DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY AVIATION SYSTEMS COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120-1798

REPLY TO
ATTENTION OF

AMSAV-Z 8 August 1989

MEMORANDUM FOR: AMSAV-BD (11-18c)

SUBJECT: CLEARANCE OF ARTICLE

1. The article entitled "Using Goal Programming to Determine the Optimal Engine Mix for UH-1 Helicopters," for presentation at the Department of Defense Cost Analysis Symposium at Leesburg, VA., revealed no classified or sensitive unclassified material. The material has been cleared for release.

2. Point of contact for this action is Robert E. Hunt, phone (314) 263-1194.

ROBERT E. HUNT
Acting Chief
Public Affairs Office

AMSAV-BD (11-18c)

7 AUG 1989

MEMORANDUM THRU AMSAV-OC

FOR AMSAV-Z

SUBJECT: Request for OPSEC Review

1. The enclosed article entitled, "Using Goal Programming to Determine the Optimal Engine Mix for UH-1 Helicopters," is scheduled for presentation at the Department of Defense Cost Analysis Symposium at Leesburg, Virginia, 6-8 September 1989. The paper with its release authorization must reach the workshop chairman NLT 8 August 1989.

2. A technical security OPSEC review of this material has been conducted by this office and reveals no classified or sensitive information.

3. Request your office review the enclosed material for possible content of classified or sensitive information, and provide release authorization NLT 8 August 1989.

4. Point of contact is Ms. Kimberly S. Schenken, Ext. 1184.

Encl

EDWARD P. LAUGHLIN
Director of Systems and Cost Analysis

USING GOAL PROGRAMMING TO DETERMINE THE OPTIMAL ENGINE MIX FOR UH-1 HELICOPTERS

PRESENTED AT THE 1989 DOD COST ANALYSIS SYMPOSIUM

BY Kimberly S. Schenken GS-12
Operations Research System Analyst
Aviation Systems Command
AMSAV-BD

SYNOPSIS

This paper presents a methodology for using Sequential Linear Goal Programming to determine the optimal decision when decision makers have conflicting goals.

An example is presented to demonstrate the technique. The demonstration problems is whether the UH-1 Helicopter's engine should be rebuilt or replaced with a modern engine. The Army has several conflicting criteria to consider in this decision. For example, they want to minimize both Investment cost and operating and support costs, and maximize the performance of the weapon system. This paper illustrates how goal programming is useful in highlighting trade-offs in decisions, and in demonstrating to decision makers the effect of postponing cost reducing improvements to weapon systems. The disadvantage of goal programmin is that the formulation of the problem is complex and many problems may require too large a problem to be feasible.

Table of Contents

Using Goal Programming to Determine The Optimal Engine Mix for UH-1 Helicopters

INTRODUCTION

All managers are faced with decisions that require them to balance conflicting criteria. For example, a Store manager may want to maximize profits but also wish to increase customer loyalty, so long-term profits are also maximized. The goals may require conflicting actions. In other cases, several goals may compete for the same scarce resources. The US Army, especially in light of current Budget Reductions, faces similar dilemmas. Another problem is the difficulty in measuring all of the important elements in a decision. For example, an important consideration in the purchase of a new weapon system is the increase in war fighting capability contributed by a new system. However, in a normal cost analysis, a rigorous comparison of the relative benefits is rarely performed. This is mainly because it is difficult to precisely quantify the benefits since the benefits are often difficult to measure in dollars. This paper demonstrates the value of goal programming in making a decision. Goal programming is a method for combining both cost and qualitative criteria in order to make the best possible decision.

Description of Goal Programming

Goal programming is a technique that produces the optimal solution given a set of management goals and assumptions. The assumptions are built into the goals and constraints. This paper will use goal programming as a tool to aid in presenting management with a range of options and will consider both the costs and benefits.

Goal programming is a variant of linear programming. Linear Programming seeks to optimize one goal, for example, minimizing costs, or maximizing profits, subject to various constraints. In Goal Programming, decision makers set several goals as well as defining system constraints. System constraints are constraints that are not easily changeable by the decision maker. An example of a system constraint is machine capacity.

Goal programming seeks to minimize the sum of the deviations from the goals. Management sets specific numeric goals for important objectives of the organization. One example is management setting a goal of 200 hours for the mean time between repair for helicopters. It is possible for the solution to exceed the goal or to under achieve the goal by some amount. The deviational variables hold the value of the under-achievement or over-achievement. Each goal has a d+ deviational variable which is the amount the goal was exceeded and each goal has a d- variable which is the amount by which the goal was missed.

The goals set by management are prioritized and weighted. Then the priorities and weights attached to the goals are assigned to the deviational variables related to the goal. Goal programming problems are formulated as minimization problems. The objective function minimizes the deviational variables. Each deviational variable has priorities and weights attached to it. Priority 1 is the highest priority. Several variables can have the same priority, and weights can be added to distinguish relative importance at a priority level. The higher the weight the more importance is being attached to the variable. All the deviational variables in the problem may not be included in the objective function. For example, normally it is acceptable to exceed your profit goal or under achieve your cost goal. Most of the time, it would not make sense to minimize these variables so they would not be included in your objective equation.

Explanation of Sequential Goal Programming

Sequential goal programming is a methodology for using a linear goal programming program to solve a goal programming problem. This paper will use sequential goal programming as a goal programming program that could handle the example problem (a 30 variable problem) was not available. Sequential Goal programming takes a goal programming problem and breaks it down into a series of linear programming problems. Therefore, a Linear Programming program will solve a Goal Programming problem. The linear programming program uses the Simplex method to solve the problem.

Goals of Paper

The advantages of using goal programming will be demonstrated by using goal programming to develop possible solutions to the problem of determining what engines should be used in the UH-11 Helicopter. The choice is between replacing the old engine with a modern higher performance engine or by continuing to rebuild the old engine.

Background

The UH-1 Helicopter is a common utility aircraft used by the US Army. In fact the UH-1 is the most numerous type of aircraft in the Army's inventory. This aircraft is approximately 25 years old and currently has a T53-L13B engine (T53). The T53 engine is less efficient and less powerful than newer technology engines. Therefore, the purpose of this study is to determine if it is cost-effective to replace the T53 engines with T700-GE-700 engines (T700).

Replacing the T53 engine with the T700 engine involves modifying the UH-1 aircraft by replacing the engine mount to accommodate the T700 engine. Also a speed decreasing gearbox will be added to the engine to make it compatible with the existing transmission. Replacing T53 engines with T700 engines has the advantage that T700 engines are cheaper to operate and support. The engine has a higher range and payload capacity than the T53 engine. It also has greater reserve power which is an important safety advantage. Increased reserve power decreases the risk of crash damage and loss of life as the pilot has the necessary power to get out of dangerous situations. The T700 engine is a proven engine already in the Army's inventory as the engine for the Black Hawk UH-60 Helicopters. There are no developmental costs associated with this project. Some testing is required since the speed decreasing gearbox is new and the mounting in UH-1's is new.

The main disadvantage to installing new T700 engines is that they are twice as expensive as rebuilt T53 engines. Continuing to rebuild the T53 engine is the alternative. The main benefit from this course of action is that the initial cost is much less expensive. The T53 engine is more expensive to operate and less reliable than the T700 engine. Also, it is difficult to maintain as parts are less available. When the T53 engine was new, it used parts that were common to other commercial engines. Now, there are fewer engines using the same types of parts. This results in higher costs for T53 parts as the manufacturers overhead expenses are not spread across several customers.

Description of Conflicting Goals for UH-1 Problem

In making this decision, the US Army has conflicting goals:

1. Minimize Total Life Cycle Cost
This includes minimizing the investment costs and the operating and support costs. There may be a conflict between minimizing operating and support costs and minimizing investment costs. The least expensive engine is probably not the least expensive to operate and support.

2. Maximize Performance of the Engine
The US Army would like the highest performance engine as that engine increases the War fighting capability of the Aircraft. Also, it increases crew safety and averts possible loss as increased reserve engine power decreases the risk of crash and possible loss of life and property.

The body of the paper will explain in detail the nature of the problem, the goals and trade-offs involved in possible solutions. The paper will also demonstrate how Goal Programming is useful in bringing order to the decision making process so all important aspects of the problem are considered. It will also demonstrate how Goal Programming aids in constructing the best decision to satisfy several conflicting goals. The paper will also discuss the limitations of Goal Programming and the problems encountered in formulating this problem.

Problem Statement

This paper will compare the costs and benefits of replacing T53 engines with T700 engines with the costs and benefits of rebuilding T53 engines for ten years, 1991 - 2000. Goal Programming will be the tool used to perform the comparison and analysis. This analysis should normally be for the life cycle of the engine which is approximately twenty-five years. The life cycle analysis then includes all of the costs for the item and it is Army policy to minimize the costs of the entire life cycle. The analysis is limited to ten years as this problem is being used mostly to demonstrate the validity of the technique and because the problem is kept to a manageable size.

Costs of the Alternatives

The costs of the two alternatives and explanations of the work involved in each alternative are listed below.

Replacement of T53 Engines with T700 Engines

Investment costs for installing T700 engines totaled $504,000 each in constant FY 85 dollars. The cost breakdown is as follows:

Costs per aircraft in Constant FY 85 dollars:

Aircraft Modification	$100,000
T700 Engine	374,000
Speed Decreasing Gearbox	30,000
Total Cost	$504,000

The modification cost was incurred for replacing the engine, changing the mounting and instrumentation and adding the speed decreasing gearbox. There is also a fixed cost of $15,000,000 over the life cycle of the engine for developmental/qualification testing of the modification to the aircraft.

Rebuild of T53 Engines

Rebuild of the T53 Engine costs $200,000 each in constant FY 85 dollars. The T700 engine replacement costs twice as much as continuing to rebuild T53 engines.

However the T700 engine is least expensive in Operating and Support costs as is shown below:

Operating and Support Costs
In FY 85 Constant Dollars
Dollars in Thousands
Op Tempo is 300 flying Hours per year

Cost Category	T700	T53
Fuel per Acft	$17.510	$22.041
Field Labor	.490	2.919
Depot Labor	2.709	7.095
Parts	35.100	42.450
	$55.809	$74.505

Benefit Comparison

Replacing the T53 engine with a T700 Engine has several benefits which are explained below:

Increased Performance

The T700 engine has greater engine power as it has a maximum military shaft horsepower of 1560 and the T53 engine 1400. The T700 engine also has a much greater payload capacity than the T53 engine. This is especially true in a high altitude, hot day condition, e.g., 4000 feet, 95 degrees Fahrenheit. The difference is illustrated in Figure 1 and Table 1. The T700 engine also has fuel savings of 22 percent at most shaft horsepower ranges. See figure 2. The T700 engine is less expensive per flying hour for parts costs, maintenance costs (both field maintenance and depot maintenance) and fuel costs. These benefits will not be shown in separate benefit constraints as these benefits are shown implicitly in the operating and support constraint. The T700 has a lower operating and support cost due to these lower costs. The T700 has greater power as it has a maximum military shaft horsepower of 1560 and the T53 engine has a maximum military shaft horsepower of 1400. The increased range and payload is a significant benefit to the UH-1's wartime mission of transporting personnel and equipment. Retrofit of the UH-1 with the T700 engine will increase performance by 34 percent. See Table 1.

Crew Safety

The UH-1 will be a safer aircraft if a T700 engine is installed because the aircraft will normally be performing farther away from its maximum capacity. Therefore more reserve power will be available to the pilot in case of emergency. Crew safety will be increased by 30 percent

Inventory Reduction

The T700 engine is already provisioned by the US Army because it is used by the Black Hawk Helicopter. This means that a significant cost is avoided as the parts, data and Technical manuals are already in the Army Inventory. If the T53 engine is phased out there will be cost benefits because fewer parts will need to be stocked since only one engine type is being supported. Also, only one set of technical manuals will need to be maintained. Although this is a definite cost benefit, the data needed to quantify this cost is not collected. However, the cost benefits for the T700 are estimated to be 10 percent.

The variables in the problem are defined below:

Decision Variables

T7i = The number of T700 engines bought in year i.
T5i = The number of T53 engines rebuilt in year i.

Year i = 01 to 10 year 1 = 1991 and year 10 = 2000

Deviational Variables

DIM = dollars under investment cost goal

DIP = dollars over investment cost goal

DOSM = dollars under operating and support cost goal

DOSP = dollars over operating and support cost goal

DB1M = number of points under performance goal

DB1P = number of points over performance goal

Deviational Variables (Continued)

DB2M = number of points under crew safety goal

DB2P = number of points over crew safety goal

DB3M = number of points under inventory goal

DB3P = number of points over inventory goal

Priorities of Goals

P1 Minimize exceeding cost goal for Operating and Support DOSP

P2 Minimize exceeding cost goal for Investment

P3 Minimize underachieving benefit goals DB1M, DB2M and

Reasons for Priorities

Operating and Support Costs over the life cycle of 25 years or more are more costly than the investment costs. For example, the operating and support costs equal the investment costs for the T700 engine in 9.16 years. This calculation is based on the FY 85 investment cost of $504,000 and the FY 85 annual operating and support cost of $55,000. This problem was limited to 10 years of the life cycle but the operating and support cost is still the most critical cost to control since this is a cost incurred over the entire life cycle. Controlling operating and support costs is currently a critical issue in the Department of Defense because historically cost control of O & S has been very poor. Often O & S costs have been considered only very superficially when choices between weapon systems were made. Contractors were not held to their O & S estimates. If Contractors underestimated O & S costs, penalties were not assessed against the contractors. All of this is changing, although estimating realistic O & S costs is still very difficult. At least it is difficult on a developmental system where the Army has no previous experience. For the T700 engine our estimates of O & S costs should be relatively accurate as we have had 10 years experience with the T700 engine on the Black Hawk Helicopter. The contracting language is still being perfected and is difficult issue as O & S costs must be measured over a long period of time. For all these reasons, minimizing O & S costs was considered the highest priority.

The second highest priority is Investment costs because although the Investment costs are less than total life cycle O & S costs they are still very large. The UH-1 helicopter is a relatively minor weapon system and the modification cost is relatively small compared to modification costs on an Air Force Aircraft but the total life cycle cost of replacing the T53 engine is more than one billion dollars.

The third priority are the benefits derived from the T700 Helicopter. All three benefits: performance improvement, crew safety and inventory reduction are judged to be equally important. The benefits were added as a constraint because it is important to consider other factors than cost. If the equipment does not perform the mission effectively, then money has been wasted no matter how small the amount.

FORMULATION OF PROBLEM

ALL DOLLARS ARE IN THOUSANDS

MINIMIZE: (P1)DOSM + (P2)DIP + P3(B1M + B2M + B3M)

SUBJECT TO:

OPERATING AND SUPPORT COSTS

227.49(T701) + 204.1(T702) + 180.2(T703) + 155.8(T704) + 130.9(T705) + 105.7(T706) + 80(T707) + 53.8(T708) + 27.1(T709) + DOSM - DOSP = 146307

INVESTMENT COSTS

635.1(T701) + 648.7(T702) + 660.9(T703) + 672.8(T704) + 684.9(T705) + 697.3(T706) + 709.8(T707) + 722.6(T708) + 735.6(T709) + 748.8(T710) + 15000 + 252.0(T501) + 257.4(T502) + 262.3(T503) + 267.0(T504) + 271.8(T5305) + 276.7(T506) + 281.7(T507) + 286.8(T508) + 291.9(T5309) + 297.2(T510) + DIM - DIP = 1,072,880

PERFORMANCE GOAL

T701 + T702 + T703 + T704 + T705 + T706 + T707 + T708 + T709 + T710 + DB1M - DB1P = 200

CREW SAFETY

T701 + T702 + T703 + T704 + T705 + T706 + T707 + T708 + T709 + T710 + DB2M - DB2P = 300

INVENTORY REDUCTION

T701 + T702 + T703 + T704 + T705 + T706 + T707 + T708 + T709 + T710 + DB3M - DB3P = 300

SYSTEM CONSTRAINTS

T701 + T702 + T703 + T704 + T705 + T706 + T707 + T708 + T709 + T710 <= 1720

T701 + T702 + T703 + T704 + T705 + T706 + T707 + T708 + T709 + T710 + T501 + T502 + T503 + T504 + T505 + T506 + T507 + T508 + T509 + T510 <= 3165

T501 + T502 + T503 + T504 + T505 + T506 + T507 + T508 + T509 + T510 >= 1445

AND T701 ... T710, T501 ... T510 >= 0

AND DOSM, DOSP, DIM, DIP, DB1M, DB1P, DB2M, DB2P, DB3M, DB3P >= 0

EXPLANATION OF CONSTRAINTS

The operating and support constraint considers three types of engines. The first type are engines replaced by T700 engines, the second group are T53 engines that are rebuilt, the third group of engines are T53 engines that are not overhauled or replaced by T700 engines. The first two groups are identified by the decision variables (T7i and T5i respectively). Each decision variable identifies the number of the specific type of engine procured or rebuilt in a specific year. The third group is determined by subtracting the decision variables for each year from the total number of engines in the fleet for each year. The fleet size decreases over the years as some UH-1's are retired from the fleet.

The constraint was computed as follows:

(((The sum of CYC(i)*T7j + The sum of CYC(i)*T5j)) + The sum of CYC(i)*(Fleet Size per Year(i) - (T7j + T5j)))
j = The number of engines operating in year i.
i = 1 to 10, with year 1 = 1991 and year 10 = 2000.

Table 2 contains three matrixes representing the three parts of the Operating and Support constraint. The first matrix includes the variables that represent the engines being supported in that year. An assumption is that a T700 engine procured in year 1 is not operated and supported until year 2. Similarly, a T53 engine rebuilt in year 1 is operable until year 2. This is a realistic assumption because the production leaden averages 12 months. For year 5, the variables listed would be T701, T702, T703, T704, T501, T502, T503 and T504. Each variable is multiplied by the appropriate current dollar cost for the specific year. The second matrix multiplies the T53 support cost times the T7i and T5i variables. The third matrix (a single row) subtracts the value of the second matrix from the first matrix and adds the cost of the fleet for 10 years if no T700 engines are bought. The T5i variables drop to zero because they are considered in the total fleet cost. The T700 variables become negative because they are the amount of reduction in O & S costs possible per year per T700 engine. The operating and support constraint is:

3,245,343.5 - 225.49(T701) - 204.1(T702) - 180.2(T703) - 155.8(T704) - 130.9(T705) - 105.7(T706) - 8[illegible] T707) - 53.8(T708) - 27.1(T709) + DOSM - DOSP = 3,099,036.5

This format is not compatible with the Linear programming program used for solving the program. The linear programming program expects all constants on the right hand side. When the constant (Total fleet cost for ten years if only T53's are used) on the left is moved to the right both sides are negative. The final constraint is stated as:

225.49(T701) + 204.1(T702) + 180.2(T703) + 155.8(T704) + 130.9(T705) + 105.7(T706) + 80(T707) + 53.8(T708) + 23.1(T709) + DOSM - DOSP = 146,307. The deviational variable we want to minimize is DOSM because represents the amount below our goal. The goal amount was developed by computing the O & S costs with the Program Managers desired program.

The Investment constraint consists of the current year investment cost per engine (dollars in thousands) for each variable. The investment goal was developed by computing the cost for the program managers desired program. This goal is based on budgetary restrictions. We can not afford to spend more than the goal, as we anticipate that congress will not approve higher spending levels.

The benefit constraints are all for T700 engines as no increased benefit is received from rebuilding the T53 engines for these three types of benefits. It is mandatory that the T53 engines either be rebuilt or replaced by T700 engines when they meet certain criteria. The criteria include failing condition tests. The rebuilt T53 engines are safer than worn out T53 engines but the T700 engine increase in safety is measured against the safety level of a rebuilt T53 engine in serviceable condition.

The benefit goals were developed by deciding the minimum number of T700 engines that should be bought in consideration of the benefit.

PROBLEM SOLUTIONS

The Storm Linear Programming Problem was used to solve the problem. This problem was solved iteratively by first setting the objective function to minimize the operating and support constraint. This was solved with the objective function = 0. This means that the priority 1 constraint was satisfied. A constraint was added to set DOSM = 0. The objective function was changed to minimize DIP. The optimal solution to this problem also equaled zero. Therefore, P2 was also satisfied. Another constraint setting DIP = 0 was added. The objective function was changed to minimize the benefit variables (DB1M, DB2M, and DB3M). Bounds were placed on the variables to avoid the program generating an unworkable schedule. For example, for the first two years for T700, the upper bounds were set at 25 and 50. This was so that the manufacturer has some start up time and to allow for system testing. The optimal solution which minimizes total costs for 10 years is as follows:

T700 SCHEDULE

YEAR	VARIABLE	QTY
1	T701	25
2	T702	50
3	T703	300
4	T704	500
5	T705	500
6 - 9	T706 - T709	= 0
10	T710	345

T53 SCHEDULE

YEAR	VARIABLE	QTY
1	T501	0
2	T502	0
3	T503	55
4 - 9	T504 - T509	= 0
10	T510	955

TOTAL COST (Escalated Dollars in Thousands) for Optimal Solution

Investment Cost:	$1,447,903.0
Operating and Support Cost	$2,995,576.5
Total Cost:	$4,443,479.5

See Table 3 which has the backup data from Storm showing how the solution was derived. The program managers original program is shown in Table 6. The total cost of the original proposed program is:

Investment Cost	$2,080,640.0
Operating and Support Cost	$3,099,036.0
Total Cost	$5,179,676.0

The difference is because the optimal solution is using an accelerated delivery schedule. The investment costs for T700 engines increase each year because of inflation. In the optimal solution, the investment is made sooner and the engines are bought at lower prices. The optimal solution is less expensive in O & S support because the T700's are introduced sooner and are less expensive to support.

After re-examining the optimal solution, I identified an extra system constraint in the formulation of the problem. Constraint 8 which is The sum of T5i >= 955). This constraint specified the number of T53 engines required. However, there are already constraints for the number of T700 engines and the total engines. After constraint 8 was deleted the resulting solution is better than the original optimal solution. It is better in both dollars and executability.

The optimal solution, after constraint 8 is removed, is better because there is no break in the rebuild schedule for T53 engines. The schedule for T700 engines is the same as the first solution but the schedule for T53 Engine Modifications is a quantity of 55 in year 3 and a quantity of 900 in year 4. This solution is also slightly less costly as shown below:

Escalated dollars in thousands

Investment Cost:	$1,420,720.0
Operating and Support Cost:	2,995,576.5
Total Cost	4,416,296.5

The final optimal solution is less expensive because the investment in T53 engines is made earlier in cheaper dollars (year 4 instead of year 10). The cost of investment increases each year due to inflation.

Conclusion

The main usefulness of Sequential Goal programming is that it clearly highlights the trade-offs involved in the decision. It also is a way of objectively satisfying conflicting objectives. The technique considers many possible solutions rather than just one solution. And the technique allows you to graphically demonstrate the value of funding your program immediately.

Disadvantages to the technique are that the technique is fairly complex. The quality of the answer is dependent on the quality of the formulation. Also, there is the danger of the problem being over simplified in order to remain manageable.

For example, this demonstration of the technique considers two alternatives for one program. The goal of this study is to convince decision makers to fund the most economical program. However, there is not only competition between alternatives, there is also competition between programs. To really determine the optimal investment in UH-1, it is necessary to first solve the problem above and then formulate another goal programming problem to develop the optimal use of resources between weapon systems. This problem would contain costs and relative benefits between weapon systems. My small UH-1 program had 30 variables with 10 constraints. A weapon system comparison problem would be much more complex.

Goal Programming is a useful technique to determine the optimal decision given several conflicting goals. More work needs to be done in the area of multiple criteria decision making so that realistically complex problems can be solved.

Definitions

Operating and Support Costs (O & S costs) - Those costs incurred to maintain and use the equipment. Categories of O & S costs include Petroleum and Oil Costs, spare and repair parts, field maintenance labor and depot maintenance labor.

Field Maintenance Labor - Hours of labor spent maintaining the engine at the Military Unit Level.

Depot Maintenance Labor - Hours of labor spent overhauling the engine or components at an Army Depot.

Spare Parts - These are repairable components of the aircraft. When these parts are damaged a repair program is set up to repair the component.

Repair Parts - These are parts used to repair the aircraft that once they are damaged are thrown away.

Bibliography

Benson, Robert L.
UH-1 and AH-1 Engine Replacement Cost Effective Analysis
St. Louis, MO: U.S. Army Aviation Systems Command, 1986.
USAAVSCOM TR 86-F-3

Hillier, Frederick S. and Gerald J. Lieberman
Introduction to Operations Research (4th ed.).
Oakland, CA: Holden-Day, Inc., 1986

Kwak, N.K. and Marc J. Schniederjans
Introduction to Mathematical Programming
Malabar, FL: Robert E. Krieger Publishing Company Inc., 1987

Schniederjans, Marc J.
Linear Goal Programming
Princeton, NY: Petrocelli Books, 1984

Starr, Martin K. and Milan Zeleny
Studies in the Management Sciences
Amsterdam, Netherlands: North-Holland Publishing Company, 1977

Woo, Scott S. Y. and Bernard J. Bauer, Jr.
Army Aircraft Turboshaft Engine Parametric Cost Estimating Relationship (CER)
St. Louis, MO: U.S. Army Aviation Research and Development Command, 1983.
USAAVRADCOM TM 83-F-2

Table 1

BENEFIT CONSTRAINTS

COMPARISON OF T53 AND T700 PAYLOAD AND RANGE

T700

	LOAD LBS	NAUTICAL MILES
PERFORMANCE AT SEA LEVEL STANDARD	3500	300
PERFORMANCE AT 4000 FT 90 DEGREES	3200	355

T53

	LOAD IN LBS	NAUTICAL MILES
PERFORMANCE AT SEA LEVEL STANDARD	3300	225
PERFORMANCE AT 4000 FT 90 DEGREES	2000	255

PERCENT IMPROVEMENT IN PERFORMANCE

	LOAD IN LBS	NAUTICAL MILES
PERFORMANCE AT SEA LEVEL STANDARD	6%	33%
PERFORMANCE AT 4000 FT 90 DEGREES	60%	39%

AVERAGE IMPROVEMENT BY T700

34%

Table 2

COSTS OF ACFT THAT SHOULD BE SUBTRACTED FROM TOTAL FLEET COST
AS THEY ARE BEING COUNTED AS MODIFIED OR OVERHAULED AIRCRAFT
CURRENT $ IN THOUSANDS

YR	T701	T5301	T702	T5302	T703	T5303	T704	T5304	T705	T5305	T706	T5306	T707	T5307	T708	T5308	T709	T5309	T710	T5310
1																				
2	93.3	93.3																		
3	95.4	95.4	95.4	95.4																
4	97.1	97.1	97.1	97.1	97.1	97.1														
5	98.9	98.9	98.9	98.9	98.9	98.9	98.9	98.9												
6	100.6	100.6	100.6	100.6	100.6	100.6	100.6	100.6	100.6	100.6										
7	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4								
8	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3	104.3						
9	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2	106.2				
10	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1		
TOTAL	906.3	906.3	813	813	717.6	717.6	620.5	620.5	521.6	521.6	421	421	318.6	318.6	214.3	214.3	108.1	108.1	0	0

FINAL VALUE OF VARIABLES IN OP & SUPPORT CONSTRAINT
CURRENT $ IN THOUSANDS — COSTS SHOWN PER ACFT

T701	T5301	T702	T5302	T703	T5303	T704	T5304	T705	T5305	T706	T5306	T707	T5307	T708	T5308	T709	T5309	T710	T5310		
-227.49	0	-204.1	0	-180.2	0	-155.8	0	-130.9	0	-105.7	0	-80	0	-53.8	0	-27.1	0	0	0	+	3,245,343.5

OPERATING AND SUPPCRT COST
OF TOTAL FLEET
NOT CONSIDERING ANY MODIFICATI

YR	TOT # OF ACFT	T53 COST	TOT COST OF T53 FLEET
1	3641	90.9	330,966.9
2	3585	93.3	334,480.5
3	3506	95.4	334,472.4
4	3416	97.1	331,693.6
5	3220	98.9	318,458.0
6	3122	100.6	314,073.2
7	3107	102.4	318,156.8
8	3067	104.3	319,888.1
9	3037	106.2	322,529.4
10	2966	108.1	320,624.6
			3,245,343.5

Table 3 FIRST OPTIMAL SOLUTION

STORM DATA SET LISTING
LINEAR PROGRAMMING DATA SET

Problem Description Parameters

Title : Iterative Goal Programming for UH-1 Engine

Number of variables	:	30
Number of constraints	:	10
Starting solution given	:	NO
Objective function	:	MIN

Constraint	Type
1	Operating & Support
2	Investment
3	Performance Benefit
4	Crew Safety Benefit
5	Inventory Reduction
6	No. of T700 Engines Required
7	Total No. of Engines Required
8	No of T53 Engines Required
9	Iterative Goal Constr O & S
10	Iterative Goal Constr Investment

Variables

Var 1 - 10 = T7i
Var 11 - 20 = T5i
Var 21 = DOSM
Var 22 = DOSP
Var 23 = DIM
Var 24 = DIP
Var 25 = DB1M
Var 26 = DB1P
Var 27 = DB2M
Var 28 = DB2P
Var 29 = DB3M
Var 30 = DB3P

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 1	VAR 2	VAR 3	VAR 4	VAR 5
OBJ COEFF	0.	0.	0.	0.	0.
CONSTR 1	227.4	204.1	180.2	155.8	130.9
CONSTR 2	635.1	648.7	660.9	672.8	684.9
CONSTR 3	1.	1.	1.	1.	1.
CONSTR 4	1.	1.	1.	1.	1.
CONSTR 5	1.	1.	1.	1.	1.
CONSTR 6	1.	1.	1.	1.	1.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 8	0.	0.	0.	0.	0.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	0.	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	25.	50.	300.	500.	500.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 6	VAR 7	VAR 8	VAR 9	VAR 10
OBJ COEFF	0.	0.	0.	0.	0.
CONSTR 1	105.7	80.	53.8	27.1	0.
CONSTR 2	697.3	709.8	722.6	735.6	748.8
CONSTR 3	1.	1.	1.	1.	1.
CONSTR 4	1.	1.	1.	1.	1.
CONSTR 5	1.	1.	1.	1.	1.
CONSTR 6	1.	1.	1.	1.	1.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 8	0.	0.	0.	0.	0.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	500.	500.	500.	500.	500.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 11	VAR 12	VAR 13	VAR 14	VAR 15
OBJ COEFF	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 2	252.	257.4	262.3	267.	271.8
CONSTR 3	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 4	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 5	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 6	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 8	1.	1.	1.	1.	1.
CONSTR 9	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1Ø	Ø.	Ø.	Ø.	Ø.	Ø.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	1ØØ.	3ØØ.	9ØØ.	9ØØ.	9ØØ.
INIT SOLN	Ø.	Ø.	Ø.	Ø.	Ø.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 16	VAR 17	VAR 18	VAR 19	VAR 20
OBJ COEFF	0.	0.	0.	0.	0.
CONSTR 1	0.	0.	0.	0.	0.
CONSTR 2	276.7	281.7	286.8	291.9	297.2
CONSTR 3	0.	0.	0.	0.	0.
CONSTR 4	0.	0.	0.	0.	0.
CONSTR 5	0.	0.	0.	0.	0.
CONSTR 6	0.	0.	0.	0.	0.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 8	1.	1.	1.	1.	1.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	900.	900.	900.	900.	900.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 21	VAR 22	VAR 23	VAR 24	VAR 25
OBJ COEFF	0.	0.	0.	0.	1.
CONSTR 1	1.	-1.	0.	0.	0.
CONSTR 2	0.	0.	1.	-1.	0.
CONSTR 3	0.	0.	0.	0.	1.
CONSTR 4	0.	0.	0.	0.	0.
CONSTR 5	0.	0.	0.	0.	0.
CONSTR 6	0.	0.	0.	0.	0.
CONSTR 7	0.	0.	0.	0.	0.
CONSTR 8	0.	0.	0.	0.	0.
CONSTR 9	1.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	1.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	Infinity	Infinity	Infinity	Infinity	Infinity
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 26	VAR 27	VAR 28	VAR 29	VAR 30
OBJ COEFF	Ø.	1.	Ø.	1.	Ø.
CONSTR 1	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 2	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 3	-1.	Ø.	Ø.	Ø.	Ø.
CONSTR 4	Ø.	1.	-1.	Ø.	Ø.
CONSTR 5	Ø.	Ø.	Ø.	1.	-1.
CONSTR 6	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 7	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 8	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 9	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 10	Ø.	Ø.	Ø.	Ø.	Ø.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	Infinity	Infinity	Infinity	Infinity	Infinity
INIT SOLN	Ø.	Ø.	Ø.	Ø.	Ø.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	CONST TYPE	R H S	RANGE
OBJ COEFF	XXXX	XXXX	XXXX
CONSTR 1	=	146307.	Infinity
CONSTR 2	=	2.08064E06	Infinity
CONSTR 3	=	300.	Infinity
CONSTR 4	=	200.	Infinity
CONSTR 5	=	300.	Infinity
CONSTR 6	=	1720.	Infinity
CONSTR 7	=	2675.	Infinity
CONSTR 8	>=	955.	Infinity
CONSTR 9	=	0.	Infinity
CONSTR 10	=	0.	Infinity
VARBL TYPE	XXXX	XXXX	XXXX
LOWR BOUND	XXXX	XXXX	XXXX
UPPR BOUND	XXXX	XXXX	XXXX
INIT SOLN	XXXX	XXXX	XXXX

Iterative Goal Programming for UH-1 Engine

OPTIMAL SOLUTION - SUMMARY REPORT (Nonzero Variables)

	Variable		Value	Cost
1	VAR	1	25.0000	0.0000
2	VAR	2	50.0000	0.0000
3	VAR	3	300.0000	0.0000
4	VAR	4	500.0000	0.0000
5	VAR	5	500.0000	0.0000
6	VAR	6	345.0000	0.0000
13	VAR	13	55.0000	0.0000
20	VAR	20	900.0000	0.0000
22	VAR	22	1.0346E+005	0.0000
23	VAR	23	6.3274E+005	0.0000
26	VAR	26	1420.0000	0.0000
28	VAR	28	1520.0000	0.0000
30	VAR	30	1420.0000	0.0000

Objective Function Value = 0.00000

Iterative Goal Programming for UH-1 Engine
OPTIMAL SOLUTION - DETAILED REPORT

	Variable		Value	Cost	Red. cost	Status
1	VAR	1	25.0000	0.0000	0.0000	Upper bound
2	VAR	2	50.0000	0.0000	0.0000	Upper bound
3	VAR	3	300.0000	0.0000	0.0000	Upper bound
4	VAR	4	500.0000	0.0000	0.0000	Upper bound
5	VAR	5	500.0000	0.0000	0.0000	Upper bound
6	VAR	6	345.0000	0.0000	0.0000	Basic
7	VAR	7	0.0000	0.0000	0.0000	Lower bound
8	VAR	8	0.0000	0.0000	0.0000	Lower bound
9	VAR	9	0.0000	0.0000	0.0000	Lower bound
10	VAR	10	0.0000	0.0000	0.0000	Lower bound
11	VAR	11	0.0000	0.0000	0.0000	Lower bound
12	VAR	12	0.0000	0.0000	0.0000	Lower bound
13	VAR	13	55.0000	0.0000	0.0000	Basic
14	VAR	14	0.0000	0.0000	0.0000	Lower bound
15	VAR	15	0.0000	0.0000	0.0000	Lower bound
16	VAR	16	0.0000	0.0000	0.0000	Lower bound
17	VAR	17	0.0000	0.0000	0.0000	Lower bound
18	VAR	18	0.0000	0.0000	0.0000	Lower bound
19	VAR	19	0.0000	0.0000	0.0000	Lower bound
20	VAR	20	900.0000	0.0000	0.0000	Upper bound
21	VAR	21	0.0000	0.0000	0.0000	Basic
22	VAR	22	1.0346E+005	0.0000	0.0000	Basic
23	VAR	23	6.3274E+005	0.0000	0.0000	Basic
24	VAR	24	0.0000	0.0000	0.0000	Basic
25	VAR	25	0.0000	1.0000	1.0000	Lower bound
26	VAR	26	1420.0000	0.0000	0.0000	Basic
27	VAR	27	0.0000	1.0000	1.0000	Lower bound
28	VAR	28	1520.0000	0.0000	0.0000	Basic
29	VAR	29	0.0000	1.0000	1.0000	Lower bound
30	VAR	30	1420.0000	0.0000	0.0000	Basic
38	SLACK	8	0.0000	0.0000	0.0000	Basic

Iterative Goal Programming for UH-1 Engine

OPTIMAL SOLUTION - DETAILED REPORT

	Constraint		Type	RHS	Slack	Shadow price
1	CONSTR	1	=	1.4631E+005	0.0000	0.0000
2	CONSTR	2	=	2.0806E+006	0.0000	0.0000
3	CONSTR	3	=	300.0000	0.0000	0.0000
4	CONSTR	4	=	200.0000	0.0000	0.0000
5	CONSTR	5	=	300.0000	0.0000	0.0000
6	CONSTR	6	=	1720.0000	0.0000	0.0000
7	CONSTR	7	=	2675.0000	0.0000	0.0000
8	CONSTR	8	>=	955.0000	0.0000	0.0000
9	CONSTR	9	=	0.0000	0.0000	0.0000
10	CONSTR	10	=	0.0000	0.0000	0.0000

Objective Function Value = 0.00000

Iterative Goal Programming for UH-1 Engine
SENSITIVITY ANALYSIS OF COST COEFFICIENTS

	Variable		Current Coeff.	Allowable Minimum	Allowable Maximum
1	VAR	1	0.0000	0.0000	Infinity
2	VAR	2	0.0000	0.0000	Infinity
3	VAR	3	0.0000	0.0000	Infinity
4	VAR	4	0.0000	0.0000	Infinity
5	VAR	5	0.0000	0.0000	Infinity
6	VAR	6	0.0000	-Infinity	Infinity
7	VAR	7	0.0000	0.0000	Infinity
8	VAR	8	0.0000	0.0000	Infinity
9	VAR	9	0.0000	0.0000	Infinity
10	VAR	10	0.0000	0.0000	Infinity
11	VAR	11	0.0000	0.0000	Infinity
12	VAR	12	0.0000	0.0000	Infinity
13	VAR	13	0.0000	-Infinity	Infinity
14	VAR	14	0.0000	0.0000	Infinity
15	VAR	15	0.0000	0.0000	Infinity
16	VAR	16	0.0000	0.0000	Infinity
17	VAR	17	0.0000	0.0000	Infinity
18	VAR	18	0.0000	0.0000	Infinity
19	VAR	19	0.0000	0.0000	Infinity
20	VAR	20	0.0000	0.0000	Infinity
21	VAR	21	0.0000	-Infinity	Infinity
22	VAR	22	0.0000	-7.8124E+035	7.8124E+035
23	VAR	23	0.0000	-1.9531E+035	1.9531E+035
24	VAR	24	0.0000	-Infinity	Infinity
25	VAR	25	1.0000	0.0000	Infinity
26	VAR	26	0.0000	-1.0000	Infinity
27	VAR	27	1.0000	0.0000	Infinity
28	VAR	28	0.0000	-1.0000	Infinity
29	VAR	29	1.0000	0.0000	Infinity
30	VAR	30	0.0000	-1.0000	Infinity

Iterative Goal Programming for UH-1 Engine
SENSITIVITY ANALYSIS OF RIGHT-HAND SIDE VALUES

	Constraint		Type	Current Value	Allowable Minimum	Allowable Maximum
1	CONSTR	1	=	1.4631E+005	-Infinity	2.4977E+005
2	CONSTR	2	=	2.0806E+006	1.4479E+006	Infinity
3	CONSTR	3	=	300.0000	-Infinity	1720.0000
4	CONSTR	4	=	200.0000	-Infinity	1720.0000
5	CONSTR	5	=	300.0000	-Infinity	1720.0000
6	CONSTR	6	=	1720.0000	1375.0000	1720.0000
7	CONSTR	7	=	2675.0000	2675.0000	3520.0000
8	CONSTR	8	>=	955.0000	-Infinity	955.0000
9	CONSTR	9	=	0.0000	0.0000	Infinity
10	CONSTR	10	=	0.0000	0.0000	Infinity

Table 4 Final OPTIMAL SOLUTION

STORM DATA SET LISTING
LINEAR PROGRAMMING DATA SET

Problem Description Parameters

Title : Iterative Goal Programming for UH-1 Engine

Number of variables	:	30
Number of constraints	:	9
Starting solution given	:	NO
Objective function	:	MIN

CONSTRAINT 8 DELETED

Constraint	Type
1	Operating & Support
2	Investment
3	Performance Benefit
4	Crew Safety Benefit
5	Inventory Reduction
6	No. of T700 Engines Required
7	Total No. of Engines Required
8	No of T53 Engines Required
9	Iterative Goal Constr O & S
10	Iterative Goal Constr Investment

Variables

Var 1 - 10 = T7i
Var 11 - 20 = T5i
Var 21 = DOSM
Var 22 = DOSP
Var 23 = DIM
Var 24 = DIP
Var 25 = DB1M
Var 26 = DB1P
Var 27 = DB2M
Var 28 = DB2P
Var 29 = DB3M
Var 30 = DB3P

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 1	VAR 2	VAR 3	VAR 4	VAR 5
OBJ COEFF	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1	227.4	2Ø4.1	18Ø.2	155.8	13Ø.9
CONSTR 2	635.1	648.7	66Ø.9	672.8	684.9
CONSTR 3	1.	1.	1.	1.	1.
CONSTR 4	1.	1.	1.	1.	1.
CONSTR 5	1.	1.	1.	1.	1.
CONSTR 6	1.	1.	1.	1.	1.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 9	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1Ø	Ø.	Ø.	Ø.	Ø.	Ø.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	Ø.	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	25.	5Ø.	3ØØ.	5ØØ.	5ØØ.
INIT SOLN	25.	5Ø.	3ØØ.	5ØØ.	Ø.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 6	VAR 7	VAR 8	VAR 9	VAR 10
OBJ COEFF	0.	0.	0.	0.	0.
CONSTR 1	105.7	80.	53.8	27.1	0.
CONSTR 2	697.3	709.8	722.6	735.6	748.8
CONSTR 3	1.	1.	1.	1.	1.
CONSTR 4	1.	1.	1.	1.	1.
CONSTR 5	1.	1.	1.	1.	1.
CONSTR 6	1.	1.	1.	1.	1.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	500.	500.	500.	500.	500.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 11	VAR 12	VAR 13	VAR 14	VAR 15
OBJ COEFF	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 2	252.	257.4	262.3	267.	271.8
CONSTR 3	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 4	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 5	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 6	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 9	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 1Ø	Ø.	Ø.	Ø.	Ø.	Ø.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	1ØØ.	3ØØ.	9ØØ.	9ØØ.	9ØØ.
INIT SOLN	Ø.	Ø.	Ø.	Ø.	Ø.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 16	VAR 17	VAR 18	VAR 19	VAR 20
OBJ COEFF	0.	0.	0.	0.	0.
CONSTR 1	0.	0.	0.	0.	0.
CONSTR 2	276.7	281.7	286.8	291.9	297.2
CONSTR 3	0.	0.	0.	0.	0.
CONSTR 4	0.	0.	0.	0.	0.
CONSTR 5	0.	0.	0.	0.	0.
CONSTR 6	0.	0.	0.	0.	0.
CONSTR 7	1.	1.	1.	1.	1.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	900.	900.	900.	900.	900.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 21	VAR 22	VAR 23	VAR 24	VAR 25
OBJ COEFF	Ø.	Ø.	Ø.	Ø.	1.
CONSTR 1	1.	-1.	Ø.	Ø.	Ø.
CONSTR 2	Ø.	Ø.	1.	-1.	Ø.
CONSTR 3	Ø.	Ø.	Ø.	Ø.	1.
CONSTR 4	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 5	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 6	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 7	Ø.	Ø.	Ø.	Ø.	Ø.
CONSTR 9	1.	Ø.	Ø.	Ø.	Ø.
CONSTR 1Ø	Ø.	Ø.	Ø.	1.	Ø.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	Infinity	Infinity	Infinity	Infinity	Infinity
INIT SOLN	Ø.	Ø.	Ø.	Ø.	Ø.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	VAR 26	VAR 27	VAR 28	VAR 29	VAR 30
OBJ COEFF	0.	1.	0.	1.	0.
CONSTR 1	0.	0.	0.	0.	0.
CONSTR 2	0.	0.	0.	0.	0.
CONSTR 3	-1.	0.	0.	0.	0.
CONSTR 4	0.	1.	-1.	0.	0.
CONSTR 5	0.	0.	0.	1.	-1.
CONSTR 6	0.	0.	0.	0.	0.
CONSTR 7	0.	0.	0.	0.	0.
CONSTR 9	0.	0.	0.	0.	0.
CONSTR 10	0.	0.	0.	0.	0.
VARBL TYPE	+	+	+	+	+
LOWR BOUND	-Infinity	-Infinity	-Infinity	-Infinity	-Infinity
UPPR BOUND	Infinity	Infinity	Infinity	Infinity	Infinity
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
Iterative Goal Programming for UH-1 Engine

ROW LABEL	CONST TYPE	R H S	RANGE
OBJ COEFF	XXXX	XXXX	XXXX
CONSTR 1	=	146307.	Infinity
CONSTR 2	=	2.08064E06	Infinity
CONSTR 3	=	300.	Infinity
CONSTR 4	=	200.	Infinity
CONSTR 5	=	300.	Infinity
CONSTR 6	=	1720.	Infinity
CONSTR 7	=	2675.	Infinity
CONSTR 9	=	0.	Infinity
CONSTR 10	=	0.	Infinity
VARBL TYPE	XXXX	XXXX	XXXX
LOWR BOUND	XXXX	XXXX	XXXX
UPPR BOUND	XXXX	XXXX	XXXX
INIT SOLN	XXXX	XXXX	XXXX

Iterative Goal Programming for UH-1 Engine

OPTIMAL SOLUTION - SUMMARY REPORT (Nonzero Variables)

	Variable		Value	Cost
1	VAR	1	25.0000	0.0000
2	VAR	2	50.0000	0.0000
3	VAR	3	300.0000	0.0000
4	VAR	4	500.0000	0.0000
5	VAR	5	500.0000	0.0000
6	VAR	6	345.0000	0.0000
13	VAR	13	55.0000	0.0000
14	VAR	14	900.0000	0.0000
22	VAR	22	1.0346E+005	0.0000
23	VAR	23	6.5992E+005	0.0000
26	VAR	26	1420.0000	0.0000
28	VAR	28	1520.0000	0.0000
30	VAR	30	1420.0000	0.0000

Objective Function Value = 0.00000

Iterative Goal Programming for UH-1 Engine

OPTIMAL SOLUTION - DETAILED REPORT

	Variable		Value	Cost	Red. cost	Status
1	VAR	1	25.0000	0.0000	0.0000	Upper bound
2	VAR	2	50.0000	0.0000	0.0000	Upper bound
3	VAR	3	300.0000	0.0000	0.0000	Upper bound
4	VAR	4	500.0000	0.0000	0.0000	Upper bound
5	VAR	5	500.0000	0.0000	0.0000	Upper bound
6	VAR	6	345.0000	0.0000	0.0000	Basic
7	VAR	7	0.0000	0.0000	0.0000	Lower bound
8	VAR	8	0.0000	0.0000	0.0000	Lower bound
9	VAR	9	0.0000	0.0000	0.0000	Lower bound
10	VAR	10	0.0000	0.0000	0.0000	Lower bound
11	VAR	11	0.0000	0.0000	0.0000	Lower bound
12	VAR	12	0.0000	0.0000	0.0000	Lower bound
13	VAR	13	55.0000	0.0000	0.0000	Basic
14	VAR	14	900.0000	0.0000	0.0000	Upper bound
15	VAR	15	0.0000	0.0000	0.0000	Lower bound
16	VAR	16	0.0000	0.0000	0.0000	Lower bound
17	VAR	17	0.0000	0.0000	0.0000	Lower bound
18	VAR	18	0.0000	0.0000	0.0000	Lower bound
19	VAR	19	0.0000	0.0000	0.0000	Lower bound
20	VAR	20	0.0000	0.0000	0.0000	Lower bound
21	VAR	21	0.0000	0.0000	0.0000	Basic
22	VAR	22	1.0346E+005	0.0000	0.0000	Basic
23	VAR	23	6.5992E+005	0.0000	0.0000	Basic
24	VAR	24	0.0000	0.0000	0.0000	Basic
25	VAR	25	0.0000	1.0000	1.0000	Lower bound
26	VAR	26	1420.0000	0.0000	0.0000	Basic
27	VAR	27	0.0000	1.0000	1.0000	Lower bound
28	VAR	28	1520.0000	0.0000	0.0000	Basic
29	VAR	29	0.0000	1.0000	1.0000	Lower bound
30	VAR	30	1420.0000	0.0000	0.0000	Basic

Iterative Goal Programming for UH-1 Engine
OPTIMAL SOLUTION - DETAILED REPORT

	Constraint		Type	RHS	Slack	Shadow price
1	CONSTR	1	=	1.4631E+005	0.0000	0.0000
2	CONSTR	2	=	2.0806E+006	0.0000	0.0000
3	CONSTR	3	=	300.0000	0.0000	0.0000
4	CONSTR	4	=	200.0000	0.0000	0.0000
5	CONSTR	5	=	300.0000	0.0000	0.0000
6	CONSTR	6	=	1720.0000	0.0000	0.0000
7	CONSTR	7	=	2675.0000	0.0000	0.0000
8	CONSTR	9	=	0.0000	0.0000	0.0000
9	CONSTR	10	=	0.0000	0.0000	0.0000

Objective Function Value = 0.00000

Iterative Goal Programming for UH-1 Engine
SENSITIVITY ANALYSIS OF COST COEFFICIENTS

	Variable		Current Coeff.	Allowable Minimum	Allowable Maximum
1	VAR	1	0.0000	0.0000	Infinity
2	VAR	2	0.0000	0.0000	Infinity
3	VAR	3	0.0000	0.0000	Infinity
4	VAR	4	0.0000	0.0000	Infinity
5	VAR	5	0.0000	0.0000	Infinity
6	VAR	6	0.0000	-Infinity	Infinity
7	VAR	7	0.0000	0.0000	Infinity
8	VAR	8	0.0000	0.0000	Infinity
9	VAR	9	0.0000	0.0000	Infinity
10	VAR	10	0.0000	0.0000	Infinity
11	VAR	11	0.0000	0.0000	Infinity
12	VAR	12	0.0000	0.0000	Infinity
13	VAR	13	0.0000	-Infinity	Infinity
14	VAR	14	0.0000	0.0000	Infinity
15	VAR	15	0.0000	0.0000	Infinity
16	VAR	16	0.0000	0.0000	Infinity
17	VAR	17	0.0000	0.0000	Infinity
18	VAR	18	0.0000	0.0000	Infinity
19	VAR	19	0.0000	0.0000	Infinity
20	VAR	20	0.0000	0.0000	Infinity
21	VAR	21	0.0000	-Infinity	Infinity
22	VAR	22	0.0000	-7.8124E+035	7.8124E+035
23	VAR	23	0.0000	-1.9531E+035	1.9531E+035
24	VAR	24	0.0000	-Infinity	Infinity
25	VAR	25	1.0000	0.0000	Infinity
26	VAR	26	0.0000	-1.0000	Infinity
27	VAR	27	1.0000	0.0000	Infinity
28	VAR	28	0.0000	-1.0000	Infinity
29	VAR	29	1.0000	0.0000	Infinity
30	VAR	30	0.0000	-1.0000	Infinity

Iterative Goal Programming for UH-1 Engine

SENSITIVITY ANALYSIS OF RIGHT-HAND SIDE VALUES

	Constraint		Type	Current Value	Allowable Minimum	Allowable Maximum
1	CONSTR	1	=	1.4631E+005	-Infinity	2.4977E+005
2	CONSTR	2	=	2.0806E+006	1.4207E+006	Infinity
3	CONSTR	3	=	300.0000	-Infinity	1720.0000
4	CONSTR	4	=	200.0000	-Infinity	1720.0000
5	CONSTR	5	=	300.0000	-Infinity	1720.0000
6	CONSTR	6	=	1720.0000	1375.0000	1775.0000
7	CONSTR	7	=	2675.0000	2620.0000	3520.0000
8	CONSTR	9	=	0.0000	0.0000	Infinity
9	CONSTR	10	=	0.0000	0.0000	Infinity

Table 5

RM-ER 22 Dec 88

BASE YEAR 1988 DEPARTMENT OF DEFENSE DEFLATORS

FISCAL YEAR	RDTEA	PROC APA/MIPA/WTCV	PROC AMMO/OPA	OMA	MCA
1955	0.2338	0.2003	0.2556	0.2141	0.1935
1956	0.2401	0.2043	0.2660	0.2198	0.2023
1957	0.2488	0.2220	0.2863	0.2380	0.2152
1958	0.2547	0.221[illegible]	0.2896	0.2411	0.2[illegible]9
1959	0.2594	0.2183	0.2965	0.2465	0.2148
1960	0.2648	0.2138	0.2940	0.2446	0.2121
1961	0.2677	0.2179	0.3000	0.2499	0.2119
1962	0.2715	0.2180	0.2965	0.2474	0.2282
1963	0.2761	0.2109	0.2974	0.2489	0.2339
1964	0.2801	0.2150	0.2986	0.2496	0.2370
1965	0.2853	0.2172	0.3018	0.2521	0.2508
1966	0.2929	0.2342	0.3118	0.2629	0.2481
1967	0.3024	0.2493	0.3231	0.2771	0.2571
1968	0.3134	0.2619	0.3341	0.2873	0.2711
1969	0.3282	0.2690	0.3446	0.2947	0.2879
1970	0.3462	0.2795	0.3582	0.3057	0.3105
1971	0.3640	0.2924	0.3745	0.3179	0.3374
1972	0.3808	0.3047	0.3889	0.3310	0.3575
1973	0.3973	0.3194	0.4050	0.3388	0.3773
1974	0.4290	0.3464	0.4283	0.3813	0.4217
1975	0.4759	0.3859	0.4661	0.4612	0.4897
1976	0.5074	0.4212	0.4968	0.4924	0.5045
197T	0.5220	0.4345	0.5145	0.5067	0.5124
1977	0.5355	0.4534	0.5339	0.5305	0.5267
1978	0.5720	0.4858	0.5702	0.5683	0.5672
1979	0.6200	0.5293	0.6200	0.6200	0.6200
1980	0.6856	0.5918	0.6856	0.6856	0.6856
1981	0.7584	0.6604	0.7584	0.7584	0.7584
1982	0.8160	0.7547	0.8160	0.8160	0.8160
1983	0.8560	0.8227	0.8560	0.8560	0.8560
1984	0.8885	0.8885	0.8885	0.8885	0.8885
1985	0.9187	0.9187	0.9187	0.9187	0.9187
1986	0.9444	0.9444	0.9444	0.9444	0.9444
1987	0.9699	0.9699	0.9699	0.9699	0.9699
1988	1.0000	1.0000	1.0000	1.0000	1.0000

Used to go from FY85 to FY88

Encl 11

AMCRM-ER

22 Dec 88

AIRCRAFT PROCUREMENT

	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998
ESCALATION FACTOR	1.0270	1.0310	1.0400	1.0360	1.0330	1.0280	1.0230	1.0180	1.0180	1.0180	1.0180	1.0180
BASE YEAR 1987												
COMPOUND INDICES	1.0000	1.0310	1.0722	1.1108	1.1475	1.1796	1.2068	1.2285	1.2506	1.2731	1.2960	1.3193
COMPOSITE INDICES	1.0507	1.0951	1.1308	1.1640	1.1935	1.2191	1.2421	1.2645	1.2872	1.3104	1.3340	1.3580
BASE YEAR 1988												
COMPOUND INDICES	0.9699	1.0000	1.0400	1.0774	1.1130	1.1442	1.1705	1.1915	1.2130	1.2348	1.2571	1.2797
COMPOSITE INDICES	1.0191	1.0622	1.0968	1.1290	1.1576	1.1824	1.2047	1.2264	1.2485	1.2710	1.2939	1.3172
BASE YEAR 1989												
COMPOUND INDICES	0.9326	0.9615	1.0000	1.0360	1.0702	1.1032	1.1255	1.1457	1.1663	1.1873	1.2087	1.2305
COMPOSITE INDICES	0.9799	1.0214	1.0546	1.0856	1.1130	1.1369	1.1584	1.1793	1.2005	1.2221	1.2441	1.2665
BASE YEAR 1990												
COMPOUND INDICES	0.9002	0.9281	0.9653	1.0000	1.0330	1.0619	1.0863	1.1059	1.1258	1.1461	1.1667	1.1877
COMPOSITE INDICES	0.9458	0.9859	1.0179	1.0479	1.0744	1.0974	1.1182	1.1383	1.1588	1.1796	1.2009	1.2225

	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010
ESCALATION FACTOR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
BASE YEAR 1987												
COMPOUND INDICES	1.3431	1.3673	1.3919	1.4169	1.4424	1.4684	1.4948	1.5217	1.5491	1.5770	1.6054	1.6343
COMPOSITE INDICES	1.3824	1.4073	1.4326	1.4584	1.4847	1.5114	1.5386	1.5663	1.5945	1.6232	1.6524	1.6822
BASE YEAR 1988												
COMPOUND INDICES	1.3027	1.3262	1.3500	1.3743	1.3991	1.4243	1.4499	1.4760	1.5026	1.5296	1.5571	1.5852
COMPOSITE INDICES	1.3409	1.3650	1.3896	1.4146	1.4400	1.4660	1.4923	1.5192	1.5466	1.5744	1.6027	1.6316
BASE YEAR 1989												
COMPOUND INDICES	1.2526	1.2752	1.2981	1.3215	1.3453	1.3695	1.3941	1.4192	1.4448	1.4708	1.4972	1.5242
COMPOSITE INDICES	1.2893	1.3125	1.3361	1.3602	1.3847	1.4096	1.4349	1.4608	1.4871	1.5138	1.5411	1.5688
BASE YEAR 1990												
COMPOUND INDICES	1.2091	1.2308	1.2530	1.2756	1.2985	1.3219	1.3457	1.3699	1.3946	1.4197	1.4452	1.4712
COMPOSITE INDICES	1.2445	1.2669	1.2897	1.3129	1.3365	1.3606	1.3851	1.4100	1.4354	1.4612	1.4875	1.5143

OUTLAY RATES

	1ST YEAR	2ND YEAR	3RD YEAR	4TH YEAR	5TH YEAR	6TH YEAR	7TH YEAR
1987	0.2762	0.2879	0.2559	0.0900	0.0900	0.0000	0.0000
1988	0.1634	0.3566	0.2600	0.1250	0.0950	0.0000	0.0000
1989	0.1850	0.3400	0.2550	0.1250	0.0950	0.0000	0.0000
1990 AND BEYOND	0.1850	0.3400	0.2550	0.1250	0.0950	0.0000	0.0000

Used to escalate FY 88 $ to current year dollars.

Encl 2

TABLE 6
PROGRAM MANAGERS DESIRED SCHEDULE FOR UH-1 ENGINES

YEAR	QTY T700 ENGINE	QTY T53 ENGINE
1	0	10
2	0	24
3	75	250
4	240	722
5	240	750
6	240	750
7	240	659
8	240	0
9	240	0
10	205	0
TOTAL	1720	3165