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A Decision Support Model for Large Systems Using Quality Function Deployment and Goal Programming: A Capital Budgeting Problem

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A DECISION SUPPORT MODEL FOR LARGE SYSTEMS USING QUALITY FUNCTION DEPLOYMENT AND GOAL PROGRAMMING: A CAPITAL BUDGETING PROBLEM

by

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ABSTRACT

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Kenneth Lindsey, Jr.
Old Dominion University, 1996
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Effective planning for the modernization of U.S. Air Force fighter aircraft requires a perception of the future tasks these aircraft will be called upon to perform, and the improvements and modifications that will be required to successfully accomplish those tasks. A great deal of research has been done in the areas of military strategy, quality function deployment, capital budgeting, and goal programming, as separate areas of study. This thesis details the research and analysis performed for a project called The Fighter Configuration Plan (FICOP), in which these areas were integrated in a decision support model to aid the Air Force in modernization planning. The unique modernization planning approach developed through this analysis has fundamentally changed the way the Air Force plans for modernizing fighters. This research process developed a perception of the future tasks based on a framework known as Strategies to Task (STT), incorporated Quality Function Deployment (QFD) to develop metrics for the various modernization projects, and used an Integer Goal Programming Model to perform the capital budgeting. This decision support model was applied to the problem of developing long-term modernization plans for each of the existing fighter aircraft (F-16 Fighting Falcon, F-15 Eagle, F-117 Nighthawk and A-10 Thunderbolt II).

To Alecia, Nicole, Caleb, Kenneth Sr., and Evelyn Lindsey.

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CHAPTER I

INTRODUCTION

BACKGROUND

In 1994, the Commander, Air Combat Command (COMACC) initiated a study to review the existing configuration and to develop a plan for the future configurations of the F-16 Fighting Falcon. With over 1,200 of these highly advanced fighter aircraft in inventory, a shrinking budget, and a new geo-political environment, the Air Force needed a new, quantifiable, responsive process for developing optional investment strategies. The study was to be an extension of the Air Force Modernization Planning Process (MPP). The MPP is a systematic method for assessing current and future needs within the Air Force, and for organizing and developing initiatives into plans for filling those needs. Initially, the study was to consider only the proposed initiatives for improving and sustaining the F-16, obtained from several Mission Area Plans (MAPs). MAPs are the output of the MPP. The objective of the project was to develop the best affordable plan for this fighter from hundreds of competing initiatives (candidate modification projects) which spanned nine different mission areas. The scope of the study was later expanded to include all existing fighters.

The project was based on the Strategies to Task framework, a hierarchical representation of National Goals related to Department of Defense Strategy. This framework, which will be explained in detail later, was the directed setting for conducting modernization planning. A critical part of this research involved the question of how to link the allocation of resources to this framework. In the past a subjective process, based on persuasive arguments, prioritized lists, and personable champions was used to develop spending outlay recommendations. The resulting spending recommendation was not reproducible, nor was it synthesized across the set of possible investment alternatives.

The journal model adopted for this thesis is the "Empirical Research Report" as defined by Paul V. Anderson in *Technical Writing: A Reader Centered Approach, 3rd ed.* (Fort Worth: Harcourt Brace College Publishers, 1995).

Fighter Configuration Plan 1996 (FICOP 96) was undertaken to provide Air Force leadership with a comprehensive plan on how to affordably modernize the fighter fleet of over 2,400 aircraft over the next 18 years. Air Combat Command is responsible for organizing, training and equipping the Combat Air Forces (CAF) and for deciding which programs will receive funding, through the Program Objective Memorandum (POM), each cycle. A logical process and accompanying toolset for assessing the value, quickly making the trade-offs, and analyzing the results was desired to facilitate this decision process.

STRATEGIES TO TASK

The Strategies to Task Framework (Figure 1), developed by Glenn Kent (Lieutenant General USAF, retired), is a hierarchical method for linking national goals and interests with operational activities at the tactical engagement level. In the strategy to task approach, it was recommended that this framework be used as a way to define (top down) what operational tasks are required to support our national goals (Kent 1989). This approach is similar to a work breakdown structure for managing large projects, whereby project managers structure the work into small manageable elements. The ultimate utility of this hierarchy for planners, can be realized by linking the allocation of resources to this framework in an optimal manner to achieve the best overall effect. In other words, the framework should promote the allocation of resources on the basis of the greatest effect in achieving objectives and winning campaigns to support the national goals of the United States.

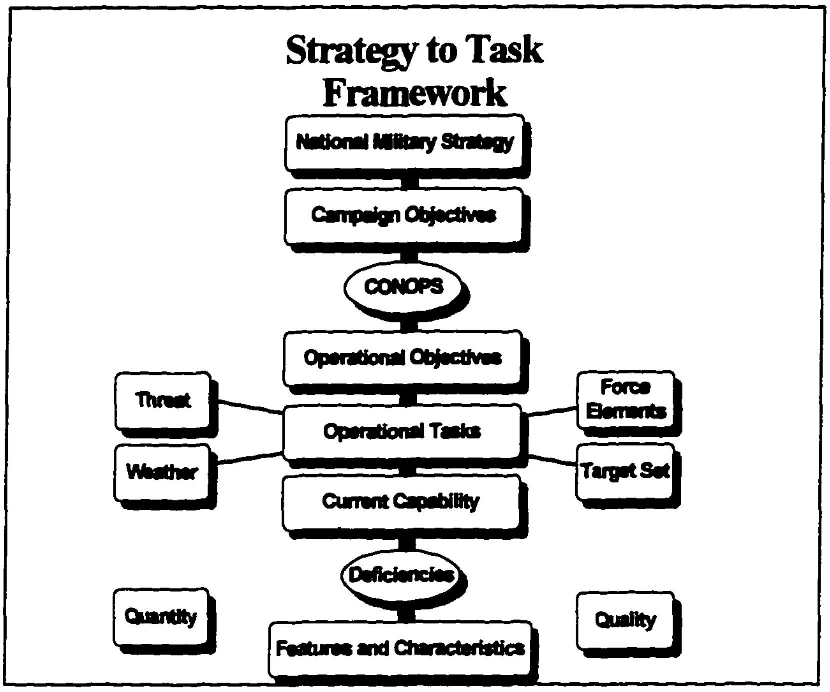

Figure 1 - Strategy to Task

National Goals (not shown here) which are at the top of this hierarchy are the nations most fundamental values. These goals are found in documents such as the U.S. Constitution and are permanent, regardless of the transient politics (Thaler 1993). The National Military Strategy of the United States of America 1995, lists the two national military objectives which U.S. Armed Forces are to accomplish. These objectives are promote stability and thwart aggression. The three components of the strategy are peacetime engagement, deterrence and conflict prevention, and fighting and winning our Nation's wars. The force required to support this strategy must possess (as a core requirement) the capability of fighting and winning two major regional conflicts (MRCs), nearly simultaneously. Five fundamental foundations brace the combat forces of the U.S. These are quality men and women, readiness, enhancements, modernization and balance (the appropriate mix of forces and capabilities). As described in the National Military Strategy (Joint Chiefs of Staff 1995): "The fourth foundation is modernization, which is vital to preserve the essential combat edge that U.S. forces now possess and to ensure future readiness. Due to budget constraints, major new investments will be pursued only where there is a substantial payoff. Existing weapons systems and platforms will continue to be updated to take advantage of rapid technological advances." This framework was directed for use within the Air Force for conducting modernization planning (HQ USAF 1994).

Figure 2 is a specific example of a strategies to task decomposition. In this example, the campaign objective is to establish air supremacy which means to gain and maintain control of the airspace. This broad, overarching objective can be further defined by the two operational objectives of reduce enemy sortie generation and defeat the enemy in the air. Reducing enemy sortie generation means to deny, damage or destroy manned air vehicles and/or their support facilities or equipment prior to vehicle launch. To defeat the enemy in the air is to deny, damage, or destroy airborne enemy aerospace vehicles prior to their employment of weapons against friendly forces including land, naval, and air units. The operational objectives can be further disaggregated and more specifically defined by the two operational tasks of neutralizing aircraft and neutralizing airfields. Using this systematic approach, beginning with the component of the U.S. National Military Strategy of fighting and winning our nations wars, and maintaining the capability of fighting and winning two major regional conflicts (MRCs), one can define discretely the military's specific wartime operational tasks. Thus, this approach furnishes specific top down guidance to be used in modernization planning.

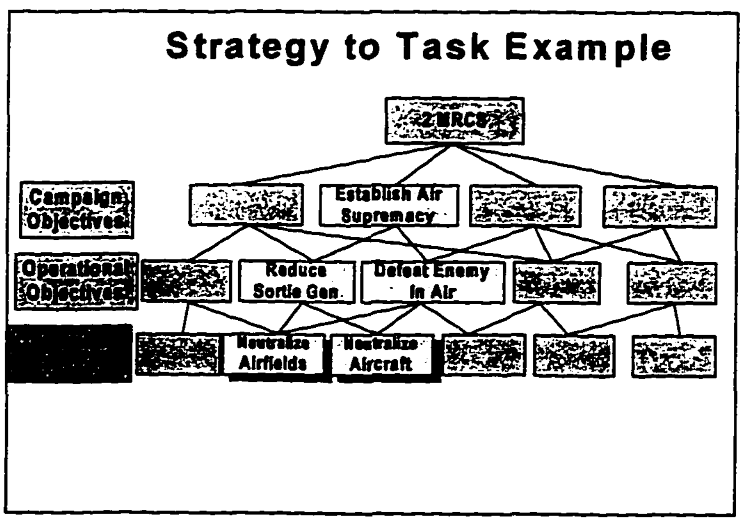

Figure 2- Strategy to Task Example

This system also provides a framework for advocating requirements from the bottom up. In other words, the tasks are directed units of work to be accomplished, and the modernization requirements are the necessary components to carry out that work. This approach also prescribes a philosophy, a systematic reasoned doctrine for advocating the importance of new modernization requirements. Although the construction of strategies to task framework is not the primary focus of this research, the significance of doing a credible job in this early definitional phase of a project cannot be over emphasized. Appendix A lists the campaign objectives, operational objectives, and operational tasks developed for this effort.

PROBLEM STATEMENT

Effective planning for the modernization of U.S. Air Force fighter aircraft requires a conception of what future tasks these aircraft will be called upon to perform, and what improvements and modifications will be required to successfully accomplish those tasks. In order to design a comprehensive, integrated plan from the myriad of potential candidate proposals, one must determine the value of individual projects and combinations of projects, assess the affordability, and finally allocate resources. This multifaceted problem affects every fighter in the Combat Air Forces (CAF) for the next eighteen years and includes programs valued at over $20 billion (Table 1). The decision process for funding new systems at Air Combat Command was an intuitive process led by a resource management team, which did not participate in the planning and up front analysis. There was no traceability, repeatability, or measurability of the combat capability impact of the budget decisions. There was also no way to quickly develop a new plan when the circumstances changed. Decisions in the past based on persuasiveness, impractical priorities, and personalities led to disconnects in logic and funding, and lacked defensible criteria. There was no responsive and quantifiable method for developing investment plans to modernize the fleet of fighter aircraft which was based on analysis, capability, and executive guidance.

Aircraft	Number of Aircraft	Number of Proposals	Capital Outlay Demand ($M)
A-10	375	34	1,713.9
F-117	54	57	2,442.7
F-15 A-D	525	81	7,305.4
F-15E	203	55	6,022.9
F-16 Blk 30	638	46	7,673.5
F-16 Blk 40	434	46	12,607.0
F-16 Blk 50	218	49	8,183.6
Miscellaneous	N/A	32	3,616.9

Table 1 - Fighter Aircraft and Proposed Modification Projects

RESEARCH OBJECTIVES

To support the attempt to link the planning process to the programming and budgeting process, a fundamental question of the value of proposed initiatives needed to be addressed. In order to assess the value, a clear understanding of management's objectives was required. Once the objectives were clearly understood, then the process of designing a decision support system to determine the most valuable alternatives could begin. The objective of this research was to design and develop a methodology which could be used to both measure the value of programs and to perform resource allocation based on that valuation process. The methodology was to develop an optimized, integrated plan of modernization programs considering the objectives of senior AF management. The optimized plan had to fit within the allocated budget, as determined by the Air Staff. The process was to consider proposed programs from several different aircraft and develop the best plan for investing across each type. In this problem, more than 400 projects, which spanned an 18 year planning window, were to be considered. Some of the projects were interrelated, which makes the resource allocation problem a more complex one. The ultimate objective was to build a decision support tool that could be used to develop a justifiable, analytical investment strategy.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

The purpose of this chapter is to review the previously published literature as it relates to multiple criteria decision making and capital budgeting, specifically military applications. The chapter is divided into three parts. The first part will describe knowledge gained from the review of published literature regarding capital budgeting and mathematical programming. The second part of the chapter will describe some relevant issues concerning the application of goal programming, as published in recent literature. The third section will focus on QFD literature which is most relevant to this research.

CAPITAL BUDGETING AND MATHEMATICAL PROGRAMMING

Capital Budgeting problems are not new, and in fact, some methods have been in existence for over 45 years. The published literature highlighted in this section will review the capital budgeting problem and related issues, discuss the application of mathematical programming, and give some related examples.

The capital budgeting problem can be broken down into the following four factors (Dean 1951):

1) <u>Demand:</u> how much money is needed for capital expenditures over the projected time periods? The "need" is generally measured by profitability.

2) <u>Supply:</u> how much money is available? This discussion centers on sources of funding (internal/external), retained earnings, etc.

3) <u>Rationing:</u> how should available capital be distributed among competing projects? Demand usually exceeds supply.

4) Timing: how should capital expenditures vary with adjustments in general business conditions? Here companies must balance savings against the risk that comes from imperfect foresight, which may produce obsolescence and excess capability.

"The capital budgeting decision is viewed as a many-sided decision of operating policy calling for collective wisdom in reconciling research dreams, production feasibility, competitive pressures and market acceptance" (Dean 1951). This statement has as much relevance today as it did 45 years ago. There are many different aspects involved in developing an investment recommendation, especially when the demand is not measured by profitability. There are many valuable lessons which can be taken from previous capital budgeting efforts which provide a useful starting point.

There are some key issues which should be addressed when dealing with capital budgeting problems. In a recent article, Dimkoff (1994) discusses some very basic budgeting mistakes, which he considers the most common ways to error when performing an economic analysis. The five mistakes highlighted are: ignoring the time value of money, basing decision on profits, emphasizing the payback method, letting sunk costs enter capital, and failure to consider only incremental costs. Mistakes number one, time value of money, number four, sunk costs, and number five, incremental costs are pertinent to this work. Regarding the time value of money issue, the author discusses problems with efforts which failed to capture the current worth of future sums of money. On the sunk costs question, there were many people who would argue that this approach should give credit to those programs which were already underway. In other words, programs which had already begun spending either R&D or acquisitions dollars. The author argues that these cost are historical and should not enter the decision. The only relevant costs are the additional outlays required to complete the project. Mistake number five, failure to consider only incremental costs is somewhat related to number four. In this area, the rule is that unless the organization will spend or receive more cash because of the project, the costs must not enter into the analysis. These lessons learned provided useful guidance in establishing capital budgeting philosophy.

In 1966 OR/MS analysts had a breakthrough linking some of the emerging optimization techniques to this type of problem and formulated and solved capital budgeting problems using linear programming (Bierman 1980). Initially, these problems were performed with the simplex algorithm and eventually analysts began using integer programming techniques for project selection models. Early references to Goal Programming (GP) and Capital Budgeting articles date back to 1973 (Schniederjans 1995). The following articles give more recent examples of GP (and one multiple objective, mixed integer problem) applied to capital budgeting problems.

Khorramshahgol and Okoruwa (1994) developed a GP model to allocate funds among different shopping malls to maximize investor's revenue. In this article, the authors used a Poisson regression model to forecast the expected patronization for different malls as one of the inputs into their GP model. The Delphi technique was used to specify the objectives for allocating resources. The model had three goals: predicted patronization rate, average income, and number of major tenants. The model would suggest, an optimum solution that would allocate funds for footage leases at different shopping malls.

Ramanathan and Ganesh (1995) developed a GP model which was integrated with the Analytic Heirarchy Process (AHP) to evaluate energy alternatives for lighting in households in India. The model had seven decision variables representing the different energy sources (Kerosene to Electricity) and 12 objectives. AHP priorities were elicited and used for qualitative assessment of the objectives where there was no quantitative data available. System efficiency, for example could be computed using historical data. Safety factors, on the other hand were computed using AHP. The model allocated the amount of each source which should be used for lighting based on the energy, economic and environmental objectives.

Barbarosoglu and Pinhas (1995) used a mixed integer programming model (not goal programming) in conjunction with AHP to allocate funds from the World Bank among several water provision and waste water treatment projects. These authors dealt with multiple goals in a different manner. Their approach was to use AHP to compare the objectives (economic, social, and political) and then to develop a heirarchy linked to the individual alternatives. Using this approach, the four drinking water projects and five waste water projects were evaluated. The mixed integer problem would allocate the resources among the alternatives across a 15 year planning horizon.

Thus, mathematical programming, specifically GP applications continue to be applied to the field of capital budgeting. These examples demonstrate the wide variety of problems to which these techniques have been applied. In each of these cases, the number of alternatives was relatively small, and none of the literature revealed GP applications in military capital budgeting.

GOAL PROGRAMMING ISSUES

Goal Programming, an extension of linear programming, is a multiple objective approach that enables analysts and planners to come as close as possible to satisfying various goals and constraints. The subject of GP itself continues to be studied by researchers who draw on personal experience and study the experiences of others to further enhance the knowledge and understanding of this topic. The following publications were helpful in this research, and will provide key issues for discussion in subsequent chapters.

Schniederjans (1995), in his book reviewed several issues related to GP model formulation strategies which appeared in literature and offered some practical advice for improving GP models. Two of these issues which were related to those encountered in this research included "incommensurability of goal constraints" and "technological parameter estimation."

The first issue, incommensurability of goal constraint, deals with one of the more inherent problems with using GP. That is, the various goals are measured using different units. For example, one goal, profitability, may be measured in dollars and another goal, trouble-free miles driven, may be measured in miles. Since a weighted, non-preemptive GP model attempts to minimize the total deviation from all goals, the solution would be biased towards the goals which have the largest magnitude, since this would result in the largest reduction in the objective function. The way Schniederjans recommends dealing with this is by scaling or normalizing of goal constraint parameters. Schniederjans offers the example:

Minimize: $Z = P_1 (d_1^- + d_1^+) + 0.1P_2 \ (d_2^- + d_2^+) + 0.9P_2 \ (d_3^- + d_3^+)$

subject to: $x_1 + x_2 - d_1^+ + d_1^- = 100$

$1{,}000x_1 - d_2^+ + d_2^- = 100{,}000$

$x_2 - d_3^+ + d_3^- = 100$

$d_i^-, d_i^+, x_j \geq 0$, for i=1, ..., 3; for j=1, ..., 2

The recommended correction method is to convert the technological coefficients and right-hand side values to percentages of their objectives by dividing by the goal constraint's respective right-hand side value and multiplying the ratio by 100. In this case, using the 2nd constraint equation above, divide 1,000(x_1) by 100,000 to get 0.01 and multiply by 100 to get a normalized value of 1. The new model would be as follows:

Minimize: $Z = P_1 (d_1^- + d_1^+) + 0.1P_2 (d_2^- + d_2^+) + 0.9P_2 (d_3^- + d_3^+)$

subject to: $x_1 + x_2 - d_1^+ + d_1^- = 100$

$x_1 - d_2^+ + d_2^- = 100$

$x_2 - d_3^+ + d_3^- = 100$

$d_i^-, d_i^+, x_j \geq 0$, for i=1, ..., 3; for j=1, ..., 2

The second issue deals with the estimation of technological parameter estimates. In his book Schniederjans discusses an approach based on the use of economics called *Input-output analysis*. This type of analysis can be used to create technological coefficients which reflect real world impact of different types of *posterior* system behavior. This means that one should be able to have some measure of this *posterior* behavior. The example given deals with the percentage of scrap generated in a multi-stage production process. In the case of evaluating these proposed modernization projects for conducting air combat, there is no way to accurately ascertain the posterior behavior, short of procuring the system and taking it to war, which is not feasible. The examples cited above, used AHP and regression techniques to evaluate alternatives, to determine the weights of their technological parameters, and perform capital budgeting.

Gass (1987), in his article, describes his experience in determining goal weights when solving large-scale goal programs. He makes the point that preemptive linear-goal programming for these type of problems is too restrictive and imposes unrealistic burden on the decision maker by requiring them to make strict statements of preemptive priorities. He also stresses that the idea of goal norming has little relevance in terms of what the basic problem really is: i.e. finding a suitable set of objective function weights that can be applied to over-and under-achievement deviation variables. This article makes a point that the analyst must determine how to best provide the decision makers with a selected set of compromise solutions from which to choose build a solution to implement. The approach the author recommends is referred to as multigoal programming. In this approach, the analyst elicits goal weightings from the decision makers as best he or she can. The resulting weighted objective linear program is solved along with sensitivity analysis about the goal. The results will therefore, include a number of compromise solutions using different weights.

Markland and Vickery (1986) describe the development of a solution strategy for solving large-scale integer goal programming problems. The application of the strategy was a computer-based multi-stage lot sizing model used for production scheduling. The paper emphasized the implementation of their model using commercial software. The reason that this article was found to be of particular interest, was due to the fact that most of the articles encountered which discussed integer goal programming approaches were applied to relatively small problems that did not propose a significant challenge to available solvers and machines. This problem consisted of 3,300 structural variables, of which, 78 were integer (production run quantities), and 85 were binary integer variables (occurrences of resource set-ups). The strategy adopted and applied was an iterative process which solved six sequential GP models in a stagewise fashion. The purpose of this approach was to reduce the number of explicit integer variables at each stage. The authors successfully applied the strategy and overcame, to some degree, the problem of sub-optimization across time periods by running the model in a stagewise-forward and a stagewise-backward approach.

Lessons learned from GP applications include issues which require careful attention, techniques for improving models and methods for solving large problems.

QUALITY FUNCTION DEPLOYMENT

In this section of the literature review, a focused discussion of pertinent QFD publications will be offered to put the application of this tool into context. The first publication is a book by two of the early Japanese QFD pioneers and the second article is a related application.

In their recently translated work, two early pioneers, Dr. Shigeru Mizuno and Yoji Akao (1994) provide a comprehensive discussion of various topics related to development and application of QFD. One of the areas discussed in their book deals with prioritization. Large, complex systems require prioritization in order to provide a strategic focus based on customer demands. The suggested method of prioritization in this text, starts with the customer demands, establishes themes for improvement based on evaluations of current circumstances, and assigning high scores to cases where there is a high level of achievement towards the stronger demands. These authors give some advice on carefully specifying the members of the evaluation team in advance, so that a bias does not develop in the scoring process. And, even though the judgments of individual members will vary based on experience, this can help rather than detract from the results. Although the specific judgments can be expected to be of the common sense variety, through combining the knowledge and wisdom of a number of properly selected evaluators, it is possible to gain a consensus regarding critical areas. Multidimensional evaluations of multiple factors, such as profitability, productivity, equipment investment, etc., must be performed to develop a business strategy. This prioritization based on customer demands is only a part of the process, and not a decision in itself. This step is simply a means to making higher-level decisions more definitive. The book concludes the chapter on prioritization with some ambiguous statements on the methodological maturity of prioritization via the demanded quality deployment table. The question of whether other operations research techniques might produce better results is raised. Clearly, this is an area where more research is needed.

In a NATO report (AGARD 1993), QFD was applied in a two-matrix architecture to study the problem of determining the potential effectiveness of 87 possible mobility improvements for NATO aircraft. The study recommends that a cost and operational effectiveness analysis (COEA) be performed to do a more thorough economic analysis. Thus, no bonafide, integrated cost and benefit analysis is offered through this work, rather a general, rough estimation of low, medium, or high for each project with a note for follow-on analysis.

The results of the literature review provide a basis for continued research. Capital budgeting problems have established links to mathematical programming, and research continues to provide new information about the formulation of GP models in this area. However, large integer GP models to perform capital budgeting were not discovered in the review of literature, and techniques for estimating the value of military systems were not revealed. The QFD literature shows that there is a precedent for using this tool for prioritization, however, no publications linked the output of QFD to capital budgeting or GP. Thus, there is a basis for the research and an opportunity to examine the integration of these techniques.

CHAPTER III

METHODOLOGY

The methodology applied in this research was an integrated approach combining Quality Function Deployment (QFD), Capital Budgeting, and Goal Programming (GP) in a unique manner (Figure 3). QFD was applied to the Strategies to Task framework to develop weights and priorities for the various candidate modification projects. These weights were termed combat capability. Capital budgeting objectives, elicited from senior leadership (called executive guidance in this diagram) served as a basis for setting management priorities. An Integer GP model was developed using the weights, generated by QFD to perform the capital budgeting and to allocate resources in an optimum manner. This chapter will describe the methodology and application.

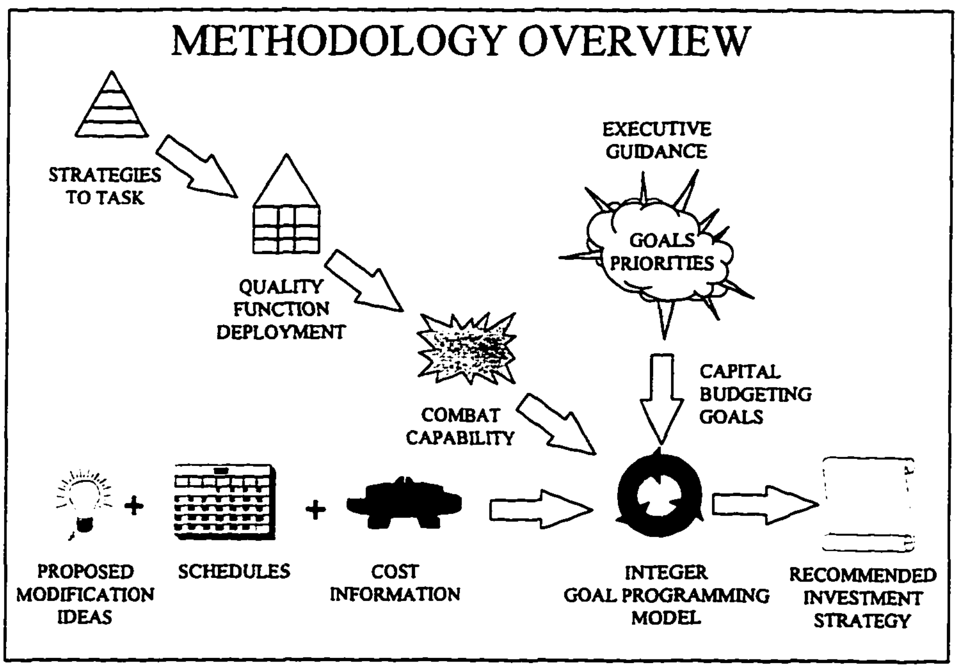

Figure 3 - Methodology Overview

QUALITY FUNCTION DEPLOYMENT AND PRIORITIZATION

QFD was used in this analysis not only to link the proposed modernization projects to the Strategies to Task framework, but was also used to establish priorities (and weights) for each project. The definition for QFD, most appropriate for the application in this thesis, is as follows: "a systematic way of ensuring that the development of product features, characteristics, and specifications, as well as the selection and development of process equipment, methods, and controls, are driven by the demands of the customer or marketplace" (Eureka and Ryan 1994). These authors also offer the following collection of definitions from practitioners to describe this tool:

- "A sophisticated Pareto analysis.
- A fundamental, commonsense approach to product development that focuses on proactive rather than reactive quality control.
- A technique to help neutralize the voice of the customer.
- A systematic way of documenting and breaking down customer needs into manageable, actionable details.
- A planning methodology that organizes relevant information to facilitate better decision making.
- A framework for customer-derived product development objectives.
- A way of reducing the uncertainty involved in product and process design.
- A technique that promotes cross-functional teamwork.
- A methodology that gets the right people together early onto work efficiently and effectively to meet customer needs." (Eureka and Ryan 1994).

One thing that is apparent from these definitions, is that QFD involves a customer, an analysis process, a product, and a team approach. This section of the methodology chapter will explain the fundamental philosophy, the basic QFD house of quality chosen, the design of the QFD matrices and the role of the evaluation team.

Fundamental Philosophy

The fundamental philosophy behind QFD and the basic philosophy of strategies to task have a very similar theme, well suited for this research. That philosophy (QFD), starts with top level strategy, systematically disaggregrates the strategy into actionable details and links lower level activities to this strategy. An underlying philosophy behind QFD, called *hoshin* management, is "a system of deploying corporate strategies and plans into yearly activities, promoted by specific targets and implementation means at all levels in the organization" (Mizuno and Akao 1994). Thus, quality planning, quality design, and quality assurance activities needed to be linked to top corporate strategies, through the use of quality functions which are cross-functional and their control interdepartmental. "*Hoshin* management is implemented not merely to achieve quality targets but also to link TQM activities for fulfillment of all critical management objectives" (Mizuno and Akao 1994). So, the corporate goals are not merely a charming rhetorical phrase. Rather, these goals become the defining force, or the underlying tactics weaving together all daily activities and focusing them on a common goal. In this context *hoshin* management has a mobilizing effect, interlocking activities from all functional areas with the strategic focus of management. QFD is a proven method for linking functional level activities to management objectives.

Strategies to task, a hierarchical method for linking national goals and interests with operational activities at the tactical engagement level, has a very similar philosophy. This method starts with the broadest national goals, and systematically links specific functional level tasks to these goals. In order to formulate the best strategic investment plan, the allocation of resources must be linked to the strategies to task framework. This linkage should be accomplished with an operational focus, in a optimal manner to achieve the best overall effect (Kent 1989).

Therefore, in the context of this research, QFD has two primary purposes. First, to translate the top level strategies into specific actionable details. This is often called the voice of the customer. In this case, the Air Combat Command (ACC) top level strategies can be derived and translated into specific detailed requirements, representing the voice of the customer. QFD provides a way of linking modernization planning activities to these critical management objectives. Secondly, QFD provides a way of prioritizing fighter aircraft modernization features, characteristics, and specifications and ensuring these are driven by the demands of the customer or ACC.

In order to determine which modernization projects would potentially yield the best overall effect in achieving objectives and winning campaigns, a scoring scheme was needed. This scheme would develop measures of worth for each candidate modification (sometimes referred to as a "solution") project. QFD was chosen as the method to generate pseudo combat capability measures. It is difficult, if not impossible to measure, in absolute terms, the marginal, potential combat capability of every modification, even with very large, complex simulations. Some of the projects considered, such as color displays, landing gear wires and switches, and improved aircraft batteries would never affect a change in the outcome of large simulation models, because these models generally do not include this level of detail. These projects however, are important candidates and provide significant capability to the user (ACC), and therefore merit careful consideration in the development of investment strategies. Many corporate organizations are turning to QFD, a market-driven product definition process, to ensure they satisfy the requirements of all important customers (Farrell 1994).

Basic House of Quality Adapted

There are many different QFD designs available, which can be customized to fit various applications. The model selected for use in this study is called a house of quality. Figure 4 shows a typical QFD House of Quality. On the left are the "what" items or the objectives (customer requirements), which have all been defined in a previous step. These "whats" often begin as loosely stated objectives of what is to be accomplished, that require further detailed definition. In order to satisfy the customer, we must attack and disaggregate these objectives into more actionable details. These details are the "how" items which you see across the top of the matrix. The roof of the house is a triangular correlation matrix, which may be used to describe the degree of correlation between each "how" item. The part of the house to the far right is labeled "why". This room is where the priorities of the what items are captured. Some objectives may be more important than others. The bottom room of the matrix, "how much" describes the relative weighting of the "hows" in the respective column above. The mechanics are based on a recurring "what" to "how" theme where you enter from the top and assess each intersection, to determine the amount of contribution a "how" has to a particular "what". This room is the relationship matrix. QFD uses a (9-3-1) standard scale placing stronger (9) emphasis on most important items, in terms of contribution strength.

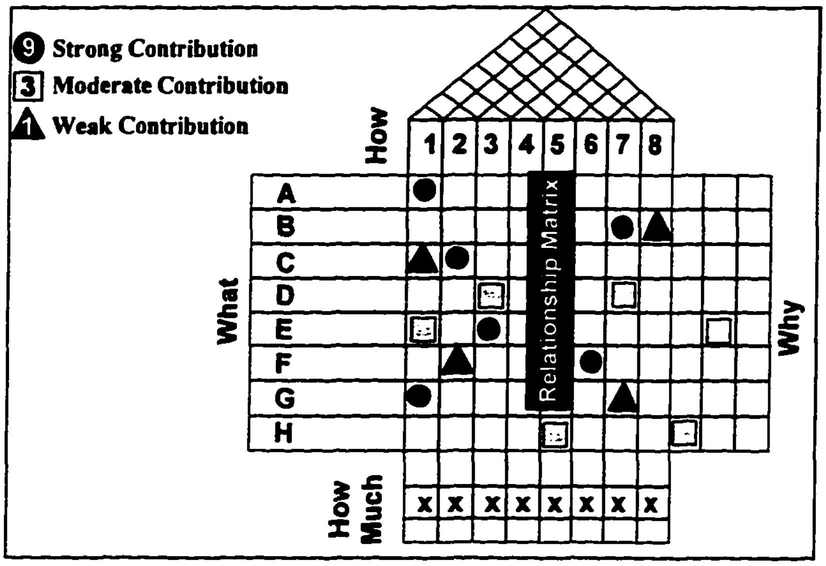

Figure 4 - QFD House of Quality

Integrated Matrix Design

The first step in this phase of the project was to lay out an inter-linked matrix design. The design process addressed some very basic but essential questions. Which operational objective is the most important? Which task is most important? Thus, the desired output at every stage in the process shaped the final matrix designs. The command defined deficiencies were prioritized through this cascading (deploying) of objectives from strategies to task analysis using interlinked houses of quality (Figure 5). This method is not foolproof, but does provide structured process for capturing intuition and knowledge that is documented and repeatable.

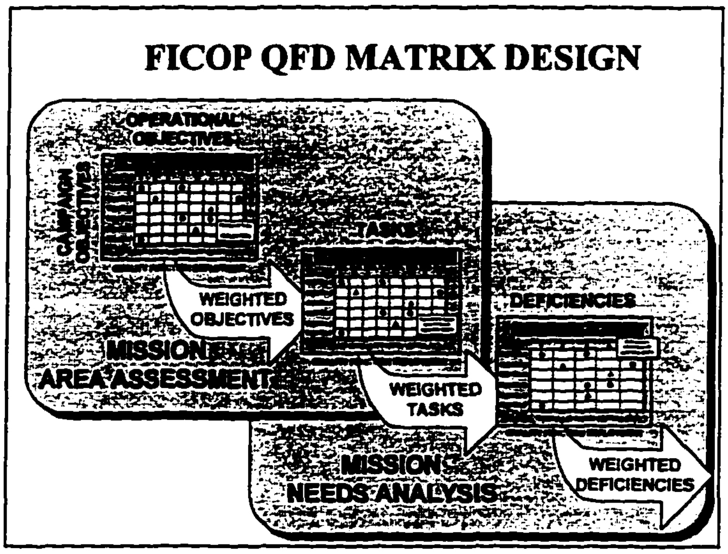

Figure 5 - FICOP QFD Matrix Design

At the end of the this matrix design, the prioritized and weighted command deficiencies were generated. The next step in the matrix design was to adjust the weighting of the deficiencies by aircraft (Figure 6). The question to be answered at this step was: Where (which aircraft) does this capability need to reside? Deficiencies are not equally relevant across platforms. A deficiency that is critical to the mission of one aircraft may have a lower applicability to another. The intent of this step was to add platform relevance to the deficiency score. The deficiencies, by the previously designed matrices, would already have a command priority and weighting, relative to all of the other deficiencies. The desired outcome of this process was to increase or decrease weights of specific prioritized deficiencies according to aircraft type, by considering the mission performed, current capability, and projected requirements. This assessment would result in 10 separate lists of deficiency weights. These deficiencies and their adjusted weightings were "deployed" in the design to the next evaluation level, the solution assessment phase.

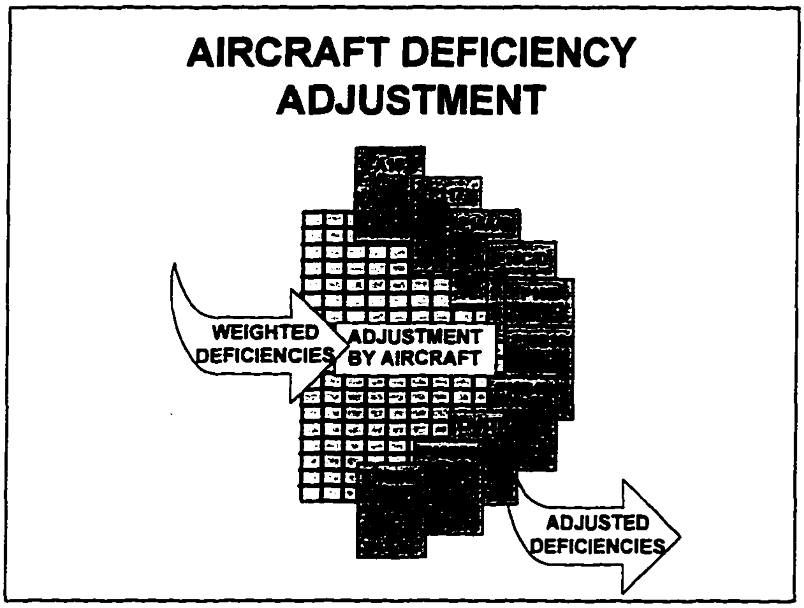

Figure 6 - Aircraft Deficiency Adjustment

The next step was to evaluate each of the candidate modification projects (solutions to deficiencies) against each of the deficiencies (Figure 7). The question to be answered by this step in the integrated matrix design was: What is the overall relative worth of the solutions in providing the capability prescribed in the deficiency descriptions? The design was meant to capture the total contribution value of each solution. A solution which could greatly assist in solving (alleviating) capability shortfall over a large number of deficiencies should receive a high score by this design. A solution which contributes to only one or a few deficiencies would receive a lower resultant weighting. This relative, marginal contribution value was referred to as a combat capability measure. Thus, at this step, every modification proposal was examined to determine which deficiencies it would help alleviate and to what degree. The results were weighted scores which were used as a measure of the potential, relative combat capability offered by that solution. This score was attributable to strategies to task, developed using a systematic analytical approach, reproducible, and consistent for each of the modifications.

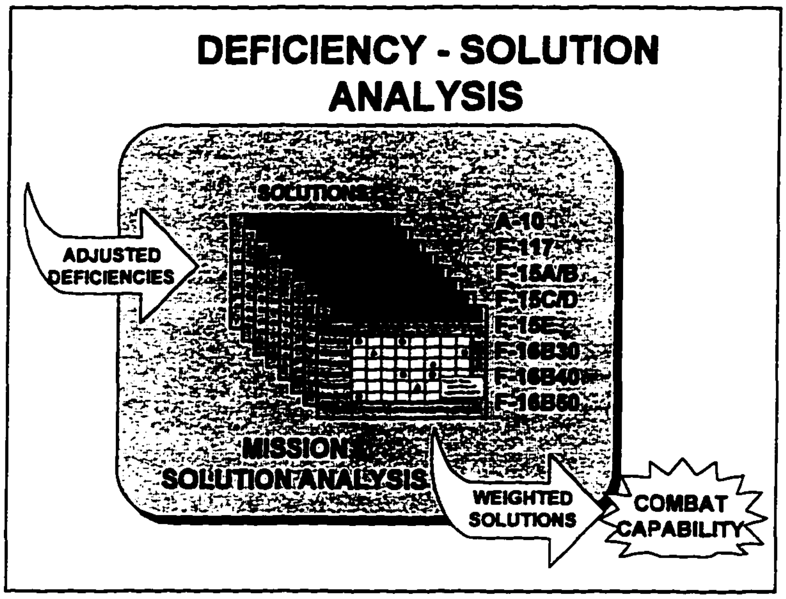

Figure 7- Deficiency - Solution Analysis

Using this integrated matrix design approach, the methodology can capture the benefit of programs which have cross-cutting contributions (Figure 8). Program A contributes to four mission areas, whereas program F contributes to 11 mission areas. Therefore, program F, in all likelihood, would have a higher contribution value score than would program A. The strength of the contribution relationships is not apparent in this example. In this case, QFD accumulates the potential benefit score for each program based on the number of deficiencies that program addresses and the degree to which the solution contributes. The interlinked matrix design explicitly captures this cross-cutting effect.

The Evaluation Team

A multifunctional group of evaluators was formed to collect the necessary information and make the necessary evaluations for the QFD analysis. The evaluation team was composed of fighter pilots, analysts, engineers, maintenance officers, intelligence and communications officers, other functional representatives (e.g. Air National Guard) and, periodically, program managers. The FICOP core team was made up of six individuals, including the author.

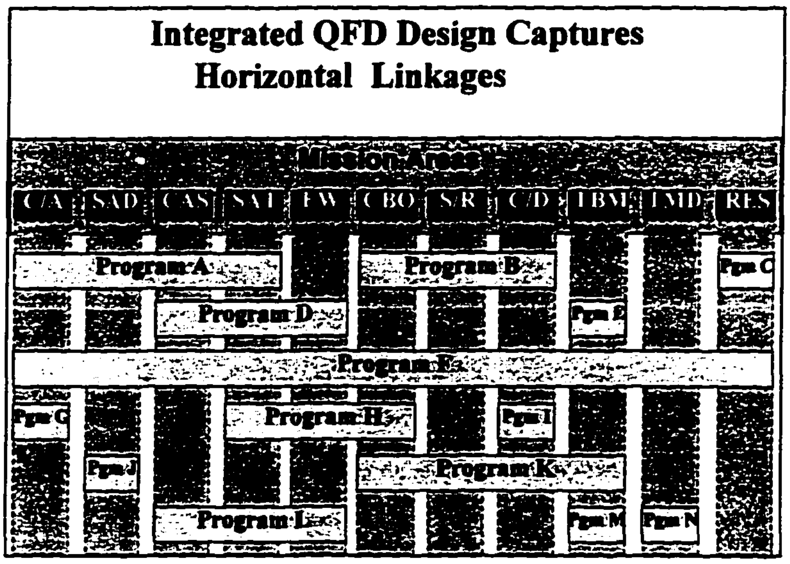

Figure 8- QFD Horizontal Linkages

The core team would often meet to prepare the matrices for the expanded team's review and evaluation, and perform consistency checks after the evaluations were completed. The expanded FICOP team would bring additional expertise, research on specific issues and functional experience to help inform the group's judgments for the evaluation process.

The core team met frequently, on average of three to times per week, over the six month time span. The job of this team was to manage the generation of the information and ensure consistency, completeness, and accuracy. The expanded evaluation group met twice a week in the early phases and about once a week after the first six weeks. Initially, the meetings were mostly brainstorming sessions to validate the strategy to task elements and definitions. The evaluation sessions were very dynamic, and the discussion at each of the intersections invaluable. Typically, the core team would meet for about two hours at a time, and the expanded evaluation group from two to four hours.

Figure 9 shows a typical (partial) QFD matrix which was generated by the evaluation team. In this matrix, the team evaluated each operational objective ("Hows") in terms of it's contribution to the campaign objectives ("Whats"). While performing this type of evaluation, contributions by those with particular knowledge on a given topic were offered to the group, thus increasing the group's overall awareness through a focused dialogue. This approach proved to be a very productive means of capturing wisdom and experience which could be used later in the process.

FICOP 96 (Example)
Operational Objective vs Campaign Objective

● Strong Contribution
◎ Moderate Contribution
△ Weak Contribution

Campaign Objectives "What" Items \ Operational Objectives "How" Items	Establish information dominance	Defeat enemy in the air	Reduce enemy sortie generation	Counter enemy air defenses	Degrade enemy command & control	Interdict ground forces	Interdict naval forces
Establish aerospace supremacy	△	●	●	●	◎		△
Establish maritime supremacy	△	△		△	◎		●
Counter weapons of mass destruction	◎	◎	◎		◎	△	△
Degrade war sustaining capability	△	△		△		◎	
Defeat ground forces	△	△	△	◎	◎	●	

Figure 9 - FICOP Example Matrix

The QFD process described above provided a structured way to articulate the Combat Air Force's fighter requirements. This process also guided the study to investigate specific issues in a deliberate fashion, rather than in an ad hoc approach. The process involved many different functional representatives and integrated their inputs into systematic scheme for assessing priorities. Thus the stage was set for a robust approach for linking the allocation of resources to this framework.

CAPITAL BUDGETING DEVELOPMENT

The capital budgeting methodology is based on research which has evolved over the years to include the use of mathematical programming algorithms that efficiently develop solutions to complex problems. Many capital budgeting models use some estimate of the potential monetary gain to be realized from the respective investments as a measure of merit in the objective function. Popular choices were Net Terminal Value (NTV), Internal Rate of Return (IRR) or Yield. In this case, since these fighter modification projects do not yield any monetary returns, the primary measure of merit is the combat capability metric. However, there are other factors which influence the investment decision which must be considered as well. This section will describe the development of the capital budgeting approach.

Integer programming models have long been applied to capital budgeting problems where the decision variables are binary. The initial problem formulation is based on a classical capital budgeting problem formulation:

$$\text{Maximize} \quad Z = \sum_{j=1}^{n} w_j x_j$$

subject to

$$\sum_{j=1}^{n} c_{tj} x_j \leq C_t,\ t=1,\ldots,T$$

where

$n =$ the number of projects

$w_j =$ the coefficient which represents the per unit, marginal value associated with each project j

(Typically, w_j represents the marginal return associated with investments in various capital projects. In this case, w_j is a measure of marginal combat capability increase associated with the different projects.)

$c_{tj} =$ cost of project j in year t

$C_t =$ the maximum allowable budget for time period t

$T =$ the total number of years, and

$x_j = 0$ or 1, represents decision variables for each project j

The problem with this approach was that there were other factors which the decision makers wanted considered in the development of an investment strategy. The other goals to be considered were reducing the cost of operating the fleet (operations and support), managing technical risk, and maximizing opportunities to share development and acquisition cost. The addition of the cost of ownership goal was the most significant, and required considerable development to define and generate. The technical risk and cost sharing were reasonably straightforward. The desire of senior leadership to broaden the factors considered moved the research away from the classical integer programming model to an integer, goal programming model (also called zero-one, goal programming, ZOGP) which will be explained below. The capital budgeting goals used in this analysis were as follows:

Combat Capability: Maximize the total combat capability value of projects selected, as measured by the QFD score of each modification project. This approach gives more credit to modification which deliver the most potential combat capability. Those projects with higher QFD score are more attractive to the model.

Cost of Ownership (Savings) : This objective was chosen to highlight projects which have a potentially significant impact (if funded and installed) in reducing the cost of operating the Air Combat Command fleet. There are projects which are proposed on the merit of their potential to save operations and support (O&S) funds over some more costly procedure currently practiced. This savings could come from either consumables, fuel, contractor support, software maintenance, manpower, or depot level repair/maintenance. Essentially, this factor captures the total possible O&S savings of a project over the time span of the study. The calculation of savings starts after the first full year of installation.

This objective considers the time value of money by computing the present value of future savings. The basic concept behind present value is that cash available in the near future is worth more than the same amount of cash at some distant point in the future (Shillinglaw and McGahran 1993). This method allows a single measure (total present value) for the cost of ownership savings, and permits each project to compete on a common basis. One of the most common mistakes made in capital budgeting is ignoring the time value of money (Dimkoff 1994). The present value calculation allowed the time value of money to be considered in determining an aggregate measure for the cost of ownership savings goal.

FMS/Joint: Maximize the participation in projects which have a significant potential/agreement for cost sharing between foreign military sales and/or joint services. Give more credit to those modifications which have FMS or Joint agreements.

Technical Risk: Minimize the technical risk value associated with the selection of the various projects which have a technical risk rating. Give more credit to modifications which have lower technical risk.

Budget Utilization: Maximize utilization of the available budget. Use as much of the available budget as possible.

The capital budgeting framework developed the basis on which to allocate resources according to the critical objectives of management. This analysis began with a more classical approach and incorporated revised direction and input from leadership. Thus, this framework provides a way of linking the allocation of resources to strategies to task and to achieving critical management objectives. Goal programming provides the multiple criteria decision making tool to perform the resource rationing.

GOAL PROGRAMMING MODEL DEVELOPMENT

Goal Programming (GP) is a multiple objective approach which allows the trade-off of different goals which are not commensurate and often conflicting. The capital budgeting model developed for this analysis, is a weighted GP model, that assigns relative weights to the deviation variables to control the level of importance of the respective goals. Within the model, the emphasis on the different variables was adjusted according to senior leadership direction. This was accomplished by adjusting the objective function coefficients for the deviation variables which correspond to the various goals. Figure 10 shows a representative output of the level of achievement for each goal. The model is a nonpreemptive model that strives to minimize the total weighted deviation from all goals stated in the model according the desired emphasis on each of these goals. The model formulation is given below.

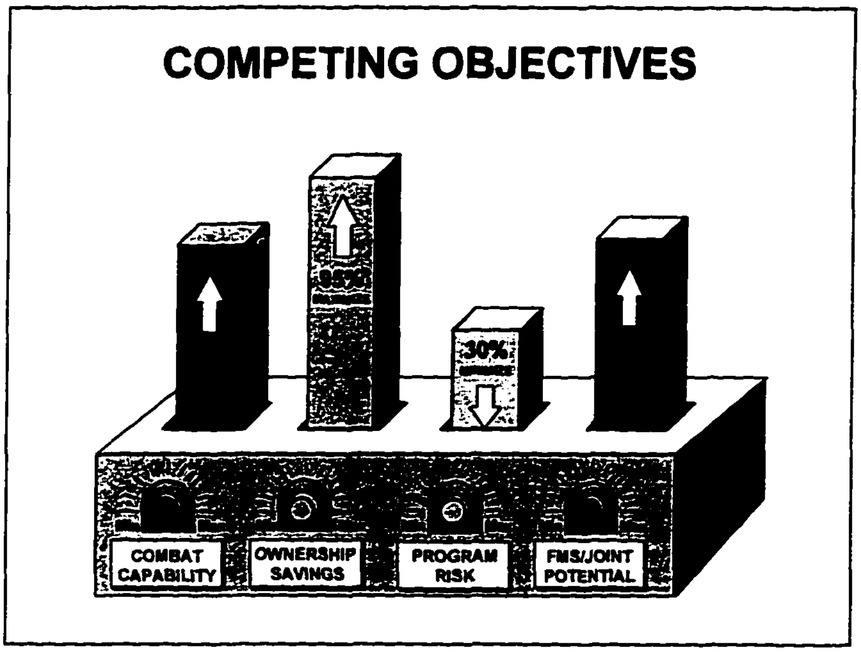

Figure 10 - Competing Objectives

Model Formulation

The GP model developed was a weighted, nonpreemptive model consisting of five goals, 400 binary decision variables and 120 constraints.

__Decision Variables:__ $x_1, x_2, x_3, \ldots x_j, \ldots x_{400}$ representing the 400 proposed, candidate modification projects. x_j is a binary variable taking the value 1 when the j^{th} project is selected or 0 if the j^{th} project is not selected.

__Objective Function:__

$$\text{Minimize} \quad Y_1 d_{wu} + Y_2 d_{cu} + Y_3 d_{fu} + Y_4 d_{rv} + Y_5 \sum_{i=1}^{m} d_{pu_i}$$

where

Y_1 to Y_5 = nonnegative constants representing the relative weight assigned to the deviation variables.

m = number of years considered.

d_{wu} = underachievement deviation variable for combat capability weight.

d_{cu} = underachievement deviation variable for cost of ownership savings.

d_{fu} = underachievement deviation variable for cost sharing (FMS/Joint).

d_{tv} = overachievement deviation variable for technical risk, and

d_{pui} = underachievement deviation variable for budget utilization.

Goal Constraints

Subject to:

- **Combat Capability:** Minimize the underachievement of the goal of attaining the total importance weight. The constraint equation for this goal is as follows:

$$\sum_{j=1}^{n} w_j x_j + d_{wu} - d_{wv} = W_{Goal}$$

where

n = the total number of projects.

w_j = the combat capability weight (QFD score) associated with each project j.

x_j = 0 or 1, represents decision variables for each project j

d_{wu} = underachievement deviation variable for combat capability.

d_{wv} = overachievement deviational variables for combat capability, and

W_{Goal} is the weight goal, the total weight possible summing across all projects.

- **Cost of Ownership Savings:** Minimize the underachievement of the goal of attaining the total O&S savings. The constraint equation for this goal is as follows:

$$\sum_{j=1}^{n} c_j x_j + d_{cu} - d_{cv} = C_{Goal}$$

where

c_j = the O&S savings (NPV) associated with each project j.

x_j = 0 or 1, represents decision variables for each project j

d_{cu} = underachievement deviational variable for O&S savings.

d_{cv} = overachievement deviational variable for O&S savings, and

C_{Goal} = the cost of ownership savings goal, the total cost of ownership savings possible summing across all projects.

- **Cost Sharing (FMS/Joint Participation):** Minimize the underachievement of the goal of attaining the total FMS/Joint score. The constraint equation for this goal is as follows:

$$\sum_{j=1}^{n} f_j x_j + d_{fu} - d_{fv} = F_{Goal}$$

where

f_j = the cost sharing score associated with each project j.

x_j = 0 or 1, represents decision variables for each project j

d_{fu} = underachievement deviational variable for cost sharing.

d_{fv} = overachievement deviational variable for cost sharing, and

F_{Goal} = the total cost sharing goal possible, summing across all projects.

- **Technical Risk:** Minimize the overachievement of the goal of attaining the lowest possible technical risk score. The constraint equation for this goal is as follows:

$$\sum_{j=1}^{n} t_j x_j + d_{tu} - d_{tv} = T_{Goal}$$

where

t_j = the technical risk score associated with each project j.

x_j = 0 or 1, represents decision variables for each project *j*

d_{tu} = underachievement deviational variable for technical risk.

d_{tv} = overachievement deviational variable for technical risk, and

T_{Goal} is the technical risk goal, in this case zero (0).

- **Budget Utilization:** Minimize the underachievement of the goal of spending the projected annual budget. The series of *m* constraint equations (one for each year) for this goal are as follows:

$$\sum_{j=1}^{n} p_{ij} x_j + d_{pu_i} - d_{pv_i} = B_{Goal_i}, \quad i=1..m$$

where

m = the number of years considered.

p_{ij} = the price (outlay required) of project j in year i.

x_j = 0 or 1, represents decision variables for each project *j*

d_{pu} = underachievement deviational variable for budget utilization.

d_{pv} = overachievement deviational variable for budget utilization, and

$B_{Goal\,i}$ = the maximum allowable budget for year i, i=1,...,m (years).

<u>Nonnegativity Constraints</u>

$x_1, x_2, x_3, \ldots x_j, \ldots x_{400}$ = nonnegative and binary.

$Y_k \geq 0$, for k=1,..,4 and

$$d_{wu}, d_{wv}, d_{cu}, d_{cv}, d_{fu}, d_{fv}, d_{tu}, d_{tv}, d_{pu}, d_{pv} \geq 0 .$$

<u>System Dependency Constraints</u> (there were more than 100 interdependency equations):

<u>Type 1:</u> $x_j - x_k = 0$ Project j and project k are codependent, if one is selected then the other must also be selected. Project j will not function without project k and the reverse also holds true.

<u>Type 2:</u> $x_j + x_k \leq 1$ Project j and project k are mutually exclusive, if one is selected then the other cannot be selected. Project j cannot be used in conjunction with project k and the reverse also holds true.

<u>Type 3:</u> $x_j - x_k \geq 0$ Project k needs project j, if project k is selected then project j must also be selected. Project j can be selected alone, however project k cannot. Project j can be used alone or in conjunction with project k and the reverse is not true. Project k provides no useful function without project j.

This model is the baseline from which many derivatives were built. One such derivative was constructed to deal with the issue of incommensurability of goal constraints. The recommended approach above (Schniederjans 1995) was very similar to the one adopted for this research with the exception of the multiplication by 100. In this particular case the above stated model changed as follows:

$$\text{Minimize } Y_1 d_{wu} + Y_2 d_{cu} + Y_3 d_{fu} + Y_4 d_{rv} + Y_5 \sum_{i=1}^{m} d_{pu}$$

$$\sum_{j=1}^{n} (w_j / W_{Goal}) x_j + d_{wu} - d_{wv} = W_{Goal} / W_{Goal}$$

$$\sum_{j=1}^{n} (c_j / C_{Goal}) x_j + d_{cu} - d_{cv} = C_{Goal} / C_{Goal}$$

$$\sum_{j=1}^{n}(f_j / F_{Goal})x_j + d_{fu} - d_{fv} = F_{Goal} / F_{Goal}$$

$$\sum_{j=1}^{n}(t_j / T_{Goal})x_j + d_{tu} - d_{tv} = T_{Goal} / T_{Goal}$$

$$\sum_{j=1}^{n}(p_{ij} / B_{Goal_i})x_j + d_{pu_i} - d_{pv_i} = B_{Goal_i} / B_{Goal_i}$$

This GP model was designed to permit management to trade off different levels of importance assigned to each of the goals, which represented critical objectives. The flexibility offered by GP to consider competing objectives which are not necessarily commensurate is one of the strengths of this tool. For example, with technical risk, the model is attempting to minimize this goal, whereas the other goals are maximizing functions. It is important to understand how the goals are developed, how they relate to one another, and what the weights are actually accomplishing.

DATA GENERATION

ACC Mission Area Plans (MAPs) provided much of the initializing data for this project. MAPs, the official documentation of the Air Force Modernization Planning Process, cover a 25 year period and use prescribed guidance (including Defense Planning Guidance and Strategies to Task) to document the most effective means of correcting task deficiencies from among nonmateriel solutions, changes in force structure, systems modifications or upgrades, science and technology applications, and new acquisitions. ACC MAPs are developed by integrated product teams with representatives from Air Force Materiel Command (AFMC), National Laboratories, and the independent research and development efforts of academic institutions and industry. The primary data derived from these documents were the descriptions of the operational tasks and the operational deficiencies and proposed solutions (aircraft modification projects).

The generation of cost data proved to be a difficult and time consuming part of this research. Although some of the proposed projects were not new ideas, unless a project was previously funded, generally there was not a completed cost estimate which could be used directly. Some of the modification projects were conceptual and therefore specific configurations and quantities had to be developed in a concept of operations before costing activities could begin. AFMC supports the MPP through Technical Planning Integrated Product Teams (TPIPTs). TPIPTs support the MPP with analysis, concept development, technology need identification, and cost estimating. In addition to coordinating and integrating AFMC support, the TPIPTs coordinate national laboratories, industry, and academia input into the MPP. AFMC provided the cost estimates as well as the assessment of technical risk and cost sharing opportunities. Table 2 lists a sample of the summarized input data.

AC Type	ID NUMBER	Weight (QFD)	FMS/Joint	Tech Risk	CostOwn	FY98	FY99
A-10	A100001	216011	0	0	21.99	3	5.9
A-10	A100002	1750597	10	5	162.64	37.6	30.1
A-10	A100003	904230	10	5	0.00	33.6	17.1
A-10	A100004	179856	0	0	0.00	0	6
A-10	A100005	1937092	0	5	33.93	0	2.4
Engines	ENGN002	134409	0	0	14.83	0.9	0.9
Engines	ENGN003	79821	0	0	0.00	0.7	0.7
Engines	ENGN004	16974	0	0	11.29	3.5	3.5

Table 2 - Sample Data Sheet

The first column is the system or aircraft type. Next is the project ID number, followed by the QFD score. The next column is the cost sharing metric. In this case, either a project has a cost sharing agreement (indicated by a score of 10) or it does not (indicated by a score of 0). The next column is the technical risk assessment. There were three values given to technical risk, high (10), medium (5), or low (0). The next column contained the cost of ownership value, the net present value of the O&S savings over the 18 year period in consideration. Then there were 18 columns which contained a total outlay required for each specific year. This sample sheet represents a Microsoft Excel (Microsoft 1994) spreadsheet which was linked to 12 other Microsoft Excel spreadsheets which contained the specific strategies to task scores, deficiency scores, modification project scores, as well as the cost data sheets. Thus, an interactive decision support system was built which could recalculate quickly. Therefore, the inputs to the goal programming model were dynamic and easily accessible. SAS (SAS 1988a) data analysis software read the inputs directly from the Excel spreadsheets and put the outputs of the GP model back into a spreadsheet.

METHODOLOGY SUMMARY

The methodology developed for this research integrated in a new way QFD, capital budgeting. and goal programming. As seen from this chapter, QFD helps to structure the information about the various proposals and develop priorities. Capital budgeting provides a well established approach to allocating resources to competing projects. Goal programming provides a way to integrate this information to meet other key management objectives. This approach is similar to some that have been applied before using other tools.

CHAPTER IV

DISCUSSION OF RESULTS AND CONCLUSIONS

RESULTS

Through this research, three very useful findings were obtained. First, a multi-stage QFD model can provide consistent technological parameter weights as inputs into a capital budgeting process. Secondly, QFD and Integer Goal Programming can be run interactively, even for large scale problems. Thirdly, and most importantly, these types of decision support tools can provide usable, responsive information to decision makers. This section will examine each of these findings and offer data to substantiate these claims.

The technological parameter estimation method adopted here is very different from any approach which was found in the literature, and is at the core of this research. Specifically, w_j, the technological parameter which represents the marginal contribution values which we call combat capability was computed using QFD. The challenge for this research was to develop technological parameter estimates which could be used as inputs into a GP model, and that were tied to the strategies to task framework. Technological parameter estimates should permit variation in range that is roughly proportional to the range of cost, in order to reach an optimal solution which makes sense. This simply means that things that are very expensive should have an opportunity, via this parameter, to receive a proportionally high combat capability score. How does one know if the answer which is produced by this decision support system is "right?" There is not just one "right" answer. The answer which is most correct is the one which the decision makers find logical, defensible, and *acceptable*. The following discussion will describe the approach taken in this research for deriving technological parameter estimates for combat capability.

In order to have meaningful results from a capital budgeting problem, as stated above the estimates for value must be uniform for all proposals (Dean 1951). The combat capability metric used in this analysis was the most important criterion. This metric was developed by using QFD to link each of the modification projects to the strategies to task framework, and to develop uniform measures of value for each proposed modification. Early in the project, during discussions with the senior leadership, the Commander of ACC drew a chart similar to Figure 11 below. The point was made during the discussion that one should be able to plot the capability versus the cost for each project and that a good selection process would pick those projects which would yield the best value. Thus, the logical, defensible and acceptable answer in this case is the set of alternatives which give the most capability for the least cost.

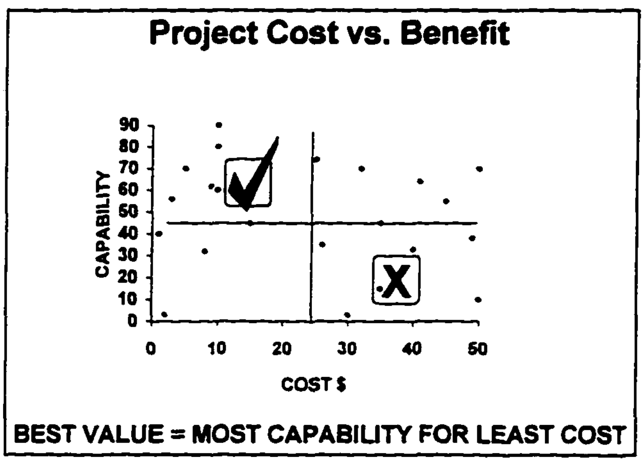

Figure 11 - Cost vs. Benefit

Using the QFD approach described above in Figures 5 through 7, this result was achieved. The magnitude of the combat capability scores adequately distinguished the importance of the projects, so that those which were expensive were only selected if their respective capability value was very high. Of course, as mentioned above there were other objectives which were considered such as reducing O&S cost, minimizing technical risk and maximizing cost sharing opportunities. The metric for each of these objectives also influenced the selection of alternatives in the goal programming model outcome. The combat capability metric, however, was the objective which appeared to be of paramount importance, both in terms of development effort and management emphasis. Therefore, it was essential that the QFD score representing this metric exhibit the desired behavior.

Figure 12 below shows an actual example with nine projects of varying cost and capability values (QFD Weights). Circles represent projects which were selected and "X" represents projects which were not. Specific project names are not given due to sensitivities about cost. Notice that the project, Mod 15 and Mod 44 are about equal in capability, but Mod 44 is more expensive. Thus it makes sense that Mod 15 would be selected. Mod 33 and Mod 21 are about the same cost, however, Mod 33 is significantly greater in capability (QFD Weight) than Mod 21. Thus Mod 33 is selected in this instance.

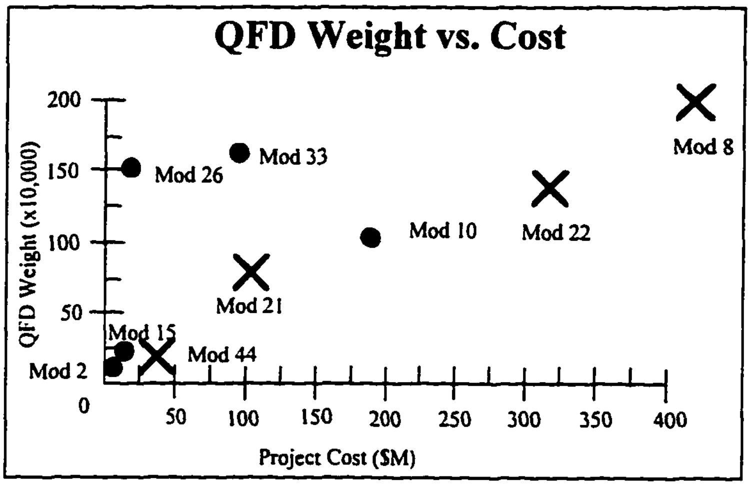

Figure 12 - QFD Weight vs. Cost

In Appendix B there are seven charts which give more detailed examples of this phenomenon. In general, it is obvious why different modifications were selected and others were not. Other forces were at work, such as the fact that there was a separate budget for each year. If a project required a large outlay in one particular year when the budget was tight, then chances were that the project would not get selected. Also, as discussed above there were over 100 interdependency relationships among the various projects. So some of the projects were mutually exclusive and some were codependent. Both of these facts directly affected which projects were selected.

QFD and Integer Goal Programming can be run interactively, even for large scale problems. By taking advantage of the available technology, and by exploring the available options in the solver, SAS/OR (SAS 1989), the cycle time was reduced dramatically. Initially, the Microsoft Excel spreadsheets were copied to a series of about 10 diskettes and moved from machine to machine to transfer the necessary information. This method was extremely time-consuming and error-prone. Thus to generate a scenario to run for the GP model, it took essentially an entire morning or afternoon just prepare the input file from the different spreadsheets. Then, once this was done, there was the problem of solving this large integer problem. Early editions of the code took 10 hours to run on a 100Mhz pentium personal computer system, and required at least 200 Megabytes of free disk space. Obviously, if this tool was to be usable, the cycle time had to be reduced. There were three primary enhancements introduced to reduce the cycle time.

The first place to realize a time savings was in preparing and transmitting the data for the GP. First, Excel had a capability to link different spreadsheets together, which required a good deal of work up front, but would pay substantial dividends later. By linking the output of the spreadsheets which computed the combat capability score, and spreadsheets which contained the cost data, the "cutting and pasting" operation was eliminated. Thus the generation of a linear programming tableau was nearly automatic. Thus whenever any change was made to the QFD calculations, only "dragging and dropping" was required to connect the spreadsheets.

The second significant improvement was the movement of the headquarters to a local area network. This technology leap preempted the requirement to carry stacks of diskettes from one place to another to move information. The timely creation of the LAN provided a medium for again "dragging and dropping" files to move them from one place to another. Common LAN servers were made available to the members of the team that provided data or acted on that data.

Finally, the time required to solve the large integer goal programming model was reduced. As noted in the literature review, large integer problems can be troublesome to solve. The only way to attack the time aspect is to experiment with the options provided by the commercial solver (SAS/OR) and the structure of the problem. SAS (SAS 1989) provided various options to use in working with integer models. One such option, *pobjective*, allowed the analyst to specify that the model only consider nodes which could lead to an integer solution within a certain range (percentage) of the objective function value from the relaxed solution. This option effectively prunes the branch and bound tree and limits the search of the solver, which can save time.

By performing analysis with the available solver options, and restructuring some of the constraint equations, the run time for the GP model was reduced to less than one hour. On average, the model would solve in about 40 minutes, and sometimes as quickly as 10 minutes. As stated in the SAS documentation (SAS 1989), the time varies with the problem structure, and the branch and bound search strategy and cannot be predicted. However, by spending some time tailoring the search options to fit a specific problem, some increase in efficiency may be possible.

Thus, QFD and Integer Goal Programming can be run interactively for a large problem. Using the changes described above, the cycle time was reduced for running a complete problem from about one per day, to about six executions per day. As the PC technology continues to evolve, there is potential to run larger problems, and to solve them even faster.

The results should provide usable, responsive information to decision makers. The spreadsheet below, Table 3, shows example summary output. The chart shows eight different runs of the GP model in the columns following the ID Number. This was one of the primary output formats used by decision makers. For each run, typically there was a baseline, meaning at the projected budget amounts for each year, and budget amounts which vary from the baseline, e.g. -10%, or -20%, etc.

ID NUMBE	b18jan01	b19jan02 =1.0	b19jan01 = 0.9	b19jan03 = 0.8	sun19jan overspend	d21feb01 baseline, qfd 10, coo 5, le, Falcon Up	d21feb02 -10%$, qfd 10, coo 5, le, Falcon Up	b21feb02 -40%$, qfd 10, coo 5, le, Falcon Up
F15C041	1	1	1	1	1	1	0	0
F15C042	0	0	0	0	0	0	0	0
F15C043	1	1	1	1	1	1	1	1
F15C044	0	0	0	0	0	0	0	0
F15C045	1	1	1	1	1	1	1	1
F15C046	1	1	0	0	0	1	1	0
F15C047	0	0	0	0	0	0	0	0
F15C048	1	1	1	1	1	1	1	1
F15C049	1	1	1	0	1	1	1	0
F15C050	1	1	1	1	1	1	1	1

Table 3 - Sample Summary Output

Other parameters were also varied. The weights assigned to the different goals, the deviational variable objective function coefficients, were adjusted according to senior leadership direction. The cases given in this example used a coefficient of 10 for the QFD weight, five for the cost of ownership value, and one for the technical risk and cost sharing. The scenario parameters were recorded for each column, and an abbreviated form was listed at the top of the column for quick reference. The way this summary spreadsheet was used was to look at the changes in the parameters, and look at the value of the decision variable for each modification program. If a program was always selected (decision variable=1), across every scenario, then this indicated that this project was a likely core requirement. In other words if the budget is reduced, it is still important. If the priorities among the goals change, and it is still selected, then it has merit under a variety of potential circumstances. The third project on this list, F15C043, has these qualities from this summary. On the other hand, F15C042 has just the opposite outcome. It is never selected by the GP model. Thus, under any of the scenarios above, this project is not a cost effective option. The data and model indicate that this would not be part of a recommended investment plan. Then there are those projects which are in the gray area. F15C041 is a good example. This project would be selected in most cases, however, if the budget gets reduced then this project becomes a less cost-effective option. This proved to be an effective way of examining possible perturbations and developing an understanding of the relative importance of different options.

The senior leadership gave direction for setting the weights of the GP model to gain a sense of why different programs were selected and recommended. Sometimes a program would be included in the baseline and fall out if the cost of ownership weight was reduced, indicating that it's value was highly dependent on the fact that the proposed project had a significant O&S cost savings. In fact, some projects with low combat capability values were selected because of their potential to save the Air Force O&S expenditures in the future. There were projects which were cost-effective choices because of both the combat capability score and the cost of ownership value. These projects were selected no matter how the weights were adjusted. The chart below, Figure 13 shows how the data was summarized and presented to leadership in the form of a plan for modernizing and sustaining each aircraft type.

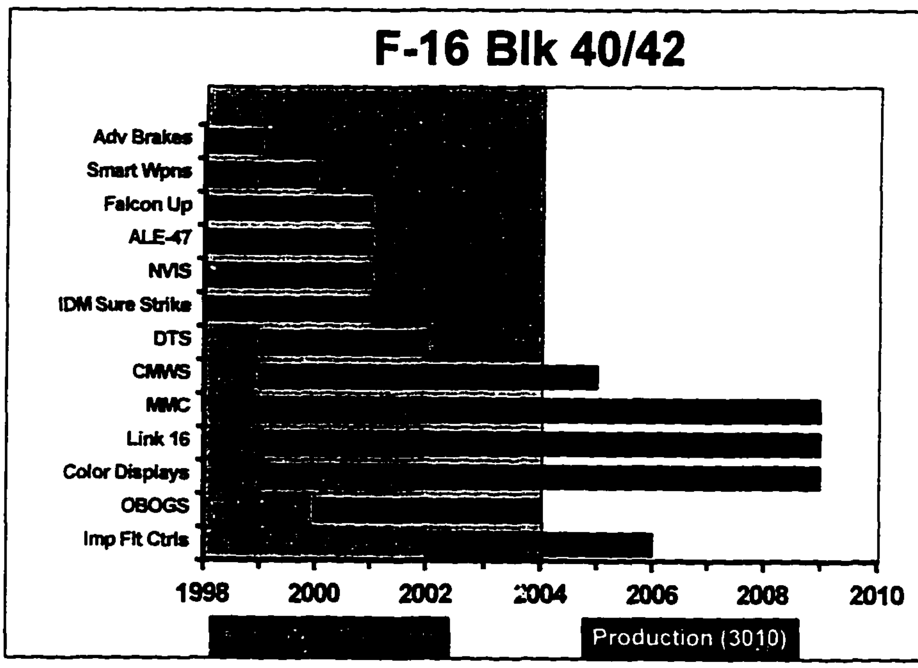

Figure 13 - Sample F-16 Plan

The findings of this research demonstrate the capacity for decision support tools to effectively deal with large complex problems. The confederation of QFD, integer goal programming, and capital budgeting provides a systematic approach to the resource allocation problem. QFD can be used to develop technological parameter estimates for qualitative objectives, such as combat capability. Integer goal programming is an efficient method to resolve conflicting objectives of management in capital budgeting decision. The analyst must be cognizant of methods and technologies which lend themselves to improving the responsiveness of these tools and must work with management to make the output meaningful.

CONCLUSIONS

The literature demonstrates that mathematical modeling in capital budgeting problems in industry is a well-established process. This research has demonstrated that these powerful techniques can be applied to government and other non-profit seeking organizations as well. Non-economic measures can be developed with careful, deliberate analysis of the goals of the organization. QFD can help in developing the prioritization and weighting, as well as estimating technological parameters for a GP model. Decision support tools such as the one described in this thesis, can be developed and used in a responsive manner to assist in the development of plans in a rapidly changing environment. This capital budgeting model was run over 300 times performing different sensitivity analyses and refining inputs. The important point here is that the key decision makers were involved in an interactive role, changing priorities (goal weights), changing projected budget amounts, and formulating plans based on objective, quantifiable, traceable, repeatable output.

Two important lessons were derived from this analysis. First, there must be "buy-in" and acceptance of the methodology by senior management personnel, and other stake holders. Marketing of the process is a never-ending task. Leadership must be convinced that the philosophy and methodology is sound. Above all, the process must be *understandable.* Stakeholders must be convinced that the methodology addresses their functional areas in a fair and equitable manner, and that it is in their best interest to participate. Secondly, the model does not *make* decisions, but rather *suggests* "optimized" investment plans. Expectations should be managed. This methodology is not a *crystal ball*, which knows all. The output of the model required sanity checks, by an integrated team of analysts and functional experts (e.g. pilots). The model was refined to provide results which are consistent with sound judgment by improving inputs such as cost, cost of ownership, combat capability metrics, and goal importance weights. However, there were still intangibles which the model did not capture such as legislation requiring changes to aircraft navigation systems. These exceptions were processed during the analysis of the results of the optimization. The key benefit of this work was that the command now has a tool which contains collective wisdom, qualitative and quantitative data, and an engine (goal programming) which allowed multiple excursions to be performed quickly. Senior leadership now has the ability to quickly respond to changes in the budget and various programs, through this automated, capital budgeting process.

The most encouraging fact that these tools are useful comes after the work is complete and the plans are adopted and carried forward to the budgeting phase. The results of this research were used by Air Combat Command in preparation and defense of the command's POM submission. This method has revolutionized the way the command did business in analyzing, preparing and defending it's position, and has now been expanded into several other areas. On July 3, 1996 COMACC released the document titled Fighter Configuration Plan (FICOP 96) Release to Industry, which explained the methodology and gave specific, detailed results to industry.

DEVELOPMENTS ADDED BY THIS RESEARCH

The developments of this research have contributed to the investigated areas in varying degrees. Capital budgeting developments: An approach was developed to capture, integrate and prioritize collective wisdom into development of measures for non-profit organizations. QFD Developments: Prioritization using the structured expanded house of quality can produce acceptable customer-based priorities, if done correctly. This is accomplished through a well-designed, logical matrix flow where the evaluation team is guided through the process by trained facilitators. Goal Programming developments: A novel method for estimating technological parameters was developed.

Solving large integer problems has long been a troublesome challenge. It is possible to solve large-scale integer goal programming problems efficiently and obtain a solution in a relatively short time. The technology has dramatically changed over the past 23 years with desktop PC's which are significantly more capable than some of the older mainframe computers. Large integer problems are most commonly solved with the branch-and-bound solution method. Due to computational requirements, this class of problems can be difficult to solve and would not have been feasible to run in the early years of Goal Programming (GP). However, this problem which had up to 450 integer, decision variables and over 120 constraints was successfully executed on a pentium PC and generally solved within 30 minutes.

FUTURE RESEARCH

The area of capital budgeting in strategic planning activities provides a rich environment for follow-on research. The questions are very old, but the development of scientific methods and the technological advances pennit the application of efficient, responsive decision support systems in new and imaginative ways. Perhaps the *crystal ball* is not as far off as one might think. There appears to be a high degree of interest in applying these types of methods to a broader problem involving initiatives and programs from across the spectrum, not only fighter modifications. There are some interesting areas which might be helpful to study in the future.

Time value of capability: Economic analyses use the net present value to capture and account for the fact that cash available in the near future is worth more than the same amount of cash at some distant point in the future. Using a non-economic measure of value, in this case, combat capability, poses an interesting question which is analogous to the idea of the time value of money. Should there be a "capability discount factor" applied to programs over the multiple years for which these program span. Using QFD, it was possible to prioritize and weight the alternatives. If there was a way to efficiently develop time-based value weights, then it would be possible to make trade-offs across the time-horizon as well as within a given year. This would allow the process to consider the rate at which technologies become obsolete, as well as the cumulative expected value of each alternative based on the remaining service life of the system.

Knowledge-Based, Goal Programming: As mentioned above, the GP model was run in excess of 300 times, performing different excursions and sensitivity analysis. There is a wealth of knowledge which is derived from an iterative analytical approach. It would have been extremely helpful to have the results of the optimization, the inputs, and the decision maker's judgment somehow captured and used to form either new goals or new constraints. This would help the results of the ultimate model to "learn" from early runs and also become more stable. This idea would allow analysts to capture relevant output data and turn it into useable information. Decision makers would perhaps become even more comfortable, if the model reached a steady state and was not so erratic.

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Naval Officer: More than 18 years of service, spanning areas such as Intelligence, Amphibious Operations, Naval Special Warfare, Joint Special Operations. This experience has included participation in several large scale joint exercises.

EDUCATION

Master of Science, Engineering Management - December, 1996, Old Dominion University

Bachelor of Science, Mathematics - August, 1981, Old Dominion University

PROFESSIONAL MEMBERSHIPS

Military Operations Research Society, American Society for Engineering Management, Defense Planning and Analysis Society, Institute for Operations Research and the Management Sciences, Naval Reserve Association, and the Fleet Reserve Association.

APPENDIX A

FICOP 96 STRATEGY TO TASK

Campaign Objectives
Establish aerospace supremacy
Establish maritime supremacy
Counter weapons of mass destruction
Degrade war sustaining capability
Defeat ground forces

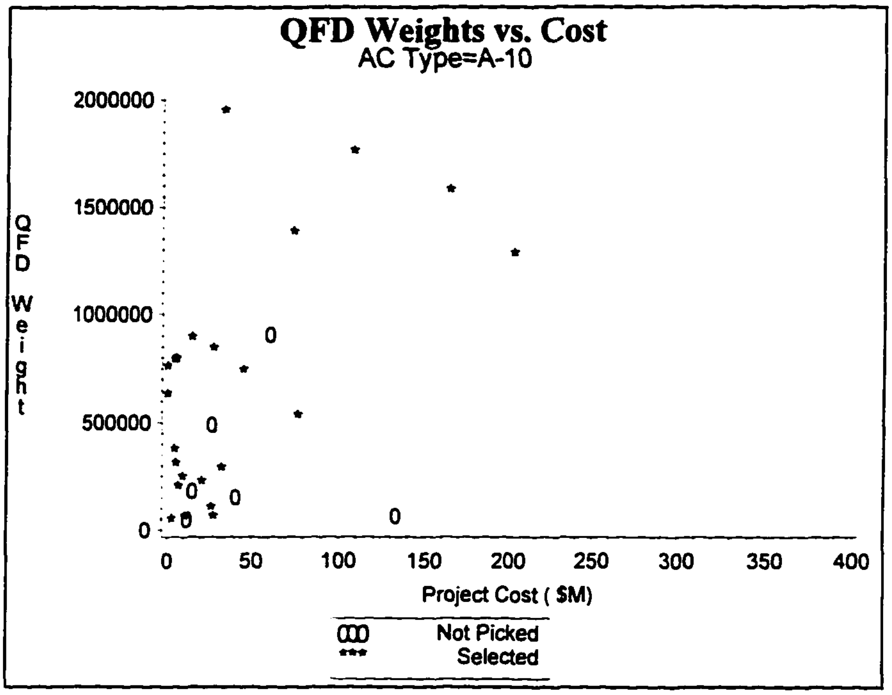
Operational Objectives
Defeat enemy in the air
Counter enemy air defenses
Reduce enemy sortie generation
Interdict ground forces
Degrade enemy command & control
Interdict naval forces
Degrade military support base
Sustain operations tempo
Defeat enemy close to friendlies
Deny economic support base
Establish information dominance
Rapidly deploy an overwhelming force
Protect forces and friendly vulnerabilities
Disrupt political base

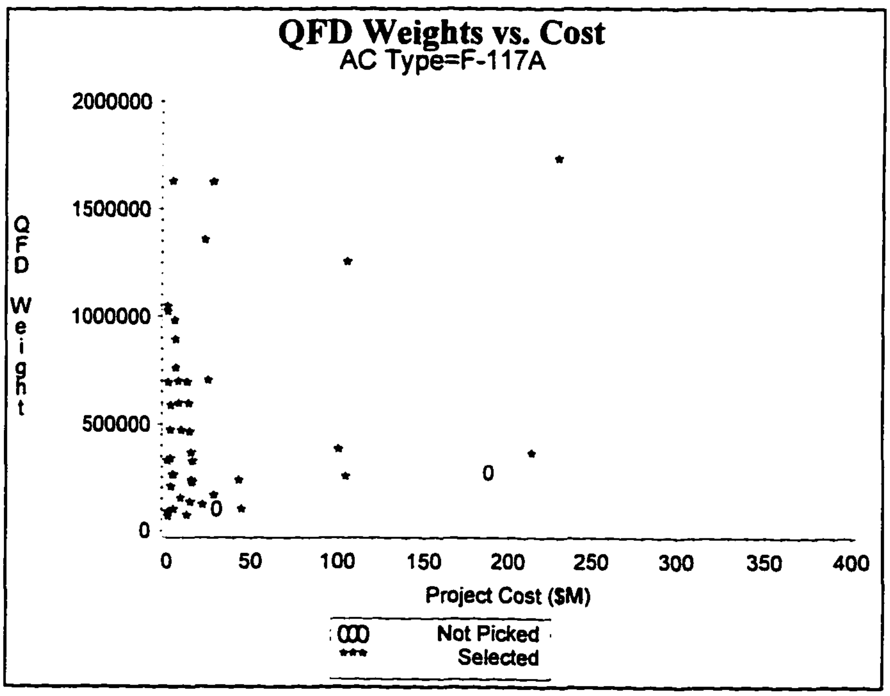
Operational Tasks
Produce aircraft sorties
Repair equipment, tools, spares
Resupply munitions, spares, consumables, POL
Destroy/damage/suppress mobile surface to air threats
Pack/configure/assemble personnel & supplies
Destroy/damage/suppress fixed surface to air threats
Collect intelligence data
Disseminate intelligence data
Destroy/damage/neutralize TMs & support on the ground
Destroy/damage/neutralize TMs inflight
Preposition equipment and supplies.
Sustain efficient operations
Deliver/maintain timely flow of personnel & supplies
Train personnel
Destroy/disable/neutralize fighter aircraft inflight
Destroy/disable/neutralize helicopters inflight
Destroy/damage/neutralize lines of communication (LOCs)
Destroy/degrade/neutralize radar and comm (EW/GCI)
Destroy/damage/neutralize power production
Destroy/damage/neutralize advancing combat forces
Destroy/disable/neutralize heavy aircraft inflight
Destroy/disable/neutralize cruise missiles & UAVs inflight

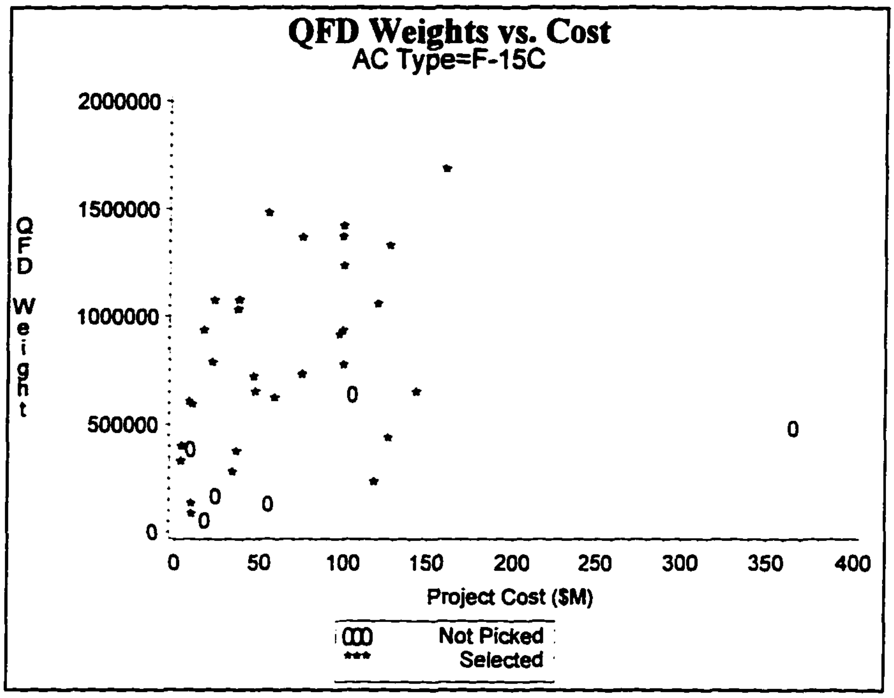
Destroy/damage/neutralize aircraft on the ground
Destroy/disable/neutralize engaged ground forces
Destroy/damage/neutralize national C4I
Destroy/damage/neutralize ports & harbors
Perform psychological operations
Neutralize enemy political and military leaders
Destroy/neutralize/deny access to WMD production & storage
Destroy/damage/neutralize airfield operating surfaces
Destroy/disable/neutralize fixed forces
Destroy/damage/neutralize industrial production
Provide warning of ballistic missile and air attack
Destroy/damage/neutralize weapons factories
Destroy/damage/neutralize naval vessels
Destroy/damage/neutralize naval support facilities
Identify/assess air sovereignty threat
Destroy/damage/neutralize mobile C2 with advancing forces
Recover Downed aircrew/isolated personnel
Destroy/damage/neutralize weapons storage sites
Destroy/damage/neutralize airfield support facilities
Destroy/disable/neutralize satellites
Conduct/coordinate airborne airstrike terminal control
Conduct/coordinate groundbased airstrike terminal control
Protect rescue operations
Escort air sovereignty threat

APPENDIX B

GRAPHS OF OUTPUT






QFD Weights vs. Cost
AC Type=F-15C
QFD Weight
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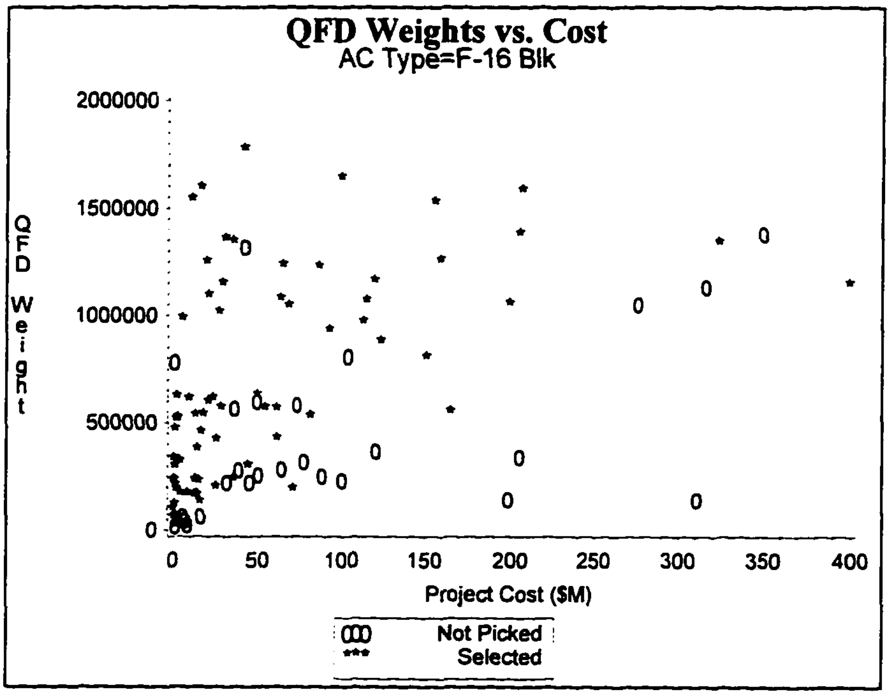
1500000
1000000
500000
0
0
50
100
150
200
250
300
350
400
Project Cost ($M)
Not Picked
Selected


QFD Weights vs. Cost
AC Type=F-16 Blk
QFD Weight
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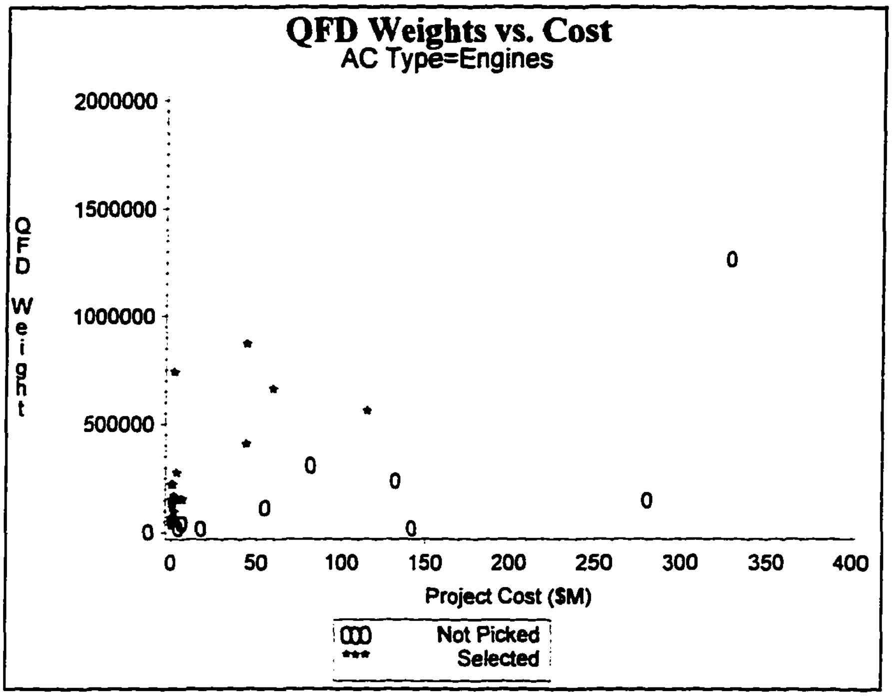
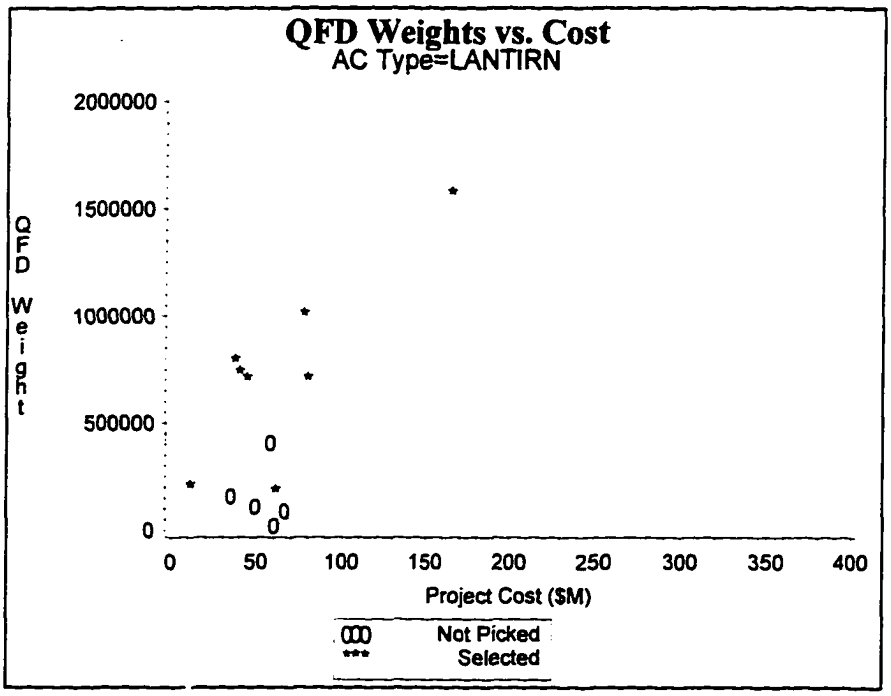
1500000
1000000
500000
0
0
50
100
150
200
250
300
350
400
Project Cost ($M)
Not Picked
Selected


QFD Weights vs. Cost
AC Type=Engines
2000000
1500000
1000000
500000
0
QFD Weight
0
50
100
150
200
250
300
350
400
Project Cost ($M)
000 Not Picked
*** Selected


QFD Weights vs. Cost
AC Type=LANTIRN
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1500000
1000000
500000
0
QFD Weight
0
50
100
150
200
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350
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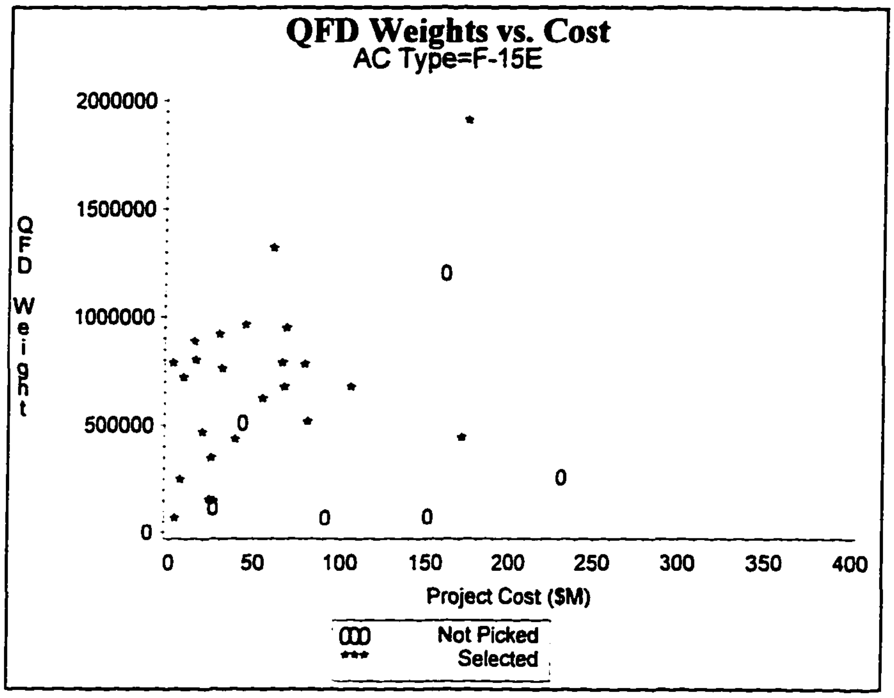
Project Cost ($M)
000 Not Picked
*** Selected


QFD Weights vs. Cost
AC Type=F-15E
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1500000
1000000
500000
0
0
50
100
150
200
250
300
350
400
Project Cost ($M)
Not Picked
Selected

APPENDIX C

SAS/OR CODE OPTIONS

The following is the SAS code used to execute the model:

```
proc lp data=copdata.lpdata  maxit1=200000   maxit2=200000  time=43200 imaxit=200000
                             printfreq=9999999  primalout=copdata.solftr1  canselect=obj
                             varselect=penalty  penaltydepth=12  backtrack=project
                             ifeasiblepause=1   pobjective=.03;
run;
 reset  canselect=obj  backtrack=project  ifeasiblepause=9999999  printfreq=99999999;
run;
```

The options of interest are canselect, varselect, penaltydepth, and pobjective. The canselect option controls the rule used to choose the next active problem when solving an integer problem. Canselct typical options are LIFO (last-in, first out), FIFO (first-in, first out), OBJ (chooses the problem whose parent has the least objective value), and PROJECT (chooses the project with the least project objective value). The varselect option controls the strategy for searching the branch and bound tree. The default option is varselect=far, which means that the strategy should use the variable to branch on which has a value farthest from an integer value. The option chosen in the code above, varselect=penalty, causes the LP to look at the cost of branching on an integer variable, in terms of the objective function. This option at times improved the solution time by cutting down the number of integer iterations. Penaltydepth is used in conjunction with the varselect=penalty option. Penaltydepth assigns the number of variables to be used as branching candidates. Pobjective is another key option which can have a significant impact on the running time. Pobjective tells the model to ignore active nodes unless the node could lead to an integer solution with an objective value at least as small as $r+p\,|r|$. In this example p is the fractional range specified in Pobjective=p, and r is the objective of the relaxed non-integer constrained problem. In the above example p=0.03, which means the model will only consider nodes which could lead to an integer solution within 3% of the objective function value from the relaxed solution. Of course, this option effectively prunes the tree and could possibly cut-off sections of the branch and bound tree that may contain an optimal solution.

APPENDIX D

SAS SAMPLE OUTPUT

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

PROBLEM SUMMARY

Min OBJECT	Objective Function
RHS	Rhs Variable
TYPE	Type Variable
Problem Density	0.040588

Variable Type	Number
Non-negative	44
Binary	476
Slack	47
Surplus	62
Total	629

Constraint Type	Number
LE	47
EQ	8
GE	62
Objective	1
Total	118

SOLUTION SUMMARY

Integer Optimal Solution

Objective value	9222.042
Phase 1 iterations	368
Phase 2 iterations	115
Phase 3 iterations	122400
Integer iterations	8072
Integer solutions	1
Initial basic feasible variables	112
Time used (secs)	2298
Number of inversions	8043
Machine epsilon	1E-8
Machine infinity	1.7976931349E308
Maximum phase 1 iterations	200000
Maximum phase 2 iterations	200000
Maximum phase 3 iterations	99999999
Maximum integer iterations	200000
Time limit (secs)	43200

The SAS System

23

09:30 Wednesday, February

21, 1996

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
1	D98U		NON-NEG	1	0.000000	1.000000
2	D98V	ALTER	NON-NEG	0	0.000000	0.000000
3	D99U		NON-NEG	1	0.000000	1.000000
4	D99V	ALTER	NON-NEG	0	0.000000	0.000000
5	D00U		NON-NEG	1	0.000000	1.000000
6	D00V	ALTER	NON-NEG	0	0.000000	0.000000
7	D01U		NON-NEG	1	0.000000	1.000000
8	D01V	ALTER	NON-NEG	0	0.000000	0.000000
9	D02U		NON-NEG	1	0.000000	1.000000
10	D02V	ALTER	NON-NEG	0	0.000000	0.000000
11	D03U		NON-NEG	1	0.000000	1.000000
12	D03V	ALTER	NON-NEG	0	0.000000	0.000000
13	D04U		NON-NEG	1	0.000000	1.000000
14	D04V	ALTER	NON-NEG	0	0.000000	0.000000
15	D05U		NON-NEG	1	0.000000	1.000000
16	D05V	ALTER	NON-NEG	0	0.000000	0.000000
17	D06U		NON-NEG	1	0.000000	1.000000
18	D06V	ALTER	NON-NEG	0	0.000000	0.000000
19	D07U		NON-NEG	1	0.000000	1.000000
20	D07V	ALTER	NON-NEG	0	0.000000	0.000000
21	D08U		NON-NEG	1	0.000000	1.000000
22	D08V	ALTER	NON-NEG	0	0.000000	0.000000
23	D09U		NON-NEG	1	0.000000	1.000000
24	D09V	ALTER	NON-NEG	0	0.000000	0.000000
25	D10U		NON-NEG	1	0.000000	1.000000
26	D10V	ALTER	NON-NEG	0	0.000000	0.000000
27	D11U		NON-NEG	1	0.000000	1.000000
28	D11V	ALTER	NON-NEG	0	0.000000	0.000000
29	D12U		NON-NEG	1	0.000000	1.000000
30	D12V	ALTER	NON-NEG	0	0.000000	0.000000
31	D13U		NON-NEG	1	0.000000	1.000000
32	D13V	ALTER	NON-NEG	0	0.000000	0.000000
33	D14U		NON-NEG	1	0.000000	1.000000
34	D14V	ALTER	NON-NEG	0	0.000000	0.000000
35	D15U		NON-NEG	1	0.000000	1.000000
36	D15V	ALTER	NON-NEG	0	0.000000	0.000000
37	DWU	BASIC	NON-NEG	0.000071	79311201	0.000000
38	DWV		NON-NEG	0	0.000000	0.000071
39	DTU		NON-NEG	0	0.000000	1.930000
40	DTV	BASIC	NON-NEG	1.93	295.000	0.000000
41	DJU	BASIC	NON-NEG	1	580.000	0.000000
42	DJV		NON-NEG	0	0.000000	1.000000

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
43	DCU	BASIC	NON-NEG	1.74	1403.216	0.000000
44	DCV		NON-NEG	0	0.000000	1.740000
45	A100001		BINARY	0	1.000000	-46.447981
46	A100002	BASIC	BINARY	0	1.000000	0.000000
47	A100003	DEGEN	BINARY	0	0.000000	0.000000
48	A100004		BINARY	0	0.000000	-12.769776
49	A100005		BINARY	0	1.000000	-186.922
50	A100006		BINARY	0	0.000000	19298.070
51	A100007		BINARY	0	1.000000	-26.809534
52	A100008		BINARY	0	1.000000	-21.327903
53	A100009		BINARY	0	1.000000	-63.140731
54	A100010		BINARY	0	1.000000	-59.491580
55	A100011		BINARY	0	1.000000	-67.796659
56	A100012	DEGEN	BINARY	0	0.000000	0.000000
57	A100013		BINARY	0	1.000000	-123.760
58	A100014	DEGEN	BINARY	0	0.000000	0.000000
59	A100015		BINARY	0	0.000000	19150.193
60	A100016		BINARY	0	1.000000	-98.484567
61	A100017	DEGEN	BINARY	0	0.000000	0.000000
62	A100018		BINARY	0	1.000000	-55.874728
63	A100019		BINARY	0	1.000000	-59.205121
64	A100020		BINARY	0	1.000000	-23.778757
65	A100021		BINARY	0	0.000000	-4.095818
66	A100022		BINARY	0	0.000000	-27.940139
67	A100023		BINARY	0	0.000000	-80.927865
68	A100026		BINARY	0	0.000000	5.054951
69	A100027		BINARY	0	1.000000	-16.746562
70	A100028		BINARY	0	0.000000	-1.124179
71	A100029		BINARY	0	0.000000	-2.817351
72	A100030		BINARY	0	0.000000	5.841560
73	A100031		BINARY	0	1.000000	-55.365516
74	A100032		BINARY	0	0.000000	19705.706
75	A100033		BINARY	0	0.000000	19298.070
76	A100034		BINARY	0	1.000000	-176.891
77	A100035		BINARY	0	0.000000	19298.070
78	A100036		BINARY	0	0.000000	19298.070
79	A100037		BINARY	0	0.000000	19298.070
80	A100038		BINARY	0	0.000000	19298.070
81	A100039		BINARY	0	0.000000	19298.070
82	A100040		BINARY	0	0.000000	19298.070
83	A100041		BINARY	0	0.000000	19298.070
84	A100042		BINARY	0	0.000000	19298.070

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LINEAR PROGRAMMING PROCEDURE

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
85	ENGN002		BINARY	0	1.000000	-35.347239
86	ENGN003		BINARY	0	1.000000	-5.667291
87	ENGN004		BINARY	0	1.000000	-20.849754
88	ENGN005		BINARY	0	0.000000	-160.442
89	ENGN006		BINARY	0	1.000000	-9.409803
90	ENGN007		BINARY	0	1.000000	-19.200250
91	ENGN008		BINARY	0	1.000000	-12.330219
92	ENGN009		BINARY	0	0.000000	-5.707819
93	ENGN010		BINARY	0	1.000000	-2.559195
94	ENGN011		BINARY	0	0.000000	2.564555
95	ENGN012		BINARY	0	1.000000	-9.279036
96	ENGN013		BINARY	0	1.000000	-51.105481
97	ENGN014		BINARY	0	1.000000	-344.884
98	ENGN015		BINARY	0	1.000000	-559.171
99	ENGN016		BINARY	0	1.000000	-36.190703
100	ENGN017		BINARY	0	1.000000	-14.601789
101	ENGN018		BINARY	0	1.000000	-289.719
102	ENGN019		BINARY	0	1.000000	-87.148326
103	ENGN020		BINARY	0	1.000000	-3.119619
104	ENGN021		BINARY	0	1.000000	-14.579424
105	ENGN022		BINARY	0	1.000000	-657.698
106	ENGN023		BINARY	0	1.000000	-182.687
107	ENGN024		BINARY	0	0.000000	-10.643610
108	ENGN025		BINARY	0	1.000000	-18.544774
109	ENGN026		BINARY	0	0.000000	-18.165670
110	ENGN027		BINARY	0	1.000000	-5.912262
111	ENGN028		BINARY	0	1.000000	-16.970083
112	ENGN029		BINARY	0	1.000000	-1.709754
113	ENGN030		BINARY	0	1.000000	-1.205154
114	ENGN031		BINARY	0	1.000000	-1.205154
115	ENGN032		BINARY	0	1.000000	-1.205154
116	ENGN033		BINARY	0	1.000000	-15.036789
117	ENGN034		BINARY	0	0.000000	19282.375
118	ENGN035		BINARY	0	1.000000	-8.078154
119	ENGN036		BINARY	0	1.000000	-277.897
120	ENGN037		BINARY	0	1.000000	-4.572462
121	ENGN038		BINARY	0	1.000000	-10.917315
122	ENGN039		BINARY	0	0.000000	11.392233
123	ENGN040		BINARY	0	0.000000	19298.070
124	ENGN041		BINARY	0	0.000000	19298.070
125	ENGN042		BINARY	0	0.000000	19298.070
126	ENGN043		BINARY	0	0.000000	19298.070

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
127	ENGN044		BINARY	0	0.000000	19298.070
128	ENGN045		BINARY	0	0.000000	19298.070
129	ENGN046		BINARY	0	0.000000	19298.070
130	ENGN047		BINARY	0	0.000000	19298.070
131	ENGN048		BINARY	0	0.000000	19298.070
132	ENGN049		BINARY	0	0.000000	19298.070
133	ENGN050		BINARY	0	0.000000	19298.070
134	ENGN051		BINARY	0	0.000000	19298.070
135	ENGN052		BINARY	0	0.000000	19298.070
136	F117001		BINARY	0	1.000000	-59.920251
137	F117002		BINARY	0	0.000000	-15.809499
138	F117003		BINARY	0	0.000000	-20.935344
139	F117004		BINARY	0	1.000000	-22.191334
140	F117005	BASIC	BINARY	0	1.000000	0.000000
141	F117006		BINARY	0	1.000000	-71.692081
142	F117007		BINARY	0	1.000000	-147.868
143	F117008		BINARY	0	1.000000	-59.253831
144	F117009		BINARY	0	1.000000	-34.773462
145	F117010		BINARY	0	0.000000	19298.070
146	F117011		BINARY	0	0.000000	19237.414
147	F117012		BINARY	0	0.000000	19298.070
148	F117013		BINARY	0	1.000000	-56.423680
149	F117014		BINARY	0	1.000000	-33.147508
150	F117015		BINARY	0	1.000000	-5.003583
151	F117016		BINARY	0	1.000000	-42.136563
152	F117017		BINARY	0	1.000000	-17.537355
153	F117018		BINARY	0	1.000000	-10.846386
154	F117019		BINARY	0	1.000000	-17.537355
155	F117020		BINARY	0	1.000000	-38.597908
156	F117021		BINARY	0	0.000000	-102.886
157	F117022		BINARY	0	0.000000	-0.035075
158	F117023		BINARY	0	0.000000	-29.819574
159	F117024		BINARY	0	0.000000	-16.549000
160	F117025		BINARY	0	0.000000	19298.070
161	F117027		BINARY	0	0.000000	-23.863591
162	F117028		BINARY	0	1.000000	-9.362868
163	F117029		BINARY	0	0.000000	19285.490
164	F117030		BINARY	0	1.000000	-43.277092
165	F117031		BINARY	0	1.000000	-6.062193
166	F117032		BINARY	0	1.000000	-5.330041
167	F117033		BINARY	0	1.000000	-3.808440
168	F117035		BINARY	0	1.000000	-32.270497

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
169	F117036		BINARY	0	1.000000	-85.708183
170	F117037		BINARY	0	1.000000	-0.073663
171	F117038		BINARY	0	0.000000	2.033120
172	F117039		BINARY	0	1.000000	-5.329438
173	F117040		BINARY	0	0.000000	3.504524
174	F117041		BINARY	0	1.000000	-15.411026
175	F117042		BINARY	0	1.000000	-17.046745
176	F117044		BINARY	0	0.000000	2.400758
177	F117046		BINARY	0	0.000000	5.548259
178	F117047		BINARY	0	0.000000	5.548259
179	F117048		BINARY	0	1.000000	-78.366073
180	F117049		BINARY	0	1.000000	-206.964
181	F117050		BINARY	0	1.000000	-32.539158
182	F117051		BINARY	0	1.000000	-69.510594
183	F117052		BINARY	0	1.000000	-115.636
184	F117053		BINARY	0	1.000000	-32.392297
185	F117054		BINARY	0	1.000000	-23.812089
186	F117055		BINARY	0	1.000000	-20.392468
187	F117056		BINARY	0	1.000000	-272.766
188	F117057		BINARY	0	1.000000	-209.009
189	F117058		BINARY	0	1.000000	-104.753
190	F117059		BINARY	0	0.000000	-27.874996
191	F117060		BINARY	0	0.000000	19298.070
192	F117061		BINARY	0	0.000000	19298.070
193	F117062		BINARY	0	0.000000	19298.070
194	F117063		BINARY	0	0.000000	19298.070
195	F117064		BINARY	0	0.000000	19298.070
196	F117065		BINARY	0	0.000000	19298.070
197	F15A003		BINARY	0	1.000000	-25.296311
198	F15A004		BINARY	0	0.000000	19298.070
199	F15A005		BINARY	0	0.000000	19298.070
200	F15A006		BINARY	0	0.000000	19298.070
201	F15A008		BINARY	0	0.000000	19298.070
202	F15A009		BINARY	0	1.000000	-67.388210
203	F15A010		BINARY	0	1.000000	-12.826612
204	F15A011		BINARY	0	0.000000	19298.070
205	F15A012		BINARY	0	0.000000	19298.070
206	F15A013		BINARY	0	1.000000	-40.724535
207	F15A015		BINARY	0	0.000000	19298.070
208	F15A017		BINARY	0	0.000000	19298.070
209	F15A018		BINARY	0	0.000000	19298.070
210	F15A019		BINARY	0	0.000000	19298.070

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
211	F15A020		BINARY	0	0.000000	19298.070
212	F15A021		BINARY	0	1.000000	-82.972309
213	F15A022		BINARY	0	1.000000	-80.000746
214	F15A023		BINARY	0	1.000000	-17.907975
215	F15A024		BINARY	0	0.000000	19298.070
216	F15A025		BINARY	0	0.000000	19298.070
217	F15A026		BINARY	0	1.000000	-23.440011
218	F15A027		BINARY	0	1.000000	-30.750917
219	F15A028		BINARY	0	0.000000	19298.070
220	F15A029		BINARY	0	1.000000	-88.387763
221	F15A030		BINARY	0	0.000000	19298.070
222	F15A032		BINARY	0	0.000000	19298.070
223	F15A033		BINARY	0	0.000000	19298.070
224	F15A035		BINARY	0	1.000000	-19.319739
225	F15A036		BINARY	0	0.000000	19298.070
226	F15A037		BINARY	0	0.000000	19298.070
227	F15A038		BINARY	0	0.000000	19298.070
228	F15A039		BINARY	0	0.000000	19298.070
229	F15A040		BINARY	0	0.000000	19298.070
230	F15A041		BINARY	0	0.000000	19298.070
231	F15A042		BINARY	0	0.000000	19298.070
232	F15A043		BINARY	0	0.000000	19298.070
233	F15C003		BINARY	0	1.000000	-89.893353
234	F15C004		BINARY	0	1.000000	-29.104751
235	F15C005		BINARY	0	1.000000	-41.308794
236	F15C006		BINARY	0	0.000000	-32.864876
237	F15C007		BINARY	0	0.000000	-12.034287
238	F15C008		BINARY	0	1.000000	-46.345649
239	F15C009		BINARY	0	0.000000	19298.070
240	F15C010		BINARY	0	1.000000	-32.408980
241	F15C011		BINARY	0	1.000000	-150.300
242	F15C012		BINARY	0	0.000000	-15.417757
243	F15C013	BASIC	BINARY	0	1.000000	0.000000
244	F15C015		BINARY	0	1.000000	-55.766773
245	F15C016		BINARY	0	1.000000	-87.058466
246	F15C017		BINARY	0	1.000000	-409.352
247	F15C018		BINARY	0	1.000000	-93.799916
248	F15C019		BINARY	0	0.000000	19298.070
249	F15C020		BINARY	0	1.000000	-25.737429
250	F15C022		BINARY	0	0.000000	19298.070
251	F15C024		BINARY	0	0.000000	-6.183781
252	F15C026		BINARY	0	0.000000	-18.575167

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
253	F15C027		BINARY	0	0.000000	19298.070
254	F15C028		BINARY	0	0.000000	-1260.633
255	F15C029		BINARY	0	0.000000	19298.070
256	F15C030		BINARY	0	1.000000	-166.952
257	F15C031	DEGEN	BINARY	0	0.000000	0.000000
258	F15C032		BINARY	0	0.000000	5.746988
259	F15C033		BINARY	0	0.000000	-44.123452
260	F15C034		BINARY	0	0.000000	0.395363
261	F15C035		BINARY	0	1.000000	-180.247
262	F15C036		BINARY	0	1.000000	-247.371
263	F15C037		BINARY	0	1.000000	-27.372630
264	F15C038		BINARY	0	1.000000	-150.718
265	F15C039	BASIC	BINARY	0	1.000000	0.000000
266	F15C040		BINARY	0	0.000000	19298.070
267	F15C041		BINARY	0	0.000000	-104.291
268	F15C042		BINARY	0	0.000000	-35.530069
269	F15C043		BINARY	0	1.000000	-65.148819
270	F15C044		BINARY	0	0.000000	-78.294718
271	F15C045		BINARY	0	1.000000	-374.216
272	F15C046		BINARY	0	0.000000	-53.192495
273	F15C047		BINARY	0	0.000000	-99.115290
274	F15C048		BINARY	0	1.000000	-157.238
275	F15C049		BINARY	0	0.000000	-30.110958
276	F15C050		BINARY	0	1.000000	-84.115196
277	F15C052		BINARY	0	0.000000	-50.823930
278	F15C054		BINARY	0	0.000000	4.540556
279	F15C055		BINARY	0	0.000000	-53.907744
280	F15C056		BINARY	0	0.000000	-1072.493
281	F15C057		BINARY	0	1.000000	-64.887544
282	F15C058		BINARY	0	0.000000	-172.688
283	F15C059		BINARY	0	0.000000	-182.338
284	F15C060		BINARY	0	0.000000	19298.070
285	F15C061		BINARY	0	0.000000	19298.070
286	F15C062		BINARY	0	0.000000	19298.070
287	F15C063		BINARY	0	0.000000	19298.070
288	F15C064		BINARY	0	0.000000	19298.070
289	F15C065		BINARY	0	0.000000	19298.070
290	F15C066		BINARY	0	0.000000	19298.070
291	F15E003		BINARY	0	1.000000	-20.047991
292	F15E004		BINARY	0	0.000000	19298.070
293	F15E005		BINARY	0	0.000000	-18.608502
294	F15E006		BINARY	0	0.000000	19298.070

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
295	F15E007		BINARY	0	0.000000	19298.070
296	F15E008		BINARY	0	0.000000	19298.070
297	F15E009		BINARY	0	1.000000	-65.702056
298	F15E010		BINARY	0	0.000000	5.904182
299	F15E011		BINARY	0	0.000000	19298.070
300	F15E012		BINARY	0	1.000000	-84.172108
301	F15E013		BINARY	0	0.000000	0.254996
302	F15E014		BINARY	0	1.000000	-64.231717
303	F15E015		BINARY	0	0.000000	-45.134026
304	F15E016		BINARY	0	0.000000	19298.070
305	F15E017		BINARY	0	0.000000	19298.070
306	F15E018		BINARY	0	1.000000	-82.883448
307	F15E020		BINARY	0	0.000000	19298.070
308	F15E021		BINARY	0	0.000000	19298.070
309	F15E022		BINARY	0	0.000000	-26.574271
310	F15E023		BINARY	0	1.000000	-66.457532
311	F15E024	BASIC	BINARY	0	1.000000	0.000000
312	F15E025		BINARY	0	1.000000	-178.720
313	F15E026		BINARY	0	1.000000	-32.137014
314	F15E028		BINARY	0	0.000000	-55.427327
315	F15E029		BINARY	0	0.000000	19298.070
316	F15E031		BINARY	0	0.000000	-37.148869
317	F15E032		BINARY	0	0.000000	-7.002979
318	F15E033		BINARY	0	0.000000	19298.070
319	F15E034		BINARY	0	0.000000	19298.070
320	F15E035		BINARY	0	0.000000	-216.147
321	F15E036		BINARY	0	0.000000	-49.423846
322	F15E037		BINARY	0	0.000000	4.477508
323	F15E038		BINARY	0	1.000000	-179.600
324	F15E039		BINARY	0	0.000000	4.775495
325	F15E040		BINARY	0	0.000000	-21.828312
326	F15E041		BINARY	0	1.000000	-62.975230
327	F15E042		BINARY	0	0.000000	-39.722020
328	F15E043		BINARY	0	1.000000	-120.083
329	F15E044		BINARY	0	0.000000	19298.070
330	F15E045		BINARY	0	0.000000	-124.790
331	F15E046		BINARY	0	0.000000	-25.788372
332	F15E047		BINARY	0	0.000000	-33.498475
333	F15E048		BINARY	0	0.000000	-140.755
334	F15E049		BINARY	0	0.000000	-85.591535
335	F15E050		BINARY	0	0.000000	-18.245443
336	F15E051		BINARY	0	1.000000	-77.188294

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VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
337	F15E052		BINARY	0	0.000000	-35.434361
338	F15E053		BINARY	0	1.000000	-50.128272
339	F15E056		BINARY	0	1.000000	-54.776784
340	F15E057		BINARY	0	0.000000	-31.053128
341	F15E058		BINARY	0	0.000000	19298.070
342	F15E059		BINARY	0	0.000000	19298.070
343	F15E060		BINARY	0	0.000000	19298.070
344	F15E061		BINARY	0	0.000000	19298.070
345	F15E062		BINARY	0	0.000000	19298.070
346	F15E063		BINARY	0	0.000000	19298.070
347	F15E064		BINARY	0	0.000000	19298.070
348	F15E065		BINARY	0	0.000000	19298.070
349	F163001		BINARY	0	0.000000	-39.647044
350	F163002		BINARY	0	1.000000	-52.812432
351	F163003		BINARY	0	1.000000	-45.826174
352	F163004		BINARY	0	1.000000	-47.723786
353	F163006		BINARY	0	1.000000	-53.481394
354	F163007		BINARY	0	0.000000	19298.070
355	F163008		BINARY	0	0.000000	-69.859690
356	F163010		BINARY	0	0.000000	-28.029385
357	F163011	DEGEN	BINARY	0	0.000000	0.000000
358	F163012	DEGEN	BINARY	0	0.000000	0.000000
359	F163013		BINARY	0	1.000000	-13.745818
360	F163014		BINARY	0	0.000000	-33.011171
361	F163015		BINARY	0	0.000000	-118.099
362	F163016		BINARY	0	1.000000	-47.677144
363	F163017		BINARY	0	0.000000	-41.206554
364	F163018		BINARY	0	1.000000	-261.081
365	F163019		BINARY	0	1.000000	-41.028268
366	F163020		BINARY	0	1.000000	-293.201
367	F163021	BASIC	BINARY	0	1.000000	0.000000
368	F163022		BINARY	0	1.000000	-54.016379
369	F163023		BINARY	0	0.000000	-49.501063
370	F163024		BINARY	0	1.000000	-49.755385
371	F163025		BINARY	0	0.000000	-137.362
372	F163026		BINARY	0	1.000000	-104.949
373	F163027		BINARY	0	0.000000	-52.299244
374	F163028		BINARY	0	1.000000	-10.890127
375	F163029		BINARY	0	1.000000	-13.056763
376	F163030		BINARY	0	1.000000	-3.268024
377	F163031		BINARY	0	1.000000	-21.523868
378	F163032		BINARY	0	0.000000	-64.708513

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
379	F163033		BINARY	0	0.000000	-95.045611
380	F163036		BINARY	0	1.000000	-98.293825
381	F163037	DEGEN	BINARY	0	0.000000	0.000000
382	F163038		BINARY	0	0.000000	6.789658
383	F163039		BINARY	0	0.000000	19298.070
384	F163040		BINARY	0	0.000000	9.329683
385	F163041		BINARY	0	1.000000	-69.477264
386	F163042		BINARY	0	0.000000	-24.466601
387	F163043		BINARY	0	0.000000	3.037024
388	F163044		BINARY	0	1.000000	-4.012885
389	F163045		BINARY	0	0.000000	-38.998850
390	F163046		BINARY	0	0.000000	19298.070
391	F163047		BINARY	0	0.000000	19298.070
392	F163048		BINARY	0	0.000000	19298.070
393	F163049		BINARY	0	0.000000	19298.070
394	F163050		BINARY	0	0.000000	19298.070
395	F163051		BINARY	0	0.000000	19298.070
396	F163052		BINARY	0	0.000000	19298.070
397	F163053		BINARY	0	0.000000	19298.070
398	F164001		BINARY	0	0.000000	19298.070
399	F164002		BINARY	0	0.000000	-68.711995
400	F164003		BINARY	0	1.000000	-113.336
401	F164004		BINARY	0	1.000000	-33.705296
402	F164005		BINARY	0	1.000000	-10.884904
403	F164006		BINARY	0	1.000000	-22.605339
404	F164007	BASIC	BINARY	0	1.000000	0.000000
405	F164008		BINARY	0	1.000000	-51.772495
406	F164009	DEGEN	BINARY	0	0.000000	0.000000
407	F164010		BINARY	0	0.000000	-34.054942
408	F164011		BINARY	0	1.000000	-280.421
409	F164013		BINARY	0	1.000000	-24.133402
410	F164014		BINARY	0	1.000000	-11.863106
411	F164017		BINARY	0	1.000000	-54.878290
412	F164018		BINARY	0	0.000000	-366.227
413	F164020		BINARY	0	1.000000	-42.652261
414	F164021		BINARY	0	0.000000	-73.349588
415	F164022		BINARY	0	0.000000	-72.325393
416	F164023	BASIC	BINARY	0	1.000000	0.000000
417	F164024		BINARY	0	0.000000	-59.809411
418	F164025		BINARY	0	1.000000	-25.984372
419	F164026		BINARY	0	1.000000	-79.489546
420	F164027		BINARY	0	1.000000	-81.528737

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
421	F164028		BINARY	0	0.000000	-14.257018
422	F164029		BINARY	0	0.000000	649.500
423	F164030	DEGEN	BINARY	0	0.000000	0.000000
424	F164031		BINARY	0	1.000000	-10.890127
425	F164032		BINARY	0	1.000000	-16.583617
426	F164033		BINARY	0	1.000000	-21.523868
427	F164034	DEGEN	BINARY	0	0.000000	0.000000
428	F164035		BINARY	0	1.000000	-33.916771
429	F164037		BINARY	0	0.000000	6.789658
430	F164038		BINARY	0	0.000000	-3.180659
431	F164039		BINARY	0	0.000000	9.329683
432	F164040	DEGEN	BINARY	0	0.000000	0.000000
433	F164041	DEGEN	BINARY	0	0.000000	0.000000
434	F164042		BINARY	0	0.000000	6.249064
435	F164044		BINARY	0	0.000000	5.587238
436	F164045		BINARY	0	0.000000	11.246683
437	F164046		BINARY	0	1.000000	-67.435978
438	F164047		BINARY	0	1.000000	-9.143203
439	F164048		BINARY	0	1.000000	-292.497
440	F164049		BINARY	0	1.000000	-302.147
441	F164050		BINARY	0	1.000000	-22.127800
442	F164051		BINARY	0	0.000000	19298.070
443	F164052		BINARY	0	0.000000	19298.070
444	F164053		BINARY	0	0.000000	19298.070
445	F164054		BINARY	0	0.000000	19298.070
446	F164055		BINARY	0	0.000000	19298.070
447	F164056		BINARY	0	0.000000	19298.070
448	F165001		BINARY	0	0.000000	-29.961650
449	F165002	BASIC	BINARY	0	1.000000	0.000000
450	F165003		BINARY	0	1.000000	-95.071706
451	F165004		BINARY	0	1.000000	-10.884904
452	F165005		BINARY	0	1.000000	-17.784937
453	F165006	BASIC	BINARY	0	1.000000	0.000000
454	F165007		BINARY	0	1.000000	-52.776577
455	F165008		BINARY	0	0.000000	-140.037
456	F165009		BINARY	0	0.000000	-35.896114
457	F165010		BINARY	0	1.000000	-303.979
458	F165011		BINARY	0	0.000000	19298.070
459	F165012		BINARY	0	1.000000	-25.839532
460	F165013		BINARY	0	0.000000	19.300000
461	F165014		BINARY	0	1.000000	-10.000000
462	F165015		BINARY	0	1.000000	-48.823090

LINEAR PROGRAMMING PROCEDURE

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
463	F165016		BINARY	0	1.000000	-73.887398
464	F165017		BINARY	0	0.000000	19298.070
465	F165018		BINARY	0	1.000000	-41.706257
466	F165019		BINARY	0	0.000000	-27.364075
467	F165020		BINARY	0	1.000000	-87.013310
468	F165021		BINARY	0	0.000000	-57.425977
469	F165022		BINARY	0	0.000000	-90.268553
470	F165023		BINARY	0	0.000000	-107.541
471	F165024		BINARY	0	1.000000	-47.966711
472	F165025		BINARY	0	1.000000	-25.984372
473	F165026		BINARY	0	1.000000	-118.930
474	F165027		BINARY	0	1.000000	-122.902
475	F165028		BINARY	0	1.000000	-105.911
476	F165029		BINARY	0	1.000000	-11.419006
477	F165030		BINARY	0	0.000000	19298.070
478	F165031		BINARY	0	1.000000	-13.745818
479	F165032		BINARY	0	1.000000	-21.523868
480	F165033		BINARY	0	0.000000	-116.415
481	F165034		BINARY	0	0.000000	6.789658
482	F165035		BINARY	0	0.000000	19298.070
483	F165036		BINARY	0	0.000000	9.329683
484	F165037		BINARY	0	1.000000	-56.693430
485	F165038		BINARY	0	0.000000	-22.988381
486	F165039		BINARY	0	0.000000	3.037024
487	F165040		BINARY	0	0.000000	0.063722
488	F165041		BINARY	0	0.000000	16.615561
489	F165042		BINARY	0	0.000000	19298.070
490	F165043		BINARY	0	0.000000	9.650000
491	F165044		BINARY	0	0.000000	-6.551845
492	F165045		BINARY	0	1.000000	-333.114
493	F165046		BINARY	0	1.000000	-333.114
494	F165047		BINARY	0	1.000000	-342.764
495	F165048		BINARY	0	1.000000	-60.760036
496	F165049		BINARY	0	0.000000	19298.070
497	F165050		BINARY	0	0.000000	19298.070
498	F165051		BINARY	0	0.000000	19298.070
499	F165052		BINARY	0	0.000000	19298.070
500	F165053		BINARY	0	0.000000	19298.070
501	LANT001		BINARY	0	0.000000	-81.289041
502	LANT002		BINARY	0	1.000000	-65.903341
503	LANT003		BINARY	0	1.000000	-61.975905
504	LANT004		BINARY	0	0.000000	-21.237454

LINEAR PROGRAMMING PROCEDURE

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
505	LANT005	DEGEN	BINARY	0	0.000000	0.000000
506	LANT006		BINARY	0	1.000000	-30.779344
507	LANT007		BINARY	0	0.000000	-16.251337
508	LANT008		BINARY	0	1.000000	-59.905687
509	LANT009		BINARY	0	1.000000	-22.597814
510	LANT010		BINARY	0	1.000000	-130.931
511	LANT011		BINARY	0	0.000000	-17.737864
512	LANT012		BINARY	0	1.000000	-24.224282
513	LANT013		BINARY	0	0.000000	-11.447335
514	LANT014		BINARY	0	0.000000	19298.070
515	LANT015		BINARY	0	0.000000	19298.070
516	LANT016		BINARY	0	0.000000	19298.070
517	LANT017		BINARY	0	0.000000	19298.070
518	LANT018		BINARY	0	0.000000	19298.070
519	LANT019		BINARY	0	0.000000	19298.070
520	LANT020		BINARY	0	0.000000	19298.070
521	A1011505	BASIC	SURPLUS		1.000000	0.000000
522	A1012305	BASIC	SURPLUS		1.000000	0.000000
523	A1020232		SLACK		0.000000	407.636
524	A1020313		SLACK		0.000000	77.961312
525	A1021314		SLACK		0.000000	44.707498
526	ENG22239	DEGEN	SLACK		0.000000	0.000000
527	F1710105	DEGEN	SURPLUS		0.000000	0.000000
528	F1710558	DEGEN	SURPLUS		0.000000	0.000000
529	F1715605		SURPLUS		0.000000	233.505
530	F1721057	DEGEN	SLACK		0.000000	0.000000
531	F1721157	DEGEN	SLACK		0.000000	0.000000
532	F1721256	DEGEN	SLACK		0.000000	0.000000
533	F1722558	DEGEN	SLACK		0.000000	0.000000
534	F1722957	DEGEN	SLACK		0.000000	0.000000
535	F5A12710	DEGEN	SURPLUS		0.000000	0.000000
536	F5C11817	DEGEN	SURPLUS		0.000000	0.000000
537	F5C13128		SURPLUS		0.000000	17.728381
538	F5C13156	DEGEN	SURPLUS		0.000000	0.000000
539	F5C13513		SURPLUS		0.000000	106.326
540	F5C14212	DEGEN	SURPLUS		0.000000	0.000000
541	F5C14342	BASIC	SURPLUS		1.000000	0.000000
542	F5C14542	BASIC	SURPLUS		1.000000	0.000000
543	F5C15657	BASIC	SURPLUS		1.000000	0.000000
544	F5C15728	BASIC	SURPLUS		1.000000	0.000000
545	F5C22829	BASIC	SLACK		1.000000	0.000000
546	F5C23254	BASIC	SLACK		1.000000	0.000000

LINEAR PROGRAMMING PROCEDURE

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
547	F5C24144	BASIC	SLACK		1.000000	0.000000
548	F5C24447	BASIC	SLACK		1.000000	0.000000
549	F5C25628	BASIC	SLACK		1.000000	0.000000
550	F5E12524		SURPLUS		0.000000	57.583184
551	F5E14145	BASIC	SURPLUS		1.000000	0.000000
552	F5E15345	BASIC	SURPLUS		1.000000	0.000000
553	F5E24548	BASIC	SLACK		1.000000	0.000000
554	F5E25248	BASIC	SLACK		1.000000	0.000000
555	F6310102	BASIC	SURPLUS		1.000000	0.000000
556	F6310126	BASIC	SURPLUS		1.000000	0.000000
557	F6311225		SURPLUS		0.000000	29.573848
558	F6311423	DEGEN	SURPLUS		0.000000	0.000000
559	F6312018	DEGEN	SURPLUS		0.000000	0.000000
560	F6312118	DEGEN	SURPLUS		0.000000	0.000000
561	F6312120		SURPLUS		0.000000	157.393
562	F6312518	BASIC	SURPLUS		1.000000	0.000000
563	F6312926	DEGEN	SURPLUS		0.000000	0.000000
564	F6313218	BASIC	SURPLUS		1.000000	0.000000
565	F6313318	BASIC	SURPLUS		1.000000	0.000000
566	F6313711		SURPLUS		0.000000	42.391975
567	F6314218	BASIC	SURPLUS		1.000000	0.000000
568	F6321911		SLACK		0.000000	56.349302
569	F6323719	DEGEN	SLACK		0.000000	0.000000
570	F6410307		SURPLUS		0.000000	39.164599
571	F6410807	DEGEN	SURPLUS		0.000000	0.000000
572	F6411102	BASIC	SURPLUS		1.000000	0.000000
573	F6411109	BASIC	SURPLUS		1.000000	0.000000
574	F6411110	BASIC	SURPLUS		1.000000	0.000000
575	F6411123	DEGEN	SURPLUS		0.000000	0.000000
576	F6411124	BASIC	SURPLUS		1.000000	0.000000
577	F6411134	BASIC	SURPLUS		1.000000	0.000000
578	F6411140	BASIC	SURPLUS		1.000000	0.000000
579	F6411141	BASIC	SURPLUS		1.000000	0.000000
580	F6411144	BASIC	SURPLUS		1.000000	0.000000
581	F6411809		SURPLUS		0.000000	135.701
582	F6411834		SURPLUS		0.000000	112.325
583	F6411840		SURPLUS		0.000000	55.966248
584	F6420641		SLACK		0.000000	3.198125
585	F6421009	BASIC	SLACK		1.000000	0.000000
586	F6422441	BASIC	SLACK		1.000000	0.000000
587	F6422923		SLACK		0.000000	752.930
588	F6423035		SLACK		0.000000	57.603867

LINEAR PROGRAMMING PROCEDURE

VARIABLE SUMMARY

Col	Variable Name	Status	Type	Price	Activity	Reduced Cost
589	F6423409	BASIC	SLACK		1.000000	0.000000
590	F6510306		SURPLUS		0.000000	47.263924
591	F6510706	DEGEN	SURPLUS		0.000000	0.000000
592	F6511008	BASIC	SURPLUS		1.000000	0.000000
593	F6511009	BASIC	SURPLUS		1.000000	0.000000
594	F6511021	BASIC	SURPLUS		1.000000	0.000000
595	F6511022	BASIC	SURPLUS		1.000000	0.000000
596	F6511023	BASIC	SURPLUS		1.000000	0.000000
597	F6511033	BASIC	SURPLUS		1.000000	0.000000
598	F6511037	DEGEN	SURPLUS		0.000000	0.000000
599	F6511038	BASIC	SURPLUS		1.000000	0.000000
600	F6511040	BASIC	SURPLUS		1.000000	0.000000
601	F6511608	BASIC	SURPLUS		1.000000	0.000000
602	F6511633	BASIC	SURPLUS		1.000000	0.000000
603	F6511637	DEGEN	SURPLUS		0.000000	0.000000
604	F6520138	BASIC	SLACK		1.000000	0.000000
605	F6520908	BASIC	SLACK		1.000000	0.000000
606	F6522338	BASIC	SLACK		1.000000	0.000000
607	F6523308	BASIC	SLACK		1.000000	0.000000
608	LAN10313	BASIC	SURPLUS		1.000000	0.000000
609	LAN11105	DEGEN	SURPLUS		0.000000	0.000000
610	LAN11107	DEGEN	SURPLUS		0.000000	0.000000
611	LAN20506		SLACK		0.000000	38.846874
612	YEAR01	BASIC	SLACK		40.789000	0.000000
613	YEAR02	BASIC	SLACK		2.716000	0.000000
614	YEAR03	BASIC	SLACK		1.807000	0.000000
615	YEAR04	BASIC	SLACK		1.182000	0.000000
616	YEAR05	BASIC	SLACK		0.250000	0.000000
617	YEAR06	BASIC	SLACK		0.370000	0.000000
618	YEAR07	BASIC	SLACK		0.005000	0.000000
619	YEAR08	BASIC	SLACK		10.953000	0.000000
620	YEAR09	BASIC	SLACK		66.423000	0.000000
621	YEAR10	BASIC	SLACK		190.742	0.000000
622	YEAR11	BASIC	SLACK		14.876000	0.000000
623	YEAR12	BASIC	SLACK		31.090000	0.000000
624	YEAR13	BASIC	SLACK		140.849	0.000000
625	YEAR14	BASIC	SLACK		185.280	0.000000
626	YEAR15	BASIC	SLACK		253.037	0.000000
627	YEAR16	BASIC	SLACK		252.900	0.000000
628	YEAR17	BASIC	SLACK		308.900	0.000000
629	YEAR18	BASIC	SLACK		314.300	0.000000

L I N E A R   P R O G R A M M I N G   P R O C E D U R E

CONSTRAINT SUMMARY

Constraint Row	Name	Type	S/S Col	Rhs	Activity	Dual Activity
1	A1011203	EQ		0	0.000000	13.410982
2	A1011505	GE	521	0	1.000000	0.000000
3	A1011517	EQ		0	0.000000	19298.070
4	A1012305	GE	522	0	1.000000	0.000000
5	A1020232	LE	523	1	1.000000	-407.636
6	A1020313	LE	524	1	1.000000	-77.961312
7	A1021314	LE	525	1	1.000000	-44.707498
8	COSTOWN	EQ		4737.5763	4737.576	1.740000
9	ENG22239	LE	526	1	1.000000	0.000000
10	F1710105	GE	527	0	0.000000	0.000000
11	F1710558	GE	528	0	0.000000	0.000000
12	F1715605	GE	529	0	0.000000	233.505
13	F1721057	LE	530	1	1.000000	0.000000
14	F1721157	LE	531	1	1.000000	0.000000
15	F1721256	LE	532	1	1.000000	0.000000
16	F1722558	LE	533	1	1.000000	0.000000
17	F1722957	LE	534	1	1.000000	0.000000
18	F5A12710	GE	535	0	0.000000	0.000000
19	F5C11817	GE	536	0	0.000000	0.000000
20	F5C13128	GE	537	0	0.000000	17.728381
21	F5C13156	GE	538	0	0.000000	0.000000
22	F5C13513	GE	539	0	0.000000	106.326
23	F5C13839	EQ		0	0.000000	-75.359187
24	F5C14212	GE	540	0	0.000000	0.000000
25	F5C14342	GE	541	0	1.000000	0.000000
26	F5C14542	GE	542	0	1.000000	0.000000
27	F5C15657	GE	543	0	1.000000	0.000000
28	F5C15728	GE	544	0	1.000000	0.000000
29	F5C22829	LE	545	1	0.000000	0.000000
30	F5C23254	LE	546	1	0.000000	0.000000
31	F5C24144	LE	547	1	0.000000	0.000000
32	F5C24447	LE	548	1	0.000000	0.000000
33	F5C25628	LE	549	1	0.000000	0.000000
34	F5E12524	GE	550	0	0.000000	57.583184
35	F5E14145	GE	551	0	1.000000	0.000000
36	F5E15345	GE	552	0	1.000000	0.000000
37	F5E24548	LE	553	1	0.000000	0.000000
38	F5E25248	LE	554	1	0.000000	0.000000
39	F6310102	GE	555	0	1.000000	0.000000
40	F6310126	GE	556	0	1.000000	0.000000
41	F6311225	GE	557	0	0.000000	29.573848
42	F6311423	GE	558	0	0.000000	0.000000

LINEAR PROGRAMMING PROCEDURE

CONSTRAINT SUMMARY

Constraint Row	Name	Type	S/S Col	Rhs	Activity	Dual Activity
43	F6312018	GE	559	0	0.000000	0.000000
44	F6312118	GE	560	0	0.000000	0.000000
45	F6312120	GE	561	0	0.000000	157.393
46	F6312518	GE	562	0	1.000000	0.000000
47	F6312926	GE	563	0	0.000000	0.000000
48	F6313218	GE	564	0	1.000000	0.000000
49	F6313318	GE	565	0	1.000000	0.000000
50	F6313711	GE	566	0	0.000000	42.391975
51	F6314218	GE	567	0	1.000000	0.000000
52	F6321911	LE	568	1	1.000000	-56.349302
53	F6323719	LE	569	1	1.000000	0.000000
54	F6410307	GE	570	0	0.000000	39.164599
55	F6410807	GE	571	0	0.000000	0.000000
56	F6411102	GE	572	0	1.000000	0.000000
57	F6411109	GE	573	0	1.000000	0.000000
58	F6411110	GE	574	0	1.000000	0.000000
59	F6411123	GE	575	0	0.000000	0.000000
60	F6411124	GE	576	0	1.000000	0.000000
61	F6411134	GE	577	0	1.000000	0.000000
62	F6411140	GE	578	0	1.000000	0.000000
63	F6411141	GE	579	0	1.000000	0.000000
64	F6411144	GE	580	0	1.000000	0.000000
65	F6411809	GE	581	0	0.000000	135.701
66	F6411834	GE	582	0	0.000000	112.325
67	F6411840	GE	583	0	0.000000	55.966248
68	F6420641	LE	584	1	1.000000	-3.198125
69	F6421009	LE	585	1	0.000000	0.000000
70	F6422441	LE	586	1	0.000000	0.000000
71	F6422923	LE	587	1	1.000000	-752.930
72	F6423035	LE	588	1	1.000000	-57.603867
73	F6423409	LE	589	1	0.000000	0.000000
74	F6510306	GE	590	0	0.000000	47.263924
75	F6510706	GE	591	0	0.000000	0.000000
76	F6511008	GE	592	0	1.000000	0.000000
77	F6511009	GE	593	0	1.000000	0.000000
78	F6511021	GE	594	0	1.000000	0.000000
79	F6511022	GE	595	0	1.000000	0.000000
80	F6511023	GE	596	0	1.000000	0.000000
81	F6511033	GE	597	0	1.000000	0.000000
82	F6511037	GE	598	0	0.000000	0.000000
83	F6511038	GE	599	0	1.000000	0.000000
84	F6511040	GE	600	0	1.000000	0.000000

LINEAR PROGRAMMING PROCEDURE

CONSTRAINT SUMMARY

Row	Constraint Name	Type	S/S Col	Rhs	Activity	Dual Activity
85	F6511608	GE	601	0	1.000000	0.000000
86	F6511633	GE	602	0	1.000000	0.000000
87	F6511637	GE	603	0	0.000000	0.000000
88	F6520138	LE	604	1	0.000000	0.000000
89	F6520908	LE	605	1	0.000000	0.000000
90	F6522338	LE	606	1	0.000000	0.000000
91	F6523308	LE	607	1	0.000000	0.000000
92	FALCONUP	EQ		3	3.000000	-18.882668
93	FMS	EQ		1650	1650.000	1.000000
94	LAN10313	GE	608	0	1.000000	0.000000
95	LAN11105	GE	609	0	0.000000	0.000000
96	LAN11107	GE	610	0	0.000000	0.000000
97	LAN20506	LE	611	1	1.000000	-38.846874
98	OBJECT	OBJECT			9222.042	.
99	TECHRISK	EQ		0	0.000000	-1.930000
100	WEIGHT	EQ		232307671	232307671	0.000071
101	YEAR01	LE	612	484.2	443.411	0.000000
102	YEAR02	LE	613	527.4	524.684	0.000000
103	YEAR03	LE	614	567.6	565.793	0.000000
104	YEAR04	LE	615	564	562.818	0.000000
105	YEAR05	LE	616	771.6	771.350	0.000000
106	YEAR06	LE	617	760.2	759.830	0.000000
107	YEAR07	LE	618	802.2	802.195	0.000000
108	YEAR08	LE	619	832.2	821.247	0.000000
109	YEAR09	LE	620	774	707.577	0.000000
110	YEAR10	LE	621	689.4	498.658	0.000000
111	YEAR11	LE	622	475.8	460.924	0.000000
112	YEAR12	LE	623	364.2	333.110	0.000000
113	YEAR13	LE	624	382.2	241.351	0.000000
114	YEAR14	LE	625	286.2	100.920	0.000000
115	YEAR15	LE	626	345	91.963000	0.000000
116	YEAR16	LE	627	334.8	81.900000	0.000000
117	YEAR17	LE	628	340.8	31.900000	0.000000
118	YEAR18	LE	629	346.2	31.900000	0.000000