are six PARAMETER statements; the numerical value of the minimum and maximum funding level, as well as the payoff, risk, time, and balance weight value of each project are entered as parameters. SCALARS include the total budget available, based on the funding strategy, and the weight coefficients for the four deviation variables. The decision variable, Xi, representing the money to be spent on the ith project in FY 88, is listed under the VARIABLES command. Also displayed here are all eight deviation variables and the achievement function variables. The POSITIVE VARIABLES command ensures non-negativity of all listed variables. The coding under the EQUATIONS command is in BNF format but includes all the system and goal constraints of the GP model. COST refers to the budget constraint that cannot be exceeded. PAYOFF, RISK, TIME, and BALANCE each represent a goal constraint. OBJDEF is the achievement function. The minimum and maximum funding constraints are singleton equations and are listed as upper and lower bounds below the EQUATIONS section of the program. The final part of the coding refers to formatting and output.

This concluded the data collection and software development process. With AHP and GP model properly supported, all that remained was to actually run the model and analyze the results.

```
*****************************************************************
*                                                               *
*   G A M S   G O A L   P R O G R A M   F O R M U L A T I O N   *
*                                                               *
*****************************************************************
$TITLE                    GP THESIS - ANDERSON
$OFFUPPER
$OFFSYMLIST OFFSYMXREF

SET  I   thirty-five major USASDC projects in five program elements

        /B122,B142,B412,B532,B612,L008,L212,L503,L721,L723,
         D044,D076,D080,D047,D112,D114,D083,K222,K623,K624,
         K225,K323,K325,K524,K321,S271,S051,S011,S052,S053,
         S243,S402,S091,S102,S281/;

PARAMETER  MIN(I)  min funding level for each project - Mdollars

                     /B122    6
                      B142    2
                      B412    9
                      B532   30
                      B612    2
                      L008    5
                      L212    2
                      L503    5
                      L721    2
                      L723    2
                      D044    1
                      D076   50
                      D080    5
                      D047   15
                      D112    1
                      D114    6
                      D083   12
                      K222   40
                      K623    5
                      K624   10
                      K225    6
                      K323    3
                      K325    4
                      K524    4
                      K321   35
                      S271   25
                      S051   15
                      S011    3
                      S052   15
                      S053    3
                      S243    3
                      S402    3
                      S091    5
                      S102    2
                      S281   12/;

PARAMETER  MAX(I)  max reqd money in each program - Mdollars

                     /B122   37
                      B142   15
                      B412   28
                      B532   95
                      B612   25
                      L008   30
                      L212   12
                      L503   24
                      L721   12
                      L723   10
                      D044   15
```

```
D076  260
D080   25
D047   55
D112    8
D114   20
D083   80
K222  187
K623   28
K624   45
K225   20
K323   50
K325   25
K524   25
K321  204
S271  105
S051   20.5
S011   13.3
S052   31
S053   19.2
S243   15
S402   35
S091   35.5
S102   20
S281  159.4/;
```

PARAMETER CORE(I) funds for each program i for core strategy - Mdollars

```
/B122      20
 B142       6.2
 B412       8.1
 B532      30
 B612       7
 L008      14.6
 L212       3.7
 L503       8.5
 L721       4.8
 L723       4
 D044       5
 D076     158
 D080       5
 D047      34.4
 D112       3
 D114      12
 D083      55
 K222     150
 K623      24
 K624      38
 K225       6
 K323       3
 K325       5
 K524      12
 K321      58
 S271      82.3
 S051      16.4
 S011      10.7
 S052      22.2
 S053       7.3
 S243       9.8
 S402      15.4
 S091      13.1
 S102      10
 S281      20.1/;
```

```
PARAMETER BASIC(I)  funds for each program i for basic strategy - Mdollars

                    /B122      20
                     B142       6.2
                     B412      10
                     B532      38.5
                     B612       7
                     L008      16
                     L212       3.9
                     L503       9
                     L721       5.1
                     L723       4.3
                     D044       5
                     D076     170.6
                     D080       5
                     D047      34.4
                     D112       7
                     D114      12
                     D083      61
                     K222     150
                     K623      24
                     K624      38
                     K225       8
                     K323       5
                     K325       5
                     K524      12
                     K321     129
                     S271      95
                     S051      16.4
                     S011      10.7
                     S052      22.2
                     S053       7.3
                     S243       9.8
                     S402      15.4
                     S091      15.3
                     S102      11.7
                     S281      39.3/;

PARAMETER ENHANCED(I)  funds for each program i for enhanced strategy

                    /B122      24.5
                     B142       7.7
                     B412      10
                     B532      51.1
                     B612      12.9
                     L008      18
                     L212       4.2
                     L503      10
                     L721       5.6
                     L723       4.8
                     D044       8
                     D076     186.5
                     D080       5
                     D047      37.4
                     D112       7
                     D114      12
                     D083      61
                     K222     177
                     K623      24
                     K624      38
                     K225      16.6
                     K323      25
                     K325       5
                     K524      14
                     K321     194
                     S271      95
                     S051      16.4
```

```
                    S011        10.7
                    S052        22.2
                    S053         8.8
                    S243        12
                    S402        15.4
                    S091        18.6
                    S102        14.2
                    S281        82.8/;

PARAMETER EXTENDED(I)  funds for each program i for extended strategy

                   /B122        27.1
                    B142         7.7
                    B412        12.4
                    B532        59.9
                    B612        15.1
                    L008        19.8
                    L212         4.5
                    L503        10.6
                    L721         6
                    L723         5.2
                    D044         8
                    D076       211.9
                    D080         5
                    D047        37.4
                    D112         7
                    D114        12
                    D083        61
                    K222       177
                    K623        24
                    K624        38
                    K225        16.6
                    K323        43
                    K325        18.4
                    K524        20
                    K321       194
                    S271        95
                    S051        18.9
                    S011        12.3
                    S052        25.6
                    S053        10.2
                    S243        13.8
                    S402        15.4
                    S091        21.5
                    S102        16.4
                    S281       112.7/;

PARAMETER  P(I) payoff weight factor for each program as determined by AHP

                   /B122  .024
                    B142  .048
                    B412  .020
                    B532  .044
                    B612  .006
                    L008  .030
                    L212  .032
                    L503  .037
                    L721  .022
                    L723  .022
                    D044  .060
                    D076  .060
                    D080  .015
                    D047  .032
                    D112  .005
                    D114  .004
                    D083  .024
                    K222  .067
```

```
K623  .005
K624  .024
K225  .027
K323  .027
K325  .027
K524  .007
K321  .045
S271  .045
S051  .023
S011  .020
S052  .025
S053  .030
S243  .049
S402  .019
S091  .036
S102  .020
S281  .018/;
```

PARAMETER R(I) risk weight factor for each program as determined by AHP

```
/B122  .048
 B142  .007
 B412  .048
 B532  .007
 B612  .033
 L008  .028
 L212  .028
 L503  .041
 L721  .023
 L723  .023
 D044  .009
 D076  .009
 D080  .029
 D047  .010
 D112  .064
 D114  .075
 D083  .005
 K222  .013
 K623  .082
 K624  .026
 K225  .011
 K323  .011
 K325  .010
 K524  .066
 K321  .010
 S271  .019
 S051  .040
 S011  .104
 S052  .034
 S053  .012
 S243  .007
 S402  .020
 S091  .011
 S102  .018
 S281  .022/;
```

PARAMETER T(I) time weight factor for each project as determined by AHP

```
/B122  .049
 B142  .006
 B412  .049
 B532  .006
 B612  .033
 L008  .035
 L212  .035
 L503  .028
 L721  .023
```

```
L723  .023
D044  .007
D076  .015
D080  .035
D047  .008
D112  .065
D114  .065
D083  .004
K222  .021
K623  .021
K624  .049
K225  .031
K323  .031
K325  .031
K524  .025
K321  .018
S271  .019
S051  .027
S011  .081
S052  .027
S053  .011
S243  .008
S402  .033
S091  .016
S102  .032
S281  .031/;
```

PARAMETER B(I) balance weight factor for each program determined by AHP

```
/B122  .025
 B142  .025
 B412  .027
 B532  .033
 B612  .033
 L008  .029
 L212  .029
 L503  .029
 L721  .029
 L723  .029
 D044  .030
 D076  .027
 D080  .027
 D047  .027
 D112  .030
 D114  .030
 D083  .027
 K222  .036
 K623  .036
 K624  .021
 K225  .021
 K323  .021
 K325  .021
 K524  .036
 K321  .036
 S271  .033
 S051  .030
 S011  .030
 S052  .030
 S053  .028
 S243  .024
 S402  .024
 S091  .034
 S102  .028
 S281  .024/;
```

```
SCALARS  BUDGET   total budget (CORE) in FY 88  Mdollars     /882.6/
         WTPNEG   weight of payoff neg deviation in OBJDEF  /.250/
         WTRPOS   weight of risk pos deviation in OBJDEF    /.250/
         WTTPOS   weight of time pos deviation in OBJDEF    /.250/
         WTBNEG   weight of balance neg deviation in OBJDEF /.250/;

VARIABLES
   X(I)        money to be spend in each program during FY88
   PPOS        positive deviation from the payoff goal constraint
   PNEG        negative deviation from the payoff goal constraint
   RPOS        positive deviation from the risk goal constraint
   RNEG        negative deviation from the risk goal constraint
   TPOS        positive deviation from the time goal constraint
   TNEG        negative deviation from the time goal constraint
   BPOS        positive deviation from the balance goal constraint
   BNEG        negative deviation from the balance goal constraint
   DEVIATION   deviation from the objective function;

POSITIVE VARIABLES  X, PPOS, PNEG, RPOS, RNEG, TPOS, TNEG, BPOS, BNEG;

EQUATIONS   COST        cost of programs cannot exceed the budget
            PAYOFF      goal number 1 - maximize payoff
            RISK        goal number 2 - minimize risk
            TIME        goal number 3 - minimize time
            BALANCE     goal number 4 - maximize balance
            OBJDEF      achievement function;

  COST..        SUM (I, X(I))  =L=  BUDGET;

  PAYOFF..      SUM (I, X(I) * P(I)) - PPOS + PNEG
                                      =E=  SUM (I, P(I) * MAX(I));

  RISK..        SUM (I, X(I) * R(I)) - RPOS + RNEG
                                      =E=  SUM (I, R(I) * MIN(I));

  TIME..        SUM (I, X(I) * T(I)) - TPOS + TNEG
                                      =E=  SUM (I, T(I) * MIN(I));

  BALANCE..     SUM (I, X(I) * B(I)) - BPOS + BNEG
                                      =E=  SUM (I, B(I) * MAX(I));

  OBJDEF..      (WTPNEG * PNEG) + (WTRPOS * RPOS) +
                (WTTPOS * TPOS) + (WTBNEG * BNEG)  =E=  DEVIATION;

*  additional constraints involving max and min funding levels

                X.LO(I)  =  MIN(I);

                X.UP(I)  =  MAX(I);

MODEL  GP /ALL/;

SOLVE GP USING LP MINIMIZING DEVIATION;
```

```
PARAMETER REPORT1 (I,*)  comperision of optima with funding level;
        REPORT1 (I, 'MINIMUM')  =  MIN(I);
        REPORT1 (I, 'OPTIMUM')  =  X.L(I);
        REPORT1 (I, 'CORE') =  CORE(I);
        REPORT1 (I, 'DIFF')  =  X.L(I) - CORE(I);
        REPORT1 (I, '% DIFF')  =  (X.L(I) - CORE(I))/(X.L(I));
        REPORT1 (I, 'MAXIMUM')  =  MAX(I);
PARAMETER REPORT2 (*) listing of goal constraint RHS targets;
        REPORT2 ('TARGET 1') = SUM (I, P(I) * MAX(I));
        REPORT2 ('TARGET 2') = SUM (I, R(I) * MIN(I));
        REPORT2 ('TARGET 3') = SUM (I, T(I) * MIN(I));
        REPORT2 ('TARGET 4') = SUM (I, B(I) * MAX(I));
PARAMETER REPORT3 (*) least squares and average deviation figures;
        REPORT3 ('LST SQRS')  = SUM (I,SQR(X.L(I) - CORE(I)));
        REPORT3 ('AVE DEV') = (SUM (I,((X.L(I)-CORE(I))/(X.L(I)))))/35;
PARAMETER REPORT4 (*) total budget check;
        REPORT4 ('TOTAL BGT') = SUM (I,X.L(I))
DISPLAY REPORT4;
DISPLAY REPORT1;
DISPLAY REPORT2;
DISPLAY REPORT3;
```

APPENDIX F

AHP OUTPUT

The APL workspace discussed in Chapter VI and shown in Appendix F was used to determine the coefficients for the goal constraint equations in the main GP program. The AHP program in the workspace was run four different times to calculate payoff, risk, time, and balance weights for each project. In the interest of brevity, only the comparison matrices, consistency ratio information, and eigenvectors from the payoff factor output are displayed on the following pages.

AHP DATA FOR MATRIX NUMBER 1

FACTOR: POTENTIAL CONTRIBUTION TO SDI
GROUP: SABM PROJECTS

COMPARISON MATRIX

1.000	1.000	2.000	1.000	5.000
1.000	1.000	2.000	1.000	5.000
.500	.500	1.000	1.000	5.000
1.000	1.000	1.000	1.000	5.000
.200	.200	.200	.200	1.000

LAMBDA(MAXIMUM): 5.078
CONSISTENCY INDEX: .019
CONSISTENCY RATIO: .017

WEIGHT EIGENVECTOR: .269 .269 .181 .234 .047
STANDARDIZED WEIGHTS: .038 .038 .026 .033 .007

AHP DATA FOR MATRIX NUMBER 2

FACTOR: POTENTIAL CONTRIBUTION TO SDI
GROUP: SLKT PROJECTS

COMPARISON MATRIX

1.000	1.000	1.000	3.000	3.000
1.000	1.000	1.000	3.000	3.000
1.000	1.000	1.000	3.000	3.000
.333	.333	.333	1.000	1.000
.333	.333	.333	1.000	1.000

LAMBDA(MAXIMUM): 5.000
CONSISTENCY INDEX: .000
CONSISTENCY RATIO: .000

WEIGHT EIGENVECTOR: .273 .273 .273 .091 .091
STANDARDIZED WEIGHTS: .039 .039 .039 .013 .013

AHP DATA FOR MATRIX NUMBER 3

FACTOR: POTENTIAL CONTRIBUTION TO SDI
GROUP: DEW PROJECTS

COMPARISON MATRIX

1.000	1.000	7.000	3.000	8.000	9.000	3.000
1.000	1.000	7.000	3.000	8.000	9.000	3.000
.143	.143	1.000	.250	5.000	6.000	.250
.333	.333	4.000	1.000	5.000	6.000	1.000
.125	.125	.200	.200	1.000	4.000	.143
.111	.111	.167	.167	.250	1.000	.111
.333	.333	4.000	1.000	7.000	9.000	1.000

LAMBDA(MAXIMUM): 7.648
CONSISTENCY INDEX: .108
CONSISTENCY RATIO: .082

WEIGHT EIGENVECTOR: .303 .303 .064 .132 .032 .019 .148
STANDARDIZED WEIGHTS: .061 .061 .013 .026 .006 .004 .030

AHP DATA FOR MATRIX NUMBER 4

FACTOR: POTENTIAL CONTRIBUTION TO SDI
GROUP: KEW PROJECTS

COMPARISON MATRIX

1.000	9.000	9.000	3.000	3.000	3.000	5.000	1.000
.111	1.000	.333	.143	.143	.143	.200	.111
.111	3.000	1.000	1.000	1.000	1.000	5.000	.333
.333	7.000	1.000	1.000	1.000	1.000	5.000	.333
.333	7.000	1.000	1.000	1.000	1.000	5.000	3.00
.333	7.000	1.000	1.000	1.000	1.000	5.000	.333
.200	5.000	.200	.200	.200	.200	1.000	.200
1.000	9.000	3.000	3.000	3.000	3.000	5.000	1.000

LAMBDA(MAXIMUM): 8.628
CONSISTENCY INDEX: .090
CONSISTENCY RATIO: .064

WEIGHT EIGENVECTOR: .303 .019 .087 .104 .104 .104 .037 .243
STANDARDIZED WEIGHTS: .069 .004 .020 .024 .024 .024 .008 .055

AHP DATA FOR MATRIX NUMBER 5

FACTOR: POTENTIAL CONTRIBUTION TO SDI
GROUP: SATKA PROJECTS

COMPARISON MATRIX

1.000	3.000	3.000	3.000	3.000	2.000	3.000	3.000	4.000	3.00
.333	1.000	1.000	1.000	1.000	.333	2.000	1.000	2.000	3.00
.333	1.000	1.000	1.000	3.000	.333	2.000	3.000	3.000	3.00
.333	1.000	1.000	1.000	2.000	.333	2.000	.500	2.000	2.00
.333	1.000	.333	.500	1.000	.333	1.000	1.000	3.000	2.00
.500	3.000	3.000	3.000	3.000	1.000	4.000	2.000	3.000	4.00
.333	.500	.500	.500	1.000	.250	1.000	.500	2.000	1.00
.333	1.000	.333	2.000	1.000	.500	2.000	1.000	2.000	2.00
.250	.500	.333	.500	.333	.333	.500	.500	1.000	.33
.333	.333	.333	.500	.500	.250	1.000	.500	3.000	1.00

LAMBDA(MAXIMUM): 10.578
CONSISTENCY INDEX: .064
CONSISTENCY RATIO: .043

WEIGHT EIGENVECTOR: .226 .086 .118 .084 .068 .195 .052 .085 .037 .049
STANDARDIZED WEIGHTS: .065 .025 .034 .024 .020 .056 .015 .024 .011 .014

```
=================================================
EIGENVECTOR FOR ELEMENTS IN ALL MATRICES OF FACTOR 1
=================================================

              HIERARCHICAL LEVEL: PAYOFF
          FACTOR: POTENTIAL CONTRIBUTION TO SDI

EIGENVECTOR:  .038 .038 .026 .033 .007 .039 .039 .039 .013 .013 .061 .061 .013
      .026 .006 .004 .030 .069 .004 .020 .024 .024 .024 .008 .055 .065 .025 .03
      4 .024 .020 .056 .015 .024 .011 .014

         CHECK--SUM OF VECTORS ELEMENTS SHOULD EQUAL 1.0
         -----------------------------------------------
                          SUM = 1.0000
=================================================


         ----------------------------
         AHP DATA FOR MATRIX NUMBER 1
         ----------------------------

FACTOR:  POTENTIAL CONTRIBUTION TO FSED DECISION
            GROUP:   SABM PROJECTS

              COMPARISON MATRIX
              -----------------
   1.000    .333   1.000    .333   5.000
   3.000   1.000   5.000   1.000   5.000
   1.000    .200   1.000    .333   5.000
   3.000   1.000   3.000   1.000   5.000
    .200    .200    .200    .200   1.000

           LAMBDA(MAXIMUM):   5.278
           CONSISTENCY INDEX:  .070
           CONSISTENCY RATIO:  .062

WEIGHT EIGENVECTOR:   .136 .371 .126 .323 .045
STANDARDIZED WEIGHTS: .019 .053 .018 .046 .006


         ----------------------------
         AHP DATA FOR MATRIX NUMBER 2
         ----------------------------

 FACTOR:  POTENTIAL CONTRIBUTION TO FSED DECISION
         GROUP:   SLKT PROJECTS

              COMPARISON MATRIX
              -----------------
   1.000   1.000   1.000   3.000   3.000
   1.000   1.000   1.000   3.000   3.000
   1.000   1.000   1.000   3.000   3.000
    .333    .333    .333   1.000   1.000
    .333    .333    .333   1.000   1.000

           LAMBDA(MAXIMUM):   5.000
           CONSISTENCY INDEX:  .000
           CONSISTENCY RATIO:  .000

WEIGHT EIGENVECTOR:   .273 .273 .273 .091 .091
STANDARDIZED WEIGHTS: .039 .039 .039 .013 .013
```

AHP DATA FOR MATRIX NUMBER 3

FACTOR: POTENTIAL CONTRIBUTION TO FSED DECISION
GROUP: DEW PROJECTS

COMPARISON MATRIX

1.000	1.000	7.000	3.000	9.000	9.000	3.000
1.000	1.000	7.000	3.000	9.000	9.000	3.000
.143	.143	1.000	.250	6.000	6.000	.250
.333	.333	4.000	1.000	8.000	8.000	1.000
.111	.111	.167	.125	1.000	3.000	.111
.111	.111	.167	.125	.333	1.000	.125
.333	.333	4.000	1.000	9.000	8.000	1.000

LAMBDA(MAXIMUM): 7.638
CONSISTENCY INDEX: .106
CONSISTENCY RATIO: .081

WEIGHT EIGENVECTOR: .302 .302 .063 .143 .025 .018 .146
STANDARDIZED WEIGHTS: .060 .060 .013 .029 .005 .004 .029

AHP DATA FOR MATRIX NUMBER 4

FACTOR: POTENTIAL CONTRIBUTION TO FSED DECISION
GROUP: KEW PROJECTS

COMPARISON MATRIX

1.000	9.000	9.000	3.000	3.000	3.000	5.000	1.000
.111	1.000	.333	.143	.143	.143	.200	.111
.111	3.000	1.000	1.000	1.000	1.000	5.000	1.000
.333	7.000	1.000	1.000	1.000	1.000	5.000	1.000
.333	7.000	1.000	1.000	1.000	1.000	5.000	1.000
.333	7.000	1.000	1.000	1.000	1.000	5.000	1.000
.200	5.000	.200	.200	.200	.200	1.000	.200
1.000	9.000	1.000	1.000	1.000	1.000	5.000	1.000

LAMBDA(MAXIMUM): 8.665
CONSISTENCY INDEX: .095
CONSISTENCY RATIO: .067

WEIGHT EIGENVECTOR: .329 .019 .103 .120 .120 .120 .037 .150
STANDARDIZED WEIGHTS: .075 .004 .024 .028 .028 .028 .008 .034

AHP DATA FOR MATRIX NUMBER 5

FACTOR: POTENTIAL CONTRIBUTION TO FSED DECISION
GROUP: SATKA PROJECTS

COMPARISON MATRIX

1.000	3.000	3.000	3.000	3.000	1.000	3.000	3.000	3.000	2.00
.333	1.000	2.000	1.000	2.000	.500	2.000	1.000	2.000	2.00
.333	.500	1.000	.333	.500	.250	.500	.500	2.000	2.00
.333	1.000	3.000	1.000	2.000	.333	2.000	.500	2.000	2.00
.333	.500	2.000	.500	1.000	.500	1.000	1.000	2.000	1.00
1.000	2.000	4.000	3.000	2.000	1.000	3.000	2.000	3.000	2.00
.333	.500	2.000	.500	1.000	.333	1.000	.500	2.000	1.00
.333	1.000	2.000	2.000	1.000	.500	2.000	1.000	2.000	.50
.333	.500	.500	.500	.500	.333	.500	.500	1.000	.33
.500	.500	.500	.500	1.000	.500	1.000	2.000	3.000	1.00

LAMBDA(MAXIMUM): 10.633
CONSISTENCY INDEX: .070
CONSISTENCY RATIO: .047

WEIGHT EIGENVECTOR: .202 .103 .058 .101 .073 .182 .065 .094 .042 .080
STANDARDIZED WEIGHTS: .058 .029 .017 .029 .021 .052 .019 .027 .012 .023

==========
EIGENVECTOR FOR ELEMENTS IN ALL MATRICES OF FACTOR 2
==========

HIERARCHICAL LEVEL: PAYOFF
FACTOR: POTENTIAL CONTRIBUTION TO FSED DECISION

EIGENVECTOR: .019 .053 .018 .046 .006 .039 .039 .039 .013 .013 .060 .060 .013 .029 .005 .004 .029 .075 .004 .024 .028 .028 .028 .008 .034 .058 .029 .017 .029 .021 .052 .019 .027 .012 .023

CHECK--SUM OF VECTORS ELEMENTS SHOULD EQUAL 1.0

SUM = 1.0000
==========

AHP DATA FOR MATRIX NUMBER 1

FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY
GROUP: SABM PROJECTS

COMPARISON MATRIX

1.000	.200	1.000	.200	5.000
5.000	1.000	5.000	1.000	5.000
1.000	.200	1.000	.200	5.000
5.000	1.000	5.000	1.000	5.000
.200	.200	.200	.200	1.000

LAMBDA(MAXIMUM): 5.434
CONSISTENCY INDEX: .108
CONSISTENCY RATIO: .097

WEIGHT EIGENVECTOR: .106 .372 .106 .372 .043
STANDARDIZED WEIGHTS: .015 .053 .015 .053 .006

AHP DATA FOR MATRIX NUMBER 2

FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY
GROUP: SLKT PROJECTS

COMPARISON MATRIX

1.000	1.000	.333	.333	.333
1.000	1.000	1.000	.333	.333
3.000	1.000	1.000	1.000	1.000
3.000	3.000	1.000	1.000	1.000
3.000	3.000	1.000	1.000	1.000

LAMBDA(MAXIMUM): 5.151
CONSISTENCY INDEX: .038
CONSISTENCY RATIO: .034

WEIGHT EIGENVECTOR: .093 .122 .230 .278 .278
STANDARDIZED WEIGHTS: .013 .017 .033 .040 .040

AHP DATA FOR MATRIX NUMBER 3

FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY
GROUP: DEW PROJECTS

COMPARISON MATRIX

1.000	1.000	3.000	2.000	9.000	9.000	6.000
1.000	1.000	3.000	2.000	9.000	9.000	6.000
.333	.333	1.000	.333	4.000	4.000	2.000
.500	.500	3.000	1.000	9.000	9.000	4.000
.111	.111	.250	.111	1.000	1.000	.200
.111	.111	.250	.111	1.000	1.000	.200
.167	.167	.500	.250	5.000	5.000	1.000

LAMBDA(MAXIMUM): 7.260
CONSISTENCY INDEX: .043
CONSISTENCY RATIO: .033

WEIGHT EIGENVECTOR: .292 .292 .095 .205 .024 .024 .069
STANDARDIZED WEIGHTS: .058 .058 .019 .041 .005 .005 .014

AHP DATA FOR MATRIX NUMBER 4

FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY
GROUP: KEW PROJECTS

COMPARISON MATRIX

1.000	9.000	1.000	3.000	3.000	3.000	9.000	1.000
.111	1.000	.111	.250	.250	.250	1.000	.111
1.000	9.000	1.000	1.000	1.000	1.000	3.000	.250
.333	4.000	1.000	1.000	1.000	1.000	9.000	1.000
.333	4.000	1.000	1.000	1.000	1.000	9.000	1.000
.333	4.000	1.000	1.000	1.000	1.000	9.000	1.000
.111	1.000	.333	.111	.111	.111	1.000	.111
1.000	9.000	4.000	1.000	1.000	1.000	9.000	1.000

LAMBDA(MAXIMUM): 8.536
CONSISTENCY INDEX: .077
CONSISTENCY RATIO: .054

WEIGHT EIGENVECTOR: .248 .024 .127 .126 .126 .126 .021 .204
STANDARDIZED WEIGHTS: .057 .005 .029 .029 .029 .029 .005 .047

AHP DATA FOR MATRIX NUMBER 5

FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY
GROUP: SATKA PROJECTS

COMPARISON MATRIX

1.000	1.000	1.000	.500	.333	.333	.500	.333	.500	1.00
1.000	1.000	1.000	1.000	.333	.250	.500	.333	.500	.50
1.000	1.000	1.000	.250	.250	.200	.500	.200	.333	.50
2.000	1.000	4.000	1.000	.500	.333	.500	.500	.500	2.00
3.000	3.000	4.000	2.000	1.000	2.000	3.000	.500	2.000	3.00
3.000	4.000	5.000	3.000	.500	1.000	2.000	.500	.500	3.00
2.000	2.000	2.000	2.000	.333	.500	1.000	.333	.500	1.00
3.000	3.000	5.000	2.000	2.000	2.000	3.000	1.000	2.000	3.00
2.000	2.000	3.000	2.000	.500	2.000	2.000	.500	1.000	3.00
1.000	2.000	2.000	.500	.333	.333	1.000	.333	.333	1.00

LAMBDA(MAXIMUM): 10.494
CONSISTENCY INDEX: .055
CONSISTENCY RATIO: .037

WEIGHT EIGENVECTOR: .049 .048 .036 .079 .174 .141 .078 .204 .133 .058

STANDARDIZED WEIGHTS: .014 .014 .010 .022 .050 .040 .022 .058 .038 .017

==========
EIGENVECTOR FOR ELEMENTS IN ALL MATRICES OF FACTOR 3
==========

HIERARCHICAL LEVEL: PAYOFF
FACTOR: POTENTIAL GENERATION OF SPINOFF TECHNOLOGY

EIGENVECTOR: .015 .053 .015 .053 .006 .013 .017 .033 .040 .040 .058 .058 .019 .041 .005 .005 .014 .057 .005 .029 .029 .029 .029 .005 .047 .014 .014 .010 .022 .050 .040 .022 .058 .038 .017

CHECK--SUM OF VECTORS ELEMENTS SHOULD EQUAL 1.0

SUM = 1.0000
==========

```
*****************************************************************
*****************************************************************
                    F I N A L   A H P   D A T A
*****************************************************************
*****************************************************************

                  HIERARCHICAL LEVEL: PAYOFF

                    NUMBER OF FACTORS:   3

          STANDARDIZED EIGENVECTOR - ALL ELEMENTS
          ---------------------------------------
 .024 .048 .020 .044 .006 .030 .032 .037 .022 .022 .060 .060 .015 .032 .005 .00
      4 .024 .067 .005 .024 .027 .027 .027 .007 .045 .045 .023 .020 .025 .030 .
      049 .019 .036 .020 .018

         CHECK - SUM OF VECTOR ELEMENTS SHOULD EQUAL 1.0

                          SUM = 1.0000

*****************************************************************
*************************************************************
```

APPENDIX G

GAMS OUTPUT

The GAMS nonlinear programming package produces an extensive and voluminous output listing for every model run. The GP model required that model iterations be performed for each of the four different budget strategies. The following four pages contains a condensed and curtailed solution summary for the model runs at the core, basic, enhanced, and extended budget levels.

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

```
**** SOLVER STATUS      1 NORMAL COMPLETION
**** MODEL STATUS       1 OPTIMAL
**** OBJECTIVE VALUE              16.6951
```

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	882.600	882.600	-0.021
---- EQU PAYOFF	68.259	68.259	68.259	0.527
---- EQU RISK	7.143	7.143	7.143	-0.301
---- EQU TIME	7.793	7.793	7.793	-0.110
---- EQU BALANCE	52.861	52.861	52.861	0.063
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.027
B142	2.000	15.000	15.000	-0.003
B412	9.000	9.000	28.000	0.029
B532	30.000	95.000	95.000	-0.002
B612	2.000	2.000	25.000	0.029
L008	5.000	5.000	30.000	0.016
L212	2.000	2.000	12.000	0.015
L503	5.000	5.000	24.000	0.015
L721	2.000	2.000	12.000	0.017
L723	2.000	2.000	10.000	0.017
D044	1.000	15.000	15.000	-0.009
D076	50.000	260.000	260.000	-0.008
D080	5.000	5.000	25.000	0.024
D047	15.000	15.000	55.000	0.006
D112	1.000	1.000	8.000	0.043
D114	6.000	6.000	20.000	0.047
D083	12.000	12.000	80.000	0.009
K222	40.000	187.000	187.000	-0.010
K623	5.000	5.000	28.000	0.043
K624	10.000	10.000	45.000	0.020
K225	6.000	6.000	20.000	0.012
K323	3.000	3.000	50.000	0.012
K325	4.000	4.000	25.000	0.012
K524	4.000	4.000	25.000	0.038
K321	35.000	108.600	204.000	.
S271	25.000	25.000	105.000	0.003
S051	15.000	15.000	20.500	0.022
S011	3.000	3.000	13.300	0.049
S052	15.000	15.000	31.000	0.019
S053	3.000	3.000	19.200	0.008
S243	3.000	15.000	15.000	-0.003
S402	3.000	3.000	35.000	0.019
S091	5.000	5.000	35.500	0.005
S102	2.000	2.000	20.000	0.018
S281	12.000	12.000	159.400	0.020

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 13.7734

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1029.100	1029.100	-0.018
---- EQU PAYOFF	68.259	68.259	68.259	0.527
---- EQU RISK	7.143	7.143	7.143	-0.301
---- EQU TIME	7.793	7.793	7.793	-0.110
---- EQU BALANCE	52.861	52.861	52.861	0.063
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.024
B142	2.000	15.000	15.000	-0.006
B412	9.000	9.000	28.000	0.026
B532	30.000	95.000	95.000	-0.005
B612	2.000	2.000	25.000	0.026
L008	5.000	5.000	30.000	0.013
L212	2.000	2.000	12.000	0.012
L503	5.000	5.000	24.000	0.012
L721	2.000	2.000	12.000	0.014
L723	2.000	2.000	10.000	0.014
D044	1.000	15.000	15.000	-0.012
D076	50.000	260.000	260.000	-0.011
D080	5.000	5.000	25.000	0.021
D047	15.000	15.000	55.000	0.003
D112	1.000	1.000	8.000	0.040
D114	6.000	6.000	20.000	0.044
D083	12.000	12.000	80.000	0.006
K222	40.000	187.000	187.000	-0.013
K623	5.000	5.000	28.000	0.040
K624	10.000	10.000	45.000	0.017
K225	6.000	6.000	20.000	0.009
K323	3.000	3.000	50.000	0.009
K325	4.000	4.000	25.000	0.009
K524	4.000	4.000	25.000	0.035
K321	35.000	204.000	204.000	-0.003
S271	25.000	76.100	105.000	.
S051	15.000	15.000	20.500	0.019
S011	3.000	3.000	13.500	0.046
S052	15.000	15.000	31.000	0.016
S053	3.000	3.000	19.200	0.005
S243	3.000	15.000	15.000	-0.006
S402	3.000	3.000	35.000	0.016
S091	5.000	5.000	35.500	0.002
S102	2.000	2.000	20.000	0.015
S281	12.000	12.000	159.400	0.017

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 10.7438

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1255.400	1255.400	-0.009
---- EQU PAYOFF	68.259	68.259	68.259	0.527
---- EQU RISK	7.143	7.143	7.143	-0.301
---- EQU TIME	7.793	7.793	7.793	-0.110
---- EQU BALANCE	52.861	52.861	52.861	0.063
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.014
B142	2.000	15.000	15.000	-0.015
B412	9.000	9.000	28.000	0.016
B532	30.000	95.000	95.000	-0.014
B612	2.000	2.000	25.000	0.017
L008	5.000	5.000	30.000	0.003
L212	2.000	2.000	12.000	0.002
L503	5.000	5.000	24.000	0.003
L721	2.000	2.000	12.000	0.005
L723	2.000	2.000	10.000	0.005
D044	1.000	15.000	15.000	-0.021
D076	50.000	260.000	260.000	-0.020
D080	5.000	5.000	25.000	0.012
D047	15.000	55.000	55.000	-0.006
D112	1.000	1.000	8.000	0.031
D114	6.000	6.000	20.000	0.035
D083	12.000	80.000	80.000	-0.004
K222	40.000	187.000	187.000	-0.023
K623	5.000	5.000	28.000	0.031
K624	10.000	10.000	45.000	0.008
K225	6.000	20.000	20.000	EPS
K323	3.000	10.700	50.000	.
K325	4.000	25.000	25.000	-3.010E-4
K524	4.000	4.000	25.000	0.025
K321	35.000	204.000	204.000	-0.012
S271	25.000	105.000	105.000	-0.009
S051	15.000	15.000	20.500	0.010
S011	3.000	3.000	13.300	0.037
S052	15.000	15.000	31.000	0.007
S053	3.000	19.200	19.200	-0.004
S243	3.000	15.000	15.000	-0.016
S402	3.000	3.000	35.000	0.007
S091	5.000	35.500	35.500	-0.007
S102	2.000	2.000	20.000	0.005
S281	12.000	12.000	159.400	0.008

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 9.9588

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1383.400	1383.400	-0.003
---- EQU PAYOFF	68.259	68.259	68.259	0.527
---- EQU RISK	7.143	7.143	7.143	-0.301
---- EQU TIME	7.793	7.793	7.793	-0.110
---- EQU BALANCE	52.861	52.861	52.861	0.063
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.009
B142	2.000	15.000	15.000	-0.021
B412	9.000	9.000	28.000	0.011
B532	30.000	95.000	95.000	-0.019
B612	2.000	2.000	25.000	0.012
L008	5.000	30.000	30.000	-0.002
L212	2.000	12.000	12.000	-0.003
L503	5.000	24.000	24.000	-0.003
L721	2.000	12.000	12.000	-6.020E-4
L723	2.000	10.000	10.000	-6.020E-4
D044	1.000	15.000	15.000	-0.027
D076	50.000	260.000	260.000	-0.026
D080	5.000	5.000	25.000	0.006
D047	15.000	55.000	55.000	-0.011
D112	1.000	1.000	8.000	0.025
D114	6.000	6.000	20.000	0.029
D083	12.000	80.000	80.000	-0.009
K222	40.000	187.000	187.000	-0.028
K623	5.000	5.000	28.000	0.025
K624	10.000	10.000	45.000	0.003
K225	6.000	20.000	20.000	-0.005
K323	3.000	50.000	50.000	-0.005
K325	4.000	25.000	25.000	-0.006
K524	4.000	4.000	25.000	0.020
K321	35.000	204.000	204.000	-0.018
S271	25.000	105.000	105.000	-0.015
S051	15.000	15.000	20.500	0.004
S011	3.000	3.000	13.300	0.031
S052	15.000	15.000	31.000	0.002
S053	3.000	19.200	19.200	-0.009
S243	3.000	15.000	15.000	-0.021
S402	3.000	3.000	35.000	0.001
S091	5.000	35.500	35.500	-0.013
S102	2.000	18.700	20.000	.
S281	12.000	12.000	159.400	0.002

APPENDIX H

AHP OUTPUT - SENSITIVITY ANALYSIS

In Chapter VII a sensitivity analysis was conducted on the GP model. In order to test the impact of changes in the achievement function coefficient weights, several modelling situations were envisioned. The function SINGLE was run in the AHP workspace on each of these four situations, and the output from these iterations is contained on the following pages.

```
================================================
                 SITUATION 1
================================================

              COMPARISON MATRIX
              -----------------
   1.000   1.000   5.000   7.000
   1.000   1.000   5.000   7.000
    .200    .200   1.000   2.000
    .143    .143    .500   1.000

           LAMBDA(MAXIMUM):   4.016
           CONSISTENCY INDEX:  .005
           CONSISTENCY RATIO:  .006

WEIGHT EIGENVECTOR:  .425 .425 .093 .056

================================================
                 SITUATION 2
================================================

              COMPARISON MATRIX
              -----------------
   1.000    .500   5.000   7.000
   2.000   1.000   7.000   9.000
    .200    .143   1.000   2.000
    .143    .111    .500   1.000

           LAMBDA(MAXIMUM):   4.040
           CONSISTENCY INDEX:  .013
           CONSISTENCY RATIO:  .015

WEIGHT EIGENVECTOR:  .330 .542 .079 .048

================================================
                 SITUATION 3
================================================

              COMPARISON MATRIX
              -----------------
   1.000   2.000    .333   7.000
    .500   1.000    .250   5.000
   3.000   4.000   1.000   9.000
    .143    .200    .111   1.000

           LAMBDA(MAXIMUM):   4.104
           CONSISTENCY INDEX:  .035
           CONSISTENCY RATIO:  .039

WEIGHT EIGENVECTOR:  .250 .152 .557 .041

================================================
                 SITUATION 4
================================================

              COMPARISON MATRIX
              -----------------
   1.000   1.000   1.000   1.000
   1.000   1.000   1.000   1.000
   1.000   1.000   1.000   1.000
   1.000   1.000   1.000   1.000

           LAMBDA(MAXIMUM):   4.000
           CONSISTENCY INDEX:  .000
           CONSISTENCY RATIO:  .000

WEIGHT EIGENVECTOR:  .250 .250 .250 .250
```

APPENDIX I

GAMS OUTPUT - SENSITIVITY ANALYSIS

The sensitivity analysis conducted in Chapter VII involved modelling four distinct situations involving fluctuations in the achievement function coefficient weights. Four situations were run on the GAMS GP model at each of the four budget strategies, so a total of sixteen model iterations were performed for the sensitivity analysis. The abbreviated GAMS output for each of these iterations is contained on the following pages.

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 14.5967

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	882.600	882.600	-0.015
---- EQU PAYOFF	68.259	68.259	68.259	0.425
---- EQU RISK	7.143	7.143	7.143	-0.425
---- EQU TIME	7.793	7.793	7.793	-0.093
---- EQU BALANCE	52.861	52.861	52.861	0.056
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.029
B142	2.000	15.000	15.000	-0.003
B412	9.000	9.000	28.000	0.030
B532	30.000	95.000	95.000	-0.002
B612	2.000	2.000	25.000	0.028
L008	5.000	5.000	30.000	0.016
L212	2.000	2.000	12.000	0.015
L503	5.000	5.000	24.000	0.018
L721	2.000	2.000	12.000	0.016
L723	2.000	2.000	10.000	0.016
D044	1.000	15.000	15.000	-0.007
D076	50.000	260.000	260.000	-0.007
D080	5.000	5.000	25.000	0.023
D047	15.000	15.000	55.000	0.005
D112	1.000	1.000	8.000	0.045
D114	6.000	6.000	20.000	0.050
D083	12.000	12.000	80.000	0.006
K222	40.000	187.000	187.000	-0.008
K623	5.000	5.000	28.000	0.048
K624	10.000	10.000	45.000	0.019
K225	6.000	6.000	20.000	0.010
K323	3.000	3.000	50.000	0.010
K325	4.000	4.000	25.000	0.010
K524	4.000	4.000	25.000	0.041
K321	35.000	108.600	204.000	.
S271	25.000	25.000	105.000	0.004
S051	15.000	15.000	20.500	0.023
S011	3.000	3.000	13.300	0.057
S052	15.000	15.000	31.000	0.020
S053	3.000	3.000	19.200	0.007
S243	3.000	15.000	15.000	-0.003
S402	3.000	3.000	35.000	0.017
S091	5.000	5.000	35.500	0.004
S102	2.000	2.000	20.000	0.016
S281	12.000	12.000	159.400	0.018

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 12.5762

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1029.100	1029.100	-0.011
---- EQU PAYOFF	68.259	68.259	68.259	0.425
---- EQU RISK	7.143	7.143	7.143	-0.425
---- EQU TIME	7.793	7.793	7.793	-0.093
---- EQU BALANCE	52.861	52.861	52.861	0.056
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.024
B142	2.000	15.000	15.000	-0.007
B412	9.000	9.000	28.000	0.026
B532	30.000	95.000	95.000	-0.006
B612	2.000	2.000	25.000	0.024
L008	5.000	5.000	30.000	0.012
L212	2.000	2.000	12.000	0.011
L503	5.000	5.000	24.000	0.014
L721	2.000	2.000	12.000	0.012
L723	2.000	2.000	10.000	0.012
D044	1.000	15.000	15.000	-0.012
D076	50.000	260.000	260.000	-0.011
D080	5.000	5.000	25.000	0.019
D047	15.000	15.000	55.000	0.001
D112	1.000	1.000	8.000	0.041
D114	6.000	6.000	20.000	0.046
D083	12.000	12.000	80.000	0.002
K222	40.000	187.000	187.000	-0.012
K623	5.000	5.000	28.000	0.044
K624	10.000	10.000	45.000	0.015
K225	6.000	6.000	20.000	0.006
K323	3.000	3.000	50.000	0.006
K325	4.000	4.000	25.000	0.006
K524	4.000	4.000	25.000	0.037
K321	35.000	204.000	204.000	-0.004
S271	25.000	76.100	105.000	.
S051	15.000	15.000	20.500	0.019
S011	3.000	3.000	13.300	0.053
S052	15.000	15.000	31.000	0.016
S053	3.000	3.000	19.200	0.003
S243	3.000	15.000	15.000	-0.007
S402	3.000	3.000	35.000	0.013
S091	5.000	5.000	35.500	9.0002E-5
S102	2.000	2.000	20.000	0.012
S281	12.000	12.000	159.400	0.014

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 10.5273

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1255.400	1255.400	-0.005
---- EQU PAYOFF	68.259	68.259	68.259	0.425
---- EQU RISK	7.143	7.143	7.143	-0.425
---- EQU TIME	7.793	7.793	7.793	-0.093
---- EQU BALANCE	52.861	52.861	52.861	0.056
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.018
B142	2.000	15.000	15.000	-0.013
B412	9.000	9.000	28.000	0.020
B532	30.000	95.000	95.000	-0.012
B612	2.000	2.000	25.000	0.018
L008	5.000	5.000	30.000	0.006
L212	2.000	2.000	12.000	0.005
L503	5.000	5.000	24.000	0.008
L721	2.000	2.000	12.000	0.006
L723	2.000	2.000	10.000	0.006
D044	1.000	15.000	15.000	-0.018
D076	50.000	260.000	260.000	-0.017
D080	5.000	5.000	25.000	0.013
D047	15.000	55.000	55.000	-0.005
D112	1.000	1.000	8.000	0.035
D114	6.000	6.000	20.000	0.040
D083	12.000	80.000	80.000	-0.004
K222	40.000	187.000	187.000	-0.018
K623	5.000	5.000	28.000	0.038
K624	10.000	10.000	45.000	0.009
K225	6.000	20.000	20.000	EPS
K323	3.000	10.700	50.000	.
K325	4.000	25.000	25.000	-4.250E-4
K524	4.000	4.000	25.000	0.030
K321	35.000	204.000	204.000	-0.010
S271	25.000	105.000	105.000	-0.006
S051	15.000	15.000	20.500	0.013
S011	3.000	3.000	13.300	0.047
S052	15.000	15.000	31.000	0.010
S053	3.000	19.200	19.200	-0.003
S243	3.000	15.000	15.000	-0.013
S402	3.000	3.000	35.000	0.007
S091	5.000	35.500	35.500	-0.006
S102	2.000	2.000	20.000	0.006
S281	12.000	12.000	159.400	0.008

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 10.3264

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1304.700	1383.400	.
---- EQU PAYOFF	68.259	68.259	68.259	0.425
---- EQU RISK	7.143	7.143	7.143	-0.425
---- EQU TIME	7.793	7.793	7.793	-0.093
---- EQU BALANCE	52.861	52.861	52.861	0.056
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.013
B142	2.000	15.000	15.000	-0.018
B412	9.000	9.000	28.000	0.015
B532	30.000	95.000	95.000	-0.017
B612	2.000	2.000	25.000	0.013
L008	5.000	5.000	30.000	7.8100E-4
L212	2.000	12.000	12.000	-6.900E-5
L503	5.000	5.000	24.000	0.003
L721	2.000	2.000	12.000	9.4000E-4
L723	2.000	2.000	10.000	9.4000E-4
D044	1.000	15.000	15.000	-0.023
D076	50.000	260.000	260.000	-0.022
D080	5.000	5.000	25.000	0.008
D047	15.000	55.000	55.000	-0.010
D112	1.000	1.000	8.000	0.029
D114	6.000	6.000	20.000	0.035
D083	12.000	80.000	80.000	-0.009
K222	40.000	187.000	187.000	-0.023
K623	5.000	5.000	28.000	0.033
K624	10.000	10.000	45.000	0.004
K225	6.000	20.000	20.000	-0.005
K323	3.000	50.000	50.000	-0.005
K325	4.000	25.000	25.000	-0.006
K524	4.000	4.000	25.000	0.025
K321	35.000	204.000	204.000	-0.015
S271	25.000	105.000	105.000	-0.011
S051	15.000	15.000	20.500	0.008
S011	3.000	3.000	13.300	0.042
S052	15.000	15.000	31.000	0.005
S053	3.000	19.200	19.200	-0.008
S243	3.000	15.000	15.000	-0.018
S402	3.000	3.000	35.000	0.002
S091	5.000	35.500	35.500	-0.011
S102	2.000	2.000	20.000	5.5800E-4
S281	12.000	12.000	159.400	0.003

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 12.6275

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	882.600	882.600	-0.010
---- EQU PAYOFF	68.259	68.259	68.259	0.330
---- EQU RISK	7.143	7.143	7.143	-0.542
---- EQU TIME	7.793	7.793	7.793	-0.079
---- EQU BALANCE	52.861	52.861	52.861	0.048
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.031
B142	2.000	15.000	15.000	-0.003
B412	9.000	9.000	28.000	0.032
B532	30.000	95.000	95.000	-0.002
B612	2.000	2.000	25.000	0.027
L008	5.000	5.000	30.000	0.016
L212	2.000	2.000	12.000	0.016
L503	5.000	5.000	24.000	0.021
L721	2.000	2.000	12.000	0.015
L723	2.000	2.000	10.000	0.015
D044	1.000	15.000	15.000	-0.006
D076	50.000	260.000	260.000	-0.005
D080	5.000	5.000	25.000	0.022
D047	15.000	15.000	55.000	0.004
D112	1.000	1.000	8.000	0.046
D114	6.000	6.000	20.000	0.053
D083	12.000	12.000	80.000	0.004
K222	40.000	187.000	187.000	-0.005
K623	5.000	5.000	28.000	0.052
K624	10.000	10.000	45.000	0.019
K225	6.000	6.000	20.000	0.008
K323	3.000	3.000	50.000	0.008
K325	4.000	4.000	25.000	0.008
K524	4.000	4.000	25.000	0.043
K321	35.000	108.600	204.000	.
S271	25.000	25.000	105.000	0.005
S051	15.000	15.000	20.500	0.025
S011	3.000	3.000	13.300	0.064
S052	15.000	15.000	31.000	0.021
S053	3.000	3.000	19.200	0.006
S243	3.000	15.000	15.000	-0.003
S402	3.000	3.000	35.000	0.016
S091	5.000	5.000	35.500	0.003
S102	2.000	2.000	20.000	0.014
S281	12.000	12.000	159.400	0.017

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 11.3794

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1029.100	1029.100	-0.006
---- EQU PAYOFF	68.259	68.259	68.259	0.330
---- EQU RISK	7.143	7.143	7.143	-0.542
---- EQU TIME	7.793	7.793	7.793	-0.079
---- EQU BALANCE	52.861	52.861	52.861	0.048
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.027
B142	2.000	15.000	15.000	-0.007
B412	9.000	9.000	28.000	0.028
B532	30.000	95.000	95.000	-0.006
B612	2.000	2.000	25.000	0.023
L008	5.000	5.000	30.000	0.013
L212	2.000	2.000	12.000	0.012
L503	5.000	5.000	24.000	0.017
L721	2.000	2.000	12.000	0.012
L723	2.000	2.000	10.000	0.012
D044	1.000	15.000	15.000	-0.010
D076	50.000	260.000	260.000	-0.009
D080	5.000	5.000	25.000	0.018
D047	15.000	15.000	55.000	3.8600E-4
D112	1.000	1.000	8.000	0.043
D114	6.000	6.000	20.000	0.049
D083	12.000	32.600	80.000	.
K222	40.000	187.000	187.000	-0.009
K623	5.000	5.000	28.000	0.049
K624	10.000	10.000	45.000	0.015
K225	6.000	6.000	20.000	0.005
K323	3.000	3.000	50.000	0.005
K325	4.000	4.000	25.000	0.004
K524	4.000	4.000	25.000	0.040
K321	35.000	204.000	204.000	-0.004
S271	25.000	25.000	105.000	0.002
S051	15.000	15.000	20.500	0.021
S011	3.000	3.000	13.300	0.061
S052	15.000	15.000	31.000	0.017
S053	3.000	3.000	19.200	0.002
S243	3.000	15.000	15.000	-0.007
S402	3.000	3.000	35.000	0.012
S091	5.000	35.500	35.500	-9.600E-5
S102	2.000	2.000	20.000	0.011
S281	12.000	12.000	159.400	0.013

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 10.3446

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1255.400	1255.400	-0.002
---- EQU PAYOFF	68.259	68.259	68.259	0.330
---- EQU RISK	7.143	7.143	7.143	-0.542
---- EQU TIME	7.793	7.793	7.793	-0.079
---- EQU BALANCE	52.861	52.861	52.861	0.048
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.022
B142	2.000	15.000	15.000	-0.011
B412	9.000	9.000	28.000	0.023
B532	30.000	95.000	95.000	-0.010
B612	2.000	2.000	25.000	0.018
L008	5.000	5.000	30.000	0.008
L212	2.000	2.000	12.000	0.007
L503	5.000	5.000	24.000	0.012
L721	2.000	2.000	12.000	0.007
L723	2.000	2.000	10.000	0.007
D044	1.000	15.000	15.000	-0.014
D076	50.000	260.000	260.000	-0.014
D080	5.000	5.000	25.000	0.014
D047	15.000	55.000	55.000	-0.004
D112	1.000	1.000	8.000	0.038
D114	6.000	6.000	20.000	0.045
D083	12.000	80.000	80.000	-0.005
K222	40.000	187.000	187.000	-0.014
K623	5.000	5.000	28.000	0.044
K624	10.000	10.000	45.000	0.011
K225	6.000	20.000	20.000	EPS
K323	3.000	10.700	50.000	.
K325	4.000	25.000	25.000	-5.420E-4
K524	4.000	4.000	25.000	0.035
K321	35.000	204.000	204.000	-0.008
S271	25.000	105.000	105.000	-0.003
S051	15.000	15.000	20.500	0.016
S011	3.000	3.000	13.300	0.056
S052	15.000	15.000	31.000	0.012
S053	3.000	19.200	19.200	-0.002
S243	3.000	15.000	15.000	-0.011
S402	3.000	3.000	35.000	0.008
S091	5.000	35.500	35.500	-0.005
S102	2.000	2.000	20.000	0.006
S281	12.000	12.000	159.400	0.009

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 10.2854

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1294.700	1383.400	.
---- EQU PAYOFF	68.259	68.259	68.259	0.330
---- EQU RISK	7.143	7.143	7.143	-0.542
---- EQU TIME	7.793	7.793	7.793	-0.079
---- EQU BALANCE	52.861	52.861	52.861	0.048
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.021
B142	2.000	15.000	15.000	-0.013
B412	9.000	9.000	28.000	0.022
B532	30.000	95.000	95.000	-0.012
B612	2.000	2.000	25.000	0.017
L008	5.000	5.000	30.000	0.007
L212	2.000	2.000	12.000	0.006
L503	5.000	5.000	24.000	0.011
L721	2.000	2.000	12.000	0.006
L723	2.000	2.000	10.000	0.006
D044	1.000	15.000	15.000	-0.016
D076	50.000	260.000	260.000	-0.015
D080	5.000	5.000	25.000	0.012
D047	15.000	55.000	55.000	-0.006
D112	1.000	1.000	8.000	0.037
D114	6.000	6.000	20.000	0.043
D083	12.000	80.000	80.000	-0.006
K222	40.000	187.000	187.000	-0.015
K623	5.000	5.000	28.000	0.043
K624	10.000	10.000	45.000	0.009
K225	6.000	20.000	20.000	-0.002
K323	3.000	50.000	50.000	-0.002
K325	4.000	25.000	25.000	-0.002
K524	4.000	4.000	25.000	0.034
K321	35.000	204.000	204.000	-0.010
S271	25.000	105.000	105.000	-0.005
S051	15.000	15.000	20.500	0.015
S011	3.000	3.000	13.300	0.055
S052	15.000	15.000	31.000	0.011
S053	3.000	19.200	19.200	-0.004
S243	3.000	15.000	15.000	-0.013
S402	3.000	3.000	35.000	0.006
S091	5.000	35.500	35.500	-0.006
S102	2.000	2.000	20.000	0.004
S281	12.000	12.000	159.400	0.007

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

```
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE               12.1938
```

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	882.600	882.600	-0.003
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.152
---- EQU TIME	7.793	7.793	7.793	-0.557
---- EQU BALANCE	52.861	52.861	52.861	0.041
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.031
B142	2.000	15.000	15.000	-0.005
B412	9.000	9.000	28.000	0.032
B532	30.000	95.000	95.000	-0.005
B612	2.000	2.000	25.000	0.024
L008	5.000	5.000	30.000	0.018
L212	2.000	2.000	12.000	0.018
L503	5.000	5.000	24.000	0.015
L721	2.000	2.000	12.000	0.013
L723	2.000	2.000	10.000	0.013
D044	1.000	15.000	15.000	-0.008
D076	50.000	260.000	260.000	-0.003
D080	5.000	5.000	25.000	0.022
D047	15.000	20.600	55.000	.
D112	1.000	1.000	8.000	0.047
D114	6.000	6.000	20.000	0.049
D083	12.000	80.000	80.000	-9.880E-4
K222	40.000	187.000	187.000	-0.001
K623	5.000	5.000	28.000	0.025
K624	10.000	10.000	45.000	0.028
K225	6.000	6.000	20.000	0.014
K323	3.000	3.000	50.000	0.014
K325	4.000	4.000	25.000	0.014
K524	4.000	4.000	25.000	0.024
K321	35.000	35.000	204.000	0.002
S271	25.000	25.000	105.000	0.004
S051	15.000	15.000	20.500	0.017
S011	3.000	3.000	13.300	0.058
S052	15.000	15.000	31.000	0.016
S053	3.000	3.000	19.200	0.002
S243	3.000	15.000	15.000	-0.005
S402	3.000	3.000	35.000	0.019
S091	5.000	5.000	35.500	0.003
S102	2.000	2.000	20.000	0.018
S281	12.000	12.000	159.400	0.018

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 11.9538

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1029.100	1029.100	-0.001
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.152
---- EQU TIME	7.793	7.793	7.793	-0.557
---- EQU BALANCE	52.861	52.861	52.861	0.041
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.029
B142	2.000	15.000	15.000	-0.007
B412	9.000	9.000	28.000	0.030
B532	30.000	95.000	95.000	-0.007
B612	2.000	2.000	25.000	0.022
L008	5.000	5.000	30.000	0.016
L212	2.000	2.000	12.000	0.016
L503	5.000	5.000	24.000	0.013
L721	2.000	2.000	12.000	0.011
L723	2.000	2.000	10.000	0.011
D044	1.000	15.000	15.000	-0.010
D076	50.000	260.000	260.000	-0.005
D080	5.000	5.000	25.000	0.020
D047	15.000	55.000	55.000	-0.002
D112	1.000	1.000	8.000	0.045
D114	6.000	6.000	20.000	0.047
D083	12.000	80.000	80.000	-0.003
K222	40.000	187.000	187.000	-0.003
K623	5.000	5.000	28.000	0.023
K624	10.000	10.000	45.000	0.026
K225	6.000	6.000	20.000	0.013
K323	3.000	3.000	50.000	0.013
K325	4.000	4.000	25.000	0.012
K524	4.000	4.000	25.000	0.022
K321	35.000	147.100	204.000	.
S271	25.000	25.000	105.000	0.002
S051	15.000	15.000	20.500	0.015
S011	3.000	3.000	13.300	0.056
S052	15.000	15.000	31.000	0.014
S053	3.000	3.000	19.200	4.8300E-4
S243	3.000	15.000	15.000	-0.007
S402	3.000	3.000	35.000	0.017
S091	5.000	5.000	35.500	0.001
S102	2.000	2.000	20.000	0.016
S281	12.000	12.000	159.400	0.016

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 11.8754

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1102.200	1255.400	.
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.152
---- EQU TIME	7.793	7.793	7.793	-0.557
---- EQU BALANCE	52.861	52.861	52.861	0.041
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.028
B142	2.000	15.000	15.000	-0.009
B412	9.000	9.000	28.000	0.028
B532	30.000	95.000	95.000	-0.008
B612	2.000	2.000	25.000	0.021
L008	5.000	5.000	30.000	0.015
L212	2.000	2.000	12.000	0.015
L503	5.000	5.000	24.000	0.011
L721	2.000	2.000	12.000	0.010
L723	2.000	2.000	10.000	0.010
D044	1.000	15.000	15.000	-0.011
D076	50.000	260.000	260.000	-0.006
D080	5.000	5.000	25.000	0.019
D047	15.000	55.000	55.000	-0.003
D112	1.000	1.000	8.000	0.043
D114	6.000	6.000	20.000	0.045
D083	12.000	80.000	80.000	-0.004
K222	40.000	187.000	187.000	-0.005
K623	5.000	5.000	28.000	0.021
K624	10.000	10.000	45.000	0.024
K225	6.000	6.000	20.000	0.011
K323	3.000	3.000	50.000	0.011
K325	4.000	4.000	25.000	0.011
K524	4.000	4.000	25.000	0.021
K321	35.000	204.000	204.000	-0.001
S271	25.000	25.000	105.000	8.6800E-4
S051	15.000	15.000	20.500	0.014
S011	3.000	3.000	13.300	0.055
S052	15.000	15.000	31.000	0.013
S053	3.000	19.200	19.200	-6.970E-4
S243	3.000	15.000	15.000	-0.008
S402	3.000	3.000	35.000	0.016
S091	5.000	5.000	35.500	1.9000E-4
S102	2.000	2.000	20.000	0.014
S281	12.000	12.000	159.400	0.015

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

```
**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE              11.8754
```

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1102.200	1383.400	.
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.152
---- EQU TIME	7.793	7.793	7.793	-0.557
---- EQU BALANCE	52.861	52.861	52.861	0.041
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.028
B142	2.000	15.000	15.000	-0.009
B412	9.000	9.000	28.000	0.028
B532	30.000	95.000	95.000	-0.008
B612	2.000	2.000	25.000	0.021
L008	5.000	5.000	30.000	0.015
L212	2.000	2.000	12.000	0.015
L503	5.000	5.000	24.000	0.011
L721	2.000	2.000	12.000	0.010
L723	2.000	2.000	10.000	0.010
D044	1.000	15.000	15.000	-0.011
D076	50.000	260.000	260.000	-0.006
D080	5.000	5.000	25.000	0.019
D047	15.000	55.000	55.000	-0.003
D112	1.000	1.000	8.000	0.043
D114	6.000	6.000	20.000	0.045
D083	12.000	80.000	80.000	-0.004
K222	40.000	187.000	187.000	-0.005
K623	5.000	5.000	28.000	0.021
K624	10.000	10.000	45.000	0.024
K225	6.000	6.000	20.000	0.011
K323	3.000	3.000	50.000	0.011
K325	4.000	4.000	25.000	0.011
K524	4.000	4.000	25.000	0.021
K321	35.000	204.000	204.000	-0.001
S271	25.000	25.000	105.000	8.6800E-4
S051	15.000	15.000	20.500	0.014
S011	3.000	3.000	13.300	0.055
S052	15.000	15.000	31.000	0.013
S053	3.000	19.200	19.200	-6.970E-4
S243	3.000	15.000	15.000	-0.008
S402	3.000	3.000	35.000	0.016
S091	5.000	5.000	35.500	1.9000E-4
S102	2.000	2.000	20.000	0.014
S281	12.000	12.000	159.400	0.015

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 15.7470

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	882.600	882.600	-0.013
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.250
---- EQU TIME	7.793	7.793	7.793	-0.250
---- EQU BALANCE	52.861	52.861	52.861	0.250
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.025
B142	2.000	15.000	15.000	-0.002
B412	9.000	9.000	28.000	0.026
B532	30.000	95.000	95.000	-0.003
B612	2.000	2.000	25.000	0.020
L008	5.000	5.000	30.000	0.014
L212	2.000	2.000	12.000	0.014
L503	5.000	5.000	24.000	0.014
L721	2.000	2.000	12.000	0.012
L723	2.000	2.000	10.000	0.012
D044	1.000	15.000	15.000	-0.005
D076	50.000	260.000	260.000	-0.002
D080	5.000	5.000	25.000	0.019
D047	15.000	15.000	55.000	0.003
D112	1.000	1.000	8.000	0.037
D114	6.000	6.000	20.000	0.040
D083	12.000	12.000	80.000	0.003
K222	40.000	187.000	187.000	-0.004
K623	5.000	5.000	28.000	0.029
K624	10.000	10.000	45.000	0.021
K225	6.000	6.000	20.000	0.012
K323	3.000	3.000	50.000	0.012
K325	4.000	4.000	25.000	0.011
K524	4.000	4.000	25.000	0.025
K321	35.000	108.600	204.000	.
S271	25.000	25.000	105.000	0.003
S051	15.000	15.000	20.500	0.017
S011	3.000	3.000	13.300	0.047
S052	15.000	15.000	31.000	0.015
S053	3.000	3.000	19.200	0.004
S243	3.000	15.000	15.000	-0.001
S402	3.000	3.000	35.000	0.016
S091	5.000	5.000	35.500	0.002
S102	2.000	2.000	20.000	0.014
S281	12.000	12.000	159.400	0.016

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 13.9388

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1029.100	1029.100	-0.010
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.250
---- EQU TIME	7.793	7.793	7.793	-0.250
---- EQU BALANCE	52.861	52.861	52.861	0.250
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.022
B142	2.000	15.000	15.000	-0.004
B412	9.000	9.000	28.000	0.023
B532	30.000	95.000	95.000	-0.005
B612	2.000	2.000	25.000	0.017
L008	5.000	5.000	30.000	0.011
L212	2.000	2.000	12.000	0.011
L503	5.000	5.000	24.000	0.011
L721	2.000	2.000	12.000	0.009
L723	2.000	2.000	10.000	0.009
D044	1.000	15.000	15.000	-0.008
D076	50.000	260.000	260.000	-0.005
D080	5.000	5.000	25.000	0.016
D047	15.000	15.000	55.000	2.5000E-4
D112	1.000	1.000	8.000	0.034
D114	6.000	6.000	20.000	0.037
D083	12.000	32.600	80.000	.
K222	40.000	187.000	187.000	-0.007
K623	5.000	5.000	28.000	0.026
K624	10.000	10.000	45.000	0.018
K225	6.000	6.000	20.000	0.009
K323	3.000	3.000	50.000	0.009
K325	4.000	4.000	25.000	0.009
K524	4.000	4.000	25.000	0.022
K321	35.000	204.000	204.000	-0.003
S271	25.000	25.000	105.000	5.0000E-4
S051	15.000	15.000	20.500	0.014
S011	3.000	3.000	13.300	0.044
S052	15.000	15.000	31.000	0.012
S053	3.000	3.000	19.200	0.002
S243	3.000	15.000	15.000	-0.004
S402	3.000	3.000	35.000	0.013
S091	5.000	35.500	35.500	-2.500E-4
S102	2.000	2.000	20.000	0.011
S281	12.000	12.000	159.400	0.013

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 12.0200

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1255.400	1255.400	-0.001
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.250
---- EQU TIME	7.793	7.793	7.793	-0.250
---- EQU BALANCE	52.861	52.861	52.861	0.250
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.013
B142	2.000	15.000	15.000	-0.013
B412	9.000	9.000	28.000	0.014
B532	30.000	95.000	95.000	-0.014
B612	2.000	2.000	25.000	0.008
L008	5.000	5.000	30.000	0.002
L212	2.000	2.000	12.000	0.002
L503	5.000	5.000	24.000	0.002
L721	2.000	2.000	12.000	2.5000E-4
L723	2.000	2.000	10.000	2.5000E-4
D044	1.000	15.000	15.000	-0.017
D076	50.000	260.000	260.000	-0.014
D080	5.000	5.000	25.000	0.007
D047	15.000	55.000	55.000	-0.009
D112	1.000	1.000	8.000	0.025
D114	6.000	6.000	20.000	0.028
D083	12.000	80.000	80.000	-0.009
K222	40.000	187.000	187.000	-0.016
K623	5.000	5.000	28.000	0.017
K624	10.000	10.000	45.000	0.009
K225	6.000	20.000	20.000	EPS
K323	3.000	10.700	50.000	.
K325	4.000	25.000	25.000	-2.500E-4
K524	4.000	4.000	25.000	0.013
K321	35.000	204.000	204.000	-0.012
S271	25.000	105.000	105.000	-0.008
S051	15.000	15.000	20.500	0.005
S011	3.000	3.000	13.300	0.035
S052	15.000	15.000	31.000	0.003
S053	3.000	19.200	19.200	-0.007
S243	3.000	15.000	15.000	-0.013
S402	3.000	3.000	35.000	0.004
S091	5.000	35.500	35.500	-0.009
S102	2.000	2.000	20.000	0.002
S281	12.000	12.000	159.400	0.004

S O L V E S U M M A R Y

MODEL	GP	OBJECTIVE	DEVIATION
TYPE	LP	DIRECTION	MINIMIZE
SOLVER	BDMLP	FROM LINE	450

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 11.9386

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU COST	-INF	1312.700	1383.400	.
---- EQU PAYOFF	68.259	68.259	68.259	0.250
---- EQU RISK	7.143	7.143	7.143	-0.250
---- EQU TIME	7.793	7.793	7.793	-0.250
---- EQU BALANCE	52.861	52.861	52.861	0.250
---- EQU OBJDEF	.	.	.	-1.000

COST	COST OF PROGRAMS CANNOT EXCEED THE BUDGET
PAYOFF	GOAL NUMBER 1 - MAXIMIZE PAYOFF
RISK	GOAL NUMBER 2 - MINIMIZE RISK
TIME	GOAL NUMBER 3 - MINIMIZE TIME
BALANCE	GOAL NUMBER 4 - MAXIMIZE BALANCE
OBJDEF	ACHIEVEMENT FUNCTION

---- VAR X MONEY TO BE SPENT IN EACH PROGRAM DURING FY88

	LOWER	LEVEL	UPPER	MARGINAL
B122	6.000	6.000	37.000	0.012
B142	2.000	15.000	15.000	-0.015
B412	9.000	9.000	28.000	0.012
B532	30.000	95.000	95.000	-0.016
B612	2.000	2.000	25.000	0.007
L008	5.000	5.000	30.000	0.001
L212	2.000	2.000	12.000	5.0000E-4
L503	5.000	5.000	24.000	7.5000E-4
L721	2.000	12.000	12.000	-0.001
L723	2.000	10.000	10.000	-0.001
D044	1.000	15.000	15.000	-0.018
D076	50.000	260.000	260.000	-0.016
D080	5.000	5.000	25.000	0.005
D047	15.000	55.000	55.000	-0.010
D112	1.000	1.000	8.000	0.023
D114	6.000	6.000	20.000	0.026
D083	12.000	80.000	80.000	-0.010
K222	40.000	187.000	187.000	-0.017
K623	5.000	5.000	28.000	0.015
K624	10.000	10.000	45.000	0.007
K225	6.000	20.000	20.000	-0.001
K323	3.000	50.000	50.000	-0.001
K325	4.000	25.000	25.000	-0.002
K524	4.000	4.000	25.000	0.012
K321	35.000	204.000	204.000	-0.013
S271	25.000	105.000	105.000	-0.010
S051	15.000	15.000	20.500	0.003
S011	3.000	3.000	13.300	0.034
S052	15.000	15.000	31.000	0.001
S053	3.000	19.200	19.200	-0.009
S243	3.000	15.000	15.000	-0.014
S402	3.000	3.000	35.000	0.002
S091	5.000	35.500	35.500	-0.011
S102	2.000	2.000	20.000	5.0000E-4
S281	12.000	12.000	159.400	0.003

LIST OF REFERENCES

1. US Army Strategic Defense Command, Report to Congress, 1986.

2. US Army Strategic Defense Command, WPD Priority Listing, 3 Dec 1986.

3. US Army Strategic Defense Command, Huntsville Resource Management Priority Briefing, 22 November 1986.

4. Liberatore, M.J. and Titus, G.J., "The Practice of Management Science in R&D Project Management," Management Science, v. 29, pp. 962-974, August 1983.

5. Souder, W.E., "A Scoring Methodology for Assessing the Suitability of Management Science Models," Management Science, v. 18, pp. B526-B543, June 1972.

6. Moore, J.R. and Baker, N.R., "An Analytical Approach to Scoring Model Design - Application to Research and Development Project Selection," IEEE Transactions on Engineering Management, v. EM16, pp. 90-98, August 1967.

7. Gargiulo, G.R. Hannoch, J., Hettz, D.B., and Zang, T., "Developing Systematic Procedures for Directing Research Programs," IRE Transactions on Engineering Management, v. EM8, pp. 34-47, March 1961.

8. Motley, C.M. and Newton, R.D., "The Selection of Projects for Industrial Research," Operations Research, v. 7, pp. 740-751, November-December 1959.

9. Dean, B.V. and Nishry, M.J., "Scoring and Profitability Models for Evaluating and Selecting Projects," Operations Research, v. 13, pp. 550-569, July-August 1965.

10. Bierman, H., Bonini, C.P., and Hausman, W.H., Quantitative Analysis for Business Decisions, pp. 65-77, Richard D. Irwin, Inc., 1977.

11. Raiffia, H., Decision Analysis: Introductory Lectures on Choices Under Uncertainty, p. 385, Addison-Wesley, 1968.

12. Jackson, B., "Decision Methods for Evaluating R&D Projects," Research Management, v. 12, pp. 20-25, 1982.

13. Hespos, R.F. and Strassmann, P.A., "Stochastic Decision Trees for the Analysis of Investment Decisions," Management Science, v. 11, pp. B244-B259, August, 1965.

14. Olsen, F., "The Control of Research Funds," Coordination, Control, and Financing of Industrial Research, pp. 99-108, Crown Press, 1955.

15. Gearing, C.E. and Adams, B.H., R&D Project Selection as an Expression of Institutional Preference, unpublished paper, NASA, 1972.

16. Souder, W.E.,"A System for Using R&D Project Evaluation Methods," Research Management, v. 21, pp. 29-37, September 1978.

17. Keefer, D.L., "Allocation Planning for R&D with Uncertainty and Multiple Objectives,: IEEE Transactions on Engineering Management, v. EM25, pp. 8-14, February 1978.

18. Costello, D., "A Practical Approach to R&D Project Selection," Technological Forecasting and Social Change, v. 23, pp. 353-368, June 1983.

19. Asher, D.I., "A Linear Programming Model for the Allocation of R&D Efforts," IRE Transactions on Engineering Management, v. EM9, December 1962.

20. Hanssman, F.T., Operations Research Techniques for Capital Investment, pp. 94-104, John Wiley and Sons, 1968.

21. Weingartner, H.M., Mathematical Programming and the Analysis of Capital Budgeting Problems, Prentice-Hall, 1963.

22. Taylor, B.W., Moore, L.J., and Clayton, E.R., "R&D Project Selection and Manpower Allocation with Integer Nonlinear Goal Programming," Management Science, v. 28, pp. 1149-1158, October 1982.

23. Charnes, A. and Cooper, W.W., Management Models and Industrial Applications of Linear Programming, John Wiley and Sons, 1961.

24. Charnes, A. and Stedry, A.C., "Chance-Constrained Model for Real-Time Control in Research and Development Management," Management Science, v. 12, pp. 876-891, July 1964.

25. Salvia, A.A. and Ludwig, W.R., "An Application of Goal Programming at Lord Corporation," Interfaces, v. 9, pp. 129-133, August 1979.

26. Ignizio, J.P., "An Approach to the Capital Budgeting Problem with Multiple Objectives," The Engineering Economist, v. 21, pp. 259-272, April 1977.

27. Winkofsky, E.P., Baker, N.R., and Sweeney, D.J., "A Decision Process Model of R&D Resource Allocation in Hierarchical Organizations," Management Science, v. 27, pp. 268-283, March 1981.

28. Steven, S.S., "The Direct Estimation of Sensory Magnitudes--Loudness," The American Journal of Psychology, v. 69, pp. 1-5, 1956.

29. Dyer, R.F., Mathews, J.J., Wright, C.E., and Yudowitch, K.L., Questionnaire Construction Manual, US Army Research Institute for Behavioral Sciences, September 1976,

30. Guilford, J.P., "Scale Values Derived from the Method of Choices," Psychometrica, v. 2, pp. 139-150, 1937.

31. Comrey, A.L., "A Proposed Method for Absolute Ratio Scaling," Psychometrica, v. 15, pp. 317-325, 1950.

32. Saaty, T.L., "A Scaling Method for Priorities in Hierarchical Structures," Journal of Mathematical Psychology, v. 15, pp. 234-281, June 1977.

33. Gray, P., "Book review: The Analytic Hierarchy Process by Thomas L. Saaty," Interfaces, v. 14, pp. 97-99, May-June 1984.

34. Zahedi, F., "The Analytic Hierarchy Process - A Survey of the Method and its Applications," Interfaces, v. 16, pp. 96-108, July-August 1986.

35. Johnson, C.R. and Hihn, J.M., "Prioritization of Research Projects," Energy Storage: The Transactions of the First International Assembly on Energy Storage, pp. 562-566, Permagon Press, 1980.

36. Sinuany-Stern, Z., "A Network Optimization Model for Budget Allocation in a Multi-campus University," Journal of the Operational Research Society, v. 35, pp. 749-757, 1984.

37. Arbel, A., "A University Budget Problem: A Priority-Based Approach," Socio-Economic Planning Sciences, v. 17, pp. 181-189, 1983.

38. Gilliam, L. and Rose, A.J., APL: An Interactive Approach, 3rd ed., John Wiley and Sons, 1984.

39. Schrage, L., Linear, Integer, and Quadratic Programming with LINDO, The Scientific Press, 1981.

40. Schrage, L., The GINO Nonlinear Programming System, The Scientific Press, 1984.

41. Brooke, A., Drud, A., and Meeraus, A., The Generalized Algebraic Modelling System, Development Research Department, World Bank, 1982.

42. Rosenthal, R., "OA4102 Nonlinear Programming, Naval Postgraduate School," personal course notes, 1987.

43. Miller, I. and Freund, J.E., Probability and Statistics for Engineers, 3rd ed., pp. 282-286, Prentice-Hall, 1985.

44. Statgraphics Statistical Graphics System, pp. 20.1-24.20, STSC, 1986.

45. Saaty, T.L. and Vargas, L.G., The Logic of Priorities, Kluwer-Nijhoff Publishing, pp. 14-41, 1982.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Deputy Undersecretary of the Army for Operations Research Room 2E261, Pentagon Washington, D.C. 20310	2
4.	Commander US Army Strategic Defense Command P.O. Box 15280 Arlington, Virginia 22215-0150	1
5.	Commander US Army Strategic Defense Command ATTN: COL Michael Volpe Arlington, Virginia 22215-0150	1
6.	Commander US Army Strategic Defense Command ATTN: DASD-DP (COL Leon R. Yourtee III) Arlington, Virginia 22215-0150	3
7.	Commander US Army Strategic Defense Command ATTN: DASD-DP (LTC John S. Donnellon) Arlington, Virginia 22215-0150	1
8.	Commander US Army Strategic Defense Command ATTN: DASD-PP (MAJ August C. Manguso) Arlington, Virginia 22215-0150	1
9.	Professor Dan C. Boger, Code 54Bo Department of Operations Research Naval Postgraduate School Monterey, California 93943	5

10. Professor Alvin F. Andrus, Code 55As 1
Department of Operations Research
Naval Postgraduate School
Monterey, California 93943

11. Department of the Army 4
Deputy Chief of Staff for Opns and Plans
ATTN: DAMO-SSW (CPT Steven M. Anderson)
Room 3E533, The Pentagon
Washington, D.C. 20310-04

12. Professor C.R. Jones, Code 74Jo 1
Department of Operations Research
Naval Postgraduate School
Monterey, California 93943

13. CDR Nelson Spires 1
OP-943G1
Pentagon, Room 5D773
Washington, D.C. 20350

14. CDR James Carlson 1
OP-982
Pentagon, Room 5C711
Washington, D.C. 20350

15. RADM R.C. Macke 1
Commander
Naval Space Command
Dahlgren, VA 22448

16. Dr. Louis Marquet 1
Deputy for Technology, SDIO
1717 H Street, N.W.
Washington, D.C. 20006

17. LCDR Scott Palmer 1
PMW-142
Space and Naval Warfare Systems Command
Washington, D.C. 22202

END
FEB.
1988
DTIC