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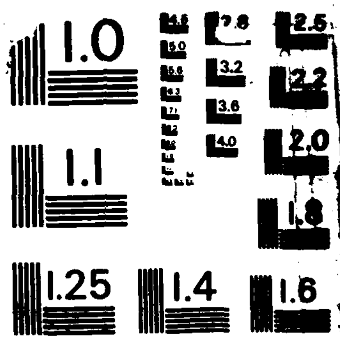

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AFIT/GST/ENS/87M-1

A METHODOLOGY FOR AUTOMATION OF TANK ALLOCATION

THESIS

William G. Adams
Captain, USA

AFIT/GST/ENS/87M-1

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The automation of the current manual allocation process will increase the time available to conduct a more thorough analysis of the restructure of the tank force and possible production improvement options by the U.S. Army Armor Center. The methodology has an advantage over the current process because tank allocation is accomplished in an optimal manner.

ABSTRACT

The primary objective of this research effort is to evaluate a methodology for the automation of tank allocation. The methodology proposed is a constrained transportation problem of linear programming. It is based on the concepts first proposed by ~~Edward H.~~ Bowman who developed the transportation method for production scheduling, planning, and inventory control. This methodology is applicable because of the allocation of several types of tanks to a fixed number of units. The cost coefficients for the objective function of the constrained transportation problem are derived from the combat capability measure formulated by Michael S. Remias, in his work, *An Analytical Framework for Efficiency Evaluation and Determination of Preferred Main Battle Tank Fleet*. The constrained transportation problem is solved for each time period of a ten-year allocation plan. Within each time period, the combat capabilities of the units are maximized by minimizing the deviation of each unit from being equipped with the "best" tank as compared to the actual tank it receives.

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A METHODOLOGY FOR AUTOMATION OF TANK ALLOCATION

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

William G. Adams, B.S.
Captain, USA

March 1987

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Preface

The purpose of this research effort was to determine a methodology for tank allocation. The current allocation process is done manually and requires an excessive amount of time to conduct distribution and analysis of several production options. No previous research has been done to develop a better method.

This report uses a constrained transportation problem of linear programming to distribute the tanks to units. The objective function costs use a combat capability equation developed in a previous research effort.

I would like to thank my thesis advisor, MAJ Dan Reyen, for his endless hours of reading rough drafts and explaining a multitude of topics. His guidance was essential in completing this effort. Gratitude is also expressed to CPT Wade Shaw, who provided another set of opinions on how to approach different aspects of this effort. Sincere thanks is also expressed to CPT Dave Goss, who helped write the FORTRAN programs for this effort. His expert knowledge saved me endless hours of programming. I would also like to thank CPT Dale Shirasago, who provided the graphic computer support for this paper. Finally, I would like to thank my wife, Maureen. Her understanding and love through these last eighteen months have provided the motivation to finish this undertaking.

William G. Adams

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A METHODOLOGY FOR AUTOMATION OF TANK ALLOCATION

"War is not merely a political act, but also a political instrument, a continuation of political relations, a carrying out of the same by other means."

Clausewitz, Vom Kriege, 1833

I. INTRODUCTION

The United States has continued political relations through the use of war several times in its history: the War of 1812, the Civil War, the Spanish-American War, World War I, World War II, Korea, and Vietnam. The last two conflicts, Korea and Vietnam, ushered in the concept of the limited war. Limited war does not involve global conflict such as World War I and World War II, but restricts the use of the total war fighting capability of a nation. This war fighting capability is also exemplified by the deterrence a nation presents. This deterrence to aggressive actions by another nation is maintained in part by the positioning of the nation's conventional and nuclear forces. Coupled with this positioning of forces is the alliance of nations with similar political goals. The North Atlantic Treaty Organization (NATO) is an example of such an alliance.

Today, the greatest difference in political ideologies is between the United States and the Soviet Union. The two superpowers are constantly seeking ways to maintain the balance of power in the world. In recent years, there has been a shift in emphasis from strategic nuclear forces to conventional forces. In the 1950's the United States had nuclear supremacy. After the Cuban Missile Crisis of 1962, nuclear parity between the superpowers was achieved. Although the threat of nuclear war still exists today, the Soviet Union has accepted the fact that nuclear parity between the superpowers exists. This nuclear parity has changed Soviet strategy.

Presently, the Soviets enjoy a numerical superiority in conventional weapons over the United States. With this superiority, the Soviets have chosen to exploit international weakness through the use of conventional forces. The invasion of Afghanistan, the establishment of a naval base at Cam Rahn Bay, Vietnam, and the use of military advisors in Angola are all examples of this shift in policy. This Soviet expansionism (28) has forced the U.S. to place a greater emphasis on the combat readiness of its conventional forces. "U.S. military strategy does not call for matching the size of the Soviet ground forces, but instead emphasizes refining the U.S. qualitative edge in conjunction with moderate force increases" (16:75). This qualitative edge includes not only technological advances, but also the positioning of these forces to deter Soviet expansionism.

An integral part of a country's conventional forces is its land combat power. The greatest asset of the land combat force is the tank fleet. The mobility and firepower of the tank is unmatched by any other piece of equipment in the U.S. land force arsenal today. The organization, location, and configuration of this tank fleet is critical to national security. The current tank fleet is organized according to the Division 86 concept established in 1983 as a result of a feasibility study directed by the Chief of Staff of the Army. The study focused on the development of forces to support the current AirLand battle doctrine. Inherent in the development of these forces was the integration of the M1 Abrams tank and the M2/M3 Bradley Infantry/Cavalry Fighting Vehicles (IFV/CFV) into the current force inventory (15:1).

The configuration and location of the elements of the tank fleet are imperative to maintaining a viable deterrence. The M1 tank with its capability to shoot accurately on the move makes it ideal for use in an offensive scenario. The M60A3 tank shoots accurately from a stationary position which makes it ideal in a defensive scenario. The tank fleet must be configured to use both of these capabilities. As the capabilities of either the threat or U.S. tank fleet change, the relative configuration of these forces must be changed. Inherent in the "optimal" configuration of the fleet capability is the location of the tanks, in support of military plans.

Current U.S. policy is a commitment to the defense of Europe through NATO (30:17-18). The U.S. Army is assigned two corps sectors in West Germany. Each corps sector is organized with one armored and one mechanized division, and one cavalry regiment. A modern armored division is currently composed of more than 320 tanks and 230 IFV's (36:92). A mechanized infantry division has 262 tanks and 284 IFV's. A cavalry regiment consists of over 110 CFV's and 168 tanks (15). The other major commitment within NATO is the Allied Forces Central Reserve Corps, of which one armored and two mechanized brigades are currently deployed. The Supreme Allied Commander Europe (SACEUR) has established a requirement for ten U.S. divisions to be in Europe ten days after the outbreak of hostilities. This requirement is the basis for the Prepositioning Of Material Configured to Unit Sets (POMCUS) of six division sets of equipment. POMCUS is the pre-stocking of division sets of equipment (tanks and infantry fighting vehicles) in warehouses in Europe. Upon the outbreak of hostilities, personnel from stateside units would be deployed to Europe and issued equipment from the POMCUS stocks to fight the war. The objective of POMCUS is to permit the rapid deployment of six divisions to join the four already in Europe (30:17-18). Although the Middle East has become more of a concern in recent years, the U.S. still is committed to defending Europe first. The best tanks are currently "forward fielded" to Europe to meet this commitment.

BACKGROUND

The Directorate of Combat Development (DCD) at Fort Knox, Kentucky, assists in the development of tank allocation plans. The plans normally project the requirements for the tank fleet over a 20-year planning horizon. The current process is done manually, using heuristics, and requires approximately eight hours per production option to accomplish. The heuristics consist of:

(1) unit priorities established by U.S. Army leadership. These priorities establish a fixed rank order of the tank units (31);

(2) the combat capability of the tank fleet;

(3) production levels of tank factories (31);

(4) the ripple-down effect of distributing the older model tanks of a unit which received new tanks to another unit. Since the number of new tanks each year is fixed according to production rates, the tanks which are replaced will be used by other units unless the tanks are determined to be obsolete, and;

(5) the amount of time a unit must spend with a type of tank before it can receive new tanks. Furthermore, there are no partial "fills" of a unit; one unit must be completely equipped with new tanks before another unit is started (12).

The current process consists of the manual application of the heuristics of the allocation process to a proposed production or enhancement option and the current inventory of the tank fleet. The manual development of the tank allocation plan is the second phase of a two phase process (See Figure 1.1). At the beginning of the process, a tank production option is determined by the Department of the Army. Several variables influence this selection:

(1) Advancements in technology;

(2) Decisions on force structure by the nation's policy makers (31);

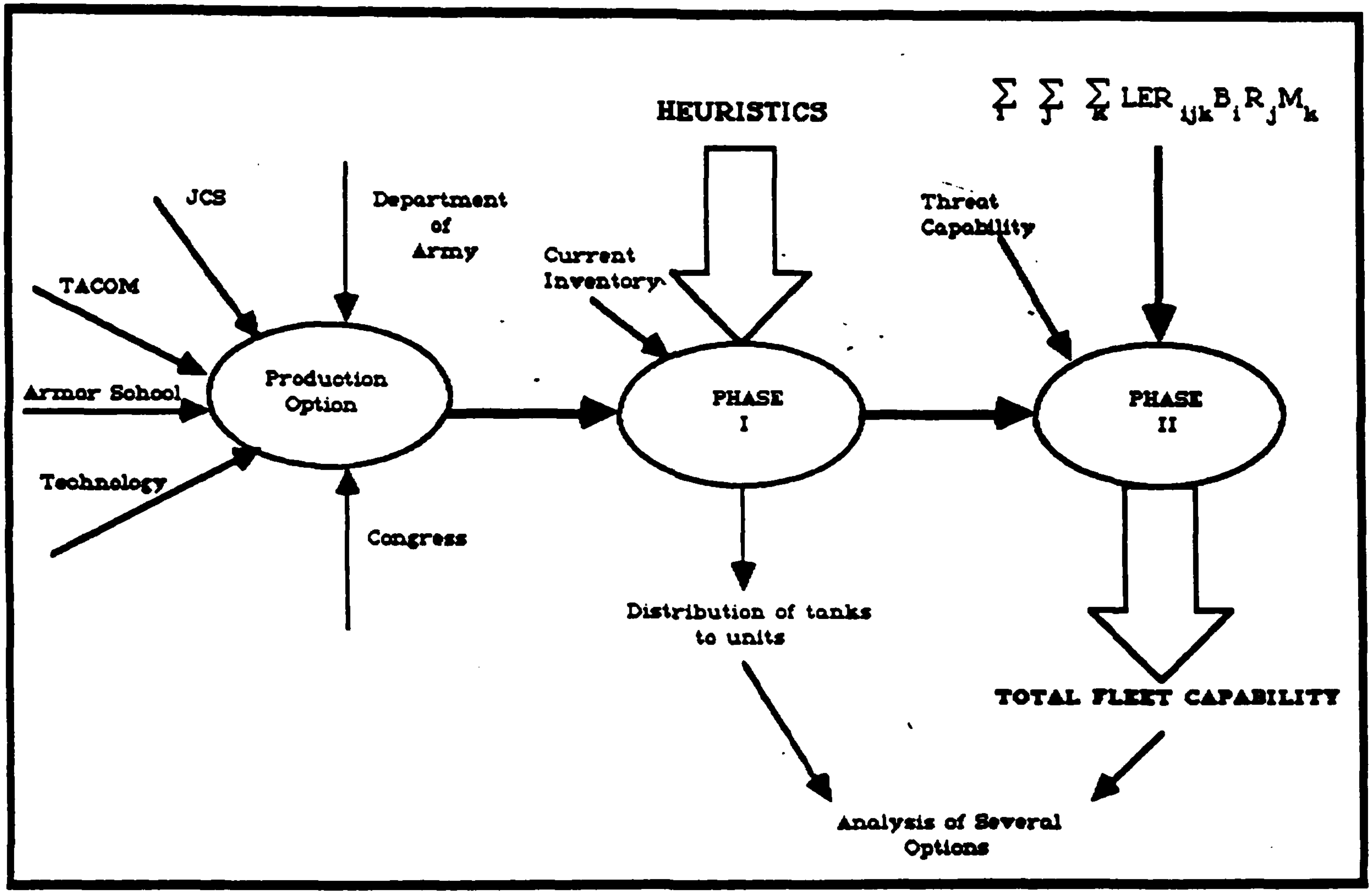


Figure 1.1. Tank Allocation Process

(3) Production levels of the tank plants established by Tank Automotive Command (TACOM), and;

(4) Desired tank forces by the Army Leadership.

Once a production option has been chosen, Phase One is accomplished. Using the decision of Phase One. DCD allocates the tanks to units using the heuristics. The tanks are allocated to the units over a twenty year period. Following the distribution of tanks, DCD then evaluates the combat capability of the current fleet and the production option. The combat capability of the tank fleet is calculated using a triple weighted sum. The formula for the weighted sum is:

$$\text{Fleet Combat Capability} = \Sigma\ \Sigma\ \Sigma\ (LER_{ijk} * B_i * R_j * M_k) \quad (1.1)$$

where: i = 1 if unit equipped with M60A1 or less
= 2 if unit equipped with M60A1(AT) or less
= 3 if unit equipped with M60A3
= 4 if unit equipped with M60A3(AT)
= 5 if unit equipped with M1
= 6 if unit equipped with M1(AT)
= 7 if unit equipped with M1+
= 8 if unit equipped with M1+(AT)
= 9 if unit equipped with M1E1/M1E2
= 10 if unit equipped with M1E1/M1E2(AT)
= 11 if unit equipped with M1E3(AT)
= 12 if unit equipped with FACS

where: j = 1 if unit equipped with T62 or less
= 2 if unit equipped with T62(90+) or less
= 3 if unit equipped with T64/T72
= 4 if unit equipped with T64(90+)/T72(90+)
= 5 if unit equipped with T80
= 6 if unit equipped with T80(90+)
= 7 if unit equipped FST(90+)

where: k = 1 if Blue is defending
= 2 if Blue is attacking
= 3 if Blue is delaying

LER_{ijk} = Loss exchange ratio of a Blue (United States) unit equipped with type tank (i) in mission profile (k) against Red (Soviet) unit with type tank (j).

B_i = Percentage of Blue fleet equipped with type tank (i).

R_j = Percentage of Red fleet equipped with type tank (j).

M_k = Percentage of time Blue units are conducting mission (k).

AT = Advanced Technology

FACS = Future Armor Combat System

FST = Future Soviet Tank

M1+ = M1 upgraded to M1E1 protection levels.

90+ = Threat advanced technology round

(11:4-124)

The calculation of the weighted sum is already computerized. The combat effectiveness of the current inventory and the proposed production option is calculated using the weighted sum (1.1). A comparison of several production options is then conducted. A selection is made concerning the "best" production option for the tank fleet. This operation is Phase Two.

Problems exist with the weighted sum methodology. First, the weighted sum (1.1) is independent of which unit receives any tanks. Total fleet capability can be calculated based on proposed production option, regardless of the tank distribution. The weighted sum relies only on the number of tanks the Red or Blue fleet has. A tank in the South Carolina

National Guard is considered to be as effective as a tank on the West/East German border. The mission profile has been fixed for global considerations by the Army Leadership (11). Second, the heuristics of the allocation process determine where tanks are distributed based on unit priorities and other constraints. Any improvement to the allocation process should use a methodology which maximizes the combat capability of the tank fleet by allocating the "best" tank to the unit which faces the greatest threat.

Remias has developed a methodology which determines a unit's combat capability based upon several factors including its mission and threat analysis. This measure of a unit's combat capability is incorporated into this research effort to aid in determining the optimal distribution of tanks. This methodology is further discussed in Chapter III.

The obvious advantage of the current manual process is that it works. However, a desired improvement over the current process is to decrease the amount of time required to conduct the allocation process. This reduction in time will permit the analysis of several options or desired changes to the tank fleet. Currently, when time is critical, the manual allocation process limits the ability of analysts to look at several production options and compare the relative distribution of tank assets. Other requirements within DCD must be temporarily suspended to complete the allocation of tank options and the analysis. This results in many additional hours of work (31).

Another shortfall of the current process is that heuristics yield only a feasible solution; the solution may not be optimal. An optimal solution based on a unit's combat capability would be a better quantitative measure. To date, no attempts have been undertaken to develop a optimal method.

PROBLEM STATEMENT

The objective of this research is to determine a methodology to automate the allocation of tanks to units and compare it with the current heuristic approach. The methodology will optimally allocate tanks to units based on threat capability and actual constraints. The methodology will be capable of accepting as interactive variables: production rates over time, quantity of type tanks on hand at the start of distribution cycle, number and organization of units, and the number of years analyzed. Factors such as manning levels, maintenance, moral, leadership and current state of training are considered to be the same for all units. The effects of combat support/combat service support elements are not considered in this research effort. Finally, the new method will make use of existing computer technology.

II. LITERATURE SEARCH

Studies to determine the best tank fleet have been conducted twice in the history of the U.S. armor force. The first study, conducted in 1972, resulted in the requirement for the M1 Main Battle Tank. The study was conducted under the direction of Brigadier General Louis C. Wagner and was called the Army Tank Program Special Tank Task Force (13). Its purpose was to provide a plan for developing the best available tank force, in adequate numbers and a timely manner,to counter the projected threat for the 1980's and beyond (11:3-29). In addition to establishing the need for the M1 tank, the study also developed the M1 production plan. This plan was determined to be the best response to the projected threat as envisioned in 1972. An important result of the M1 production plan was the formulation of the weighted sum (Equation 1.1) for determining fleet capability. The final report of the study group was issued in 1977.

The second study was conducted in 1983. It resulted in the "forward fielding" of the M1 tank to Europe and established the need for a follow-on tank in the mid-1990's (31). The study was a continuation of the first study. It contained an analysis of several production options. The production options involved the phasing in and out of different types of tanks over a period of years. The options were then analyzed using the measure of combat capability formulated in the first study. The study also addressed the rules by which tanks would be allocated to units. These rules involved the establishment of unit priorities for new tanks. The rules also addressed the disposition of the former tanks of a unit once it received new tanks. In general these rules supported the commitment to NATO and formed the basis of the heuristics for the tank allocation process.

Department of the Army

Determining the allocation of tank assets is a time consuming process (31). Department of the Army forecasts the requirements for the tank fleet five fiscal years into the future. This forecast is the authorization for equipment procurement for the next five fiscal years in accordance with the Department of Defense Planning, Programming, and Budgeting System (PPBS). "Near term" funds are approved by the Secretary of Defense and Congress for the procurement of these "approved" weapon systems in the annual budget. The Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) is tasked with the development of concepts and equipment on "how" the Army would like to fight in the future. Inherent in this task is the generation, development, and forecast of a 20-year plan for equipment. The Force Integration Systems Office (FISO) at ODCSOPS is responsible for the 20-year plan for tank assets. The Directorate of Combat Development (DCD) aids in the development of these plans. DCD and FISO currently use Lotus 1-2-3 spreadsheets to aid in the tank allocation process. The heuristics of the FISO are essentially the same as DCD's except that the timeframes differ (32).

The Structure and Composition Systems (SACS) Division of the Force Development Agency of ODCSOPS uses an "Artificial Intelligence (AI)" program based on the LISP programming language (37). The program is based on heuristic reasoning similar to that used for the tank allocation process. The program attempts to allocate all U.S. Army equipment (37). The program appears to use the principles of an expert system. The LISP/AI program is confined to use on a mainframe computer rather than a personal computer (PC). No attempt has been made to program this LISP/AI model on a PC (37).

Significant controversy exists between SACS and the FISO regarding the effectiveness of their respective methodologies (32) (37). No research has been conducted to substantiate either claim (32).

Two major trends in artificial intelligence are large expert systems and small knowledge systems (17:11-12). Large expert systems "are programs that cannot be built easily using conventional techniques" (17:12). Small knowledge systems are "programs that can be built by users rather than programmers" (17:12). The LISP/AI program of SACS is an example of a large expert system. The program deals with all U.S. Army equipment and the rules established for distribution. The tank allocation process is a small knowledge system, because it deals with only tanks and has a fixed number of rules for distribution.

Expert Systems. An expert has compiled knowledge, consisting of deep knowledge and surface knowledge. Deep knowledge is acquired from book and school, and consists of first principles, axioms, and laws. Surface knowledge consists of heuristics and domain theories. It is acquired from experience and mentors (17:33).

AI researchers have developed a programming language called a production system to describe how humans process heuristics (17:25). The production system consists of a knowledge base and inference engine. The knowledge base contains production rules and known facts. In the tank allocation process, the known facts would include the production rates, current inventory, threat capabilities, and unit times with equipment. The production rules are IF-THEN statements. An example of an IF-THEN statement is: IF Unit X receives M1 combat tanks in 1987, THEN it cannot receive newer tanks until 1991. Another example is: IF Unit Y is filled with M60A3 tanks, THEN Unit Z must also receive M60A3 tanks.

The inference engine is the reasoning mechanism which selects questions to ask the user in order to comply with the production rules (17:3). The inference engine essentially captures the decision process the expert uses to solve the problem. It uses the knowledge base to accomplish this process.

The objective of an expert system is:

> to interact with a user, requesting, and processing input information as a human expert might interact and perform the processing, ultimately determining the answers to one or more of the user's questions (17:3).

The fundamental difference between the expert system and traditional approaches to computer supported problem solving is "the independence of the domain knowledge in the knowledge base from the reasoning mechanism represented by the inference engine" (17:3).

The biggest advantage of an expert system is the automation of the decision process. With the availability of several small knowledge system shells, the adaption of the tank allocation process is possible. The combat capability of the tank units could be incorporated in the knowledge base. The ripple-down effect would involve several iterations of the decision process. Although time might not be saved, the manual calculation would be avoided since the process is "computerized".

A disadvantage of an expert system is the inability of an inexperienced user of such a system to change the various rules and facts in the knowledge base. Precise and complete documentation would be required; however, it might not alleviate the problem. The major disadvantage of an expert system is it yields only a feasible solution. The solution may not necessarily be optimal.

The Office of the Deputy Chief of Staff for Logistics (ODCSLOG) uses the Total Army Equipment Distribution Program (TAEDP). TAEDP is a computer program consisting of 600 sub-programs and requires the input of 15-18 major databases. One of these databases is the tank allocation plan. The program is written in the COBOL programming language and uses a mainframe computer. TAEDP cannot interface with a personal computer. A major problem with TAEDP is that adequate documentation does not exist (38).

TAEDP is essentially a giant "bookkeeper" of Army equipment. TAEDP differs from the tank allocation process in that it is filling the "holes" in the Army inventory created by the demand for tanks generated by the tank allocation process. It handles the following distribution requirements in the following priority:

1) Inventory Adjustment. Unit overages and shortages are reconciled and directed to units for compliance.

2) Directed Action. The training schools need to receive the new equipment first in order to train the soldiers. Forward fielding of equipment is also included in this category, as well as command directed distribution.

3) Packaging Associated Support Items of Equipment. Specific items of equipment must be distributed with another piece of equipment such as a tank. This equipment might consist of fuel and ammo trucks as well as recovery vehicles. This distribution plan is similar to the Battle Group program of the U.S. Navy.

4) C-3 Readiness Shortages. Unit commanders determine the state of readiness of their units based on personnel, training, and equipment status. This evaluation by the commander is quantified as a readiness code. It is what the commander needs to execute his mission properly. The units are filled with equipment based on their readiness code.

5) Department of Army Master Priority List (DAPL). Any equipment not already distributed according to the preceding options is distributed according to DAPL (38).

Although the rank ordering of units does occur within TAEDP, no optimization model is used. TAEDP fails to address the "capability" of units, and to allocate equipment in an optimal manner.

Department of the Air Force

The Air Force currently has no model to optimally allocate its aircraft. A model has not been developed because of changing Air Force leadership and political policies. Air Force analysts state that the development of a model would not be practical because of these changing policies (2).

The allocation of aircraft is not centralized under one office of responsibility. The tank allocation process is "centralized" under ODCSOPS, specifically the FISO. The Tactical Air Command (TAC) liaison officer at Wright-Patterson Air Force Base is responsible for the distribution of new fighters. He is not responsible for the re-distribution of older model fighters of a squadron to another squadron.

New fighters are also typically stationed at a stateside squadron first. This procedure allows the ground crews and pilots to be adequately trained on the maintenance procedures and flying capabilities of the new aircraft, before the aircraft are deployed to forward units. The squadron also receives additional aircraft above its authorized strength. Once enough aircraft are available to fill another squadron, the aircraft are deployed overseas. The tank allocation process is not similar to this procedure. New tanks are usually "shipped" to Europe or frontline units at the same time as tanks are issued to training units (31). The tanks are distributed in "battalion size" packages of 63 tanks each.

Maximum Location Covering Model

An example of a civilian application of scheduling problems is the Maximum Location Covering (MLC) model. The MLC model was used by Kolesar and Walker in 1974 to determine the relocation of fire companies to meet multiple fire alarms in New York City (23). The MLC model was also used in determining emergency medical service vehicle deployment in Austin, Texas, in 1980 (7). "The model selects sites to maximize the total demand that can be covered by a fixed number of facilities within a user specified critical response time" (7:106). The model uses linear programming and multi-objective optimization principles to solve the problem of tactical vehicle-relocation policies.

"The maximization of a number of demands covered by a fixed number of vehicles in order to meet a specified response time" differs from the tank allocation process

(7:106). The heuristics distribute the tanks to the units, and then evaluate the tank fleet efficiency. The objective of the allocation process should be the maximization of unit efficiency. This optimization can be accomplished by distributing the "best" tanks to units with the greatest threat. The MLC model uses linear programming to maximize the number of demands (23). This aspect is desired in the tank allocation process because it optimizes total demand or combat capability.

A perceived shortfall of the MLC model is its inability to handle the ripple-down effect of all tanks in the inventory. This inability is compounded further by the dynamic requirement to allocate all tanks over a 20-year period. However, the use of linear programming to maximize the number of demands is a desirable aspect for use in the tank allocation problem.

Goal Programming

Decisionmakers in industry and the military are constantly faced with problems which have conflicting goals. They must select policies for these problems which will best meet the desired goals. These selected policies may not be necessarily optimal, but rather only satisfy the decisionmakers. Goal programming is a methodology which handles problems which have a multitude of conflicting goals and subgoals (10:359).

In goal programming, the decisionmaker establishes and ranks his goals. The goals are expressed as a relationship in terms of the decision variables with linear or non-linear functions (10:359-360). The difference between goal programming and linear programming is that the goals in goal programming are not expressed as a overall single measure of effectiveness; linear programming requires that all goals be expressed "in common units and combined to give an overall single measure of effectiveness" (10:359).

The use of goal programming for the tank allocation process was disregarded. The conformation of the tank distribution to the constraints is demanded and not desired. Tanks must be distributed according to established priorities. Furthermore, the goal of the tank allocation process is to express all goals in terms of a single measure of combat effectiveness.

Production and Inventory Models

Since the tank allocation process deals with inventory and production policies,a search of inventory and production models was conducted. The production and inventory models which appeared to be the most applicable to the tank allocation process were: 1) the Wagner and Whitin algorithm; 2) the Materials Requirement Planning method; 3) the Hierarchial Production Planning method, and; 4) the Transportation Method. The merits and faults of each approach are discussed.

Wagner and Whitin Algorithm. The Wagner and Whitin algorithm is "a dynamic version of the economic lot size model"(39:89). The economic lot size model is:

$$Q = (2*D*S/H)^{1/2} \qquad (2.1)$$

where Q = quantity of items to order
D = demand
S = setup cost
H = holding cost

The Wagner and Whitin algorithm uses the principles of dynamic programming and includes a modified economic lot size formula.

Dynamic programming is "useful for making a sequence of interrelated decisions" (20:266). It provides a systematic procedure for determining the combination of decisions that maximize overall effectiveness (20:266). A problem in dynamic programming is divided into stages with a decision required at each stage (20:270). The decision at each stage is made on the basis of a recursive relationship.

In the Wagner and Whitin algorithm, the recursive relationship permits demand for a single item, the holding costs, and setup costs to vary over a number of periods (42:89). The algorithm differs from dynamic programming in that the optimal decision at each stage rolls forward from the beginning of the process to the end. Dynamic programming begins with the optimal decision at the last stage of the process and rolls backward to the first stage. The Wagner and Whitin algorithm does not allow backorders of inventory. The algorithm also differs from the basic economic lot size model because it allows varying demand at each stage.

The Wagner and Whitin algorithm permits a optimal determination to be made over a number of time periods. The determination is similar to the requirement of allocating the tanks over a twenty-year planning horizon. However, the algorithm has several disadvantages:

(1) Although the algorithm determines an optimal quantity to order, it is not robust enough to handle several different types of tanks. If one type of tank were in the armor force inventory, then the algorithm could readily be applied.

(2) The algorithm fails to work because the determination of the distribution of new tanks into one unit has direct bearing on the allocation of the former tanks of that unit to another unit. The algorithm cannot easily solve the ripple-down effect of the tank distribution process.

(3) The cost of combat effectiveness to units cannot be integrated into the algorithm.

The Wagner and Whitin algorithm can be readily adapted to a computer program. However, the disadvantages presented in the preceding paragraph preclude the use of this algorithm for the tank allocation process.

Material Requirements Planning Method. Material Requirements Planning (MRP) method creates:

> schedules identifying the specific parts and materials required to produce an end item, the exact numbers needed, and the dates when orders for these materials should be released and be received or completed within the production cycle (1:424).

The MRP approach consists of three components: 1) The Master Production Schedule; 2) The Bill of Materials (BOM) File, and; 3) The Inventory Records File. The Master Production Schedule "is an aggregate plan, stating product needs by classes of items in specific time periods" (1:426). The BOM File is "often called the product structure file or product tree since it shows how the product is put together" (1:427). The Inventory Records File is a time-phased inventory record of all supplies required by one or more items which make up the product (22:257). The MRP process uses the inputs of the Master Production Schedule, the BOM File, and the Inventory Records File to derive a solution.

A major requirement of the MRP approach is forecasting the demand for the product (27). In the tank allocation process, this product is difficult to define. The product desired from the tank allocation process is the distribution of tanks to units which achieves the maximum combat effectiveness of the tank fleet. This desired product differs from the current process, because the current process does not depend on where the "best" tanks are located. Therefore, the "product tree" for the tank allocation process is hard to determine.

A disadvantage of using MRP for the tank allocation process is that the distribution constraints for the tanks are divided between the BOM File and the Inventory Records File (34). This factor complicates the adaption of MRP to the tank allocation process. The results of the MRP process would be difficult to explain to an inexperienced user of the algorithm.

A current disadvantage of automated MRP programs is that they "cannot distinguish feasible production schedules from infeasible ones" (1:426). An automated MRP program would have to be run several times to ensure that it was not using resources which are not available (1:426). For instance, the program may allocate more tanks than are available in the inventory.

Hierarchial Production Planning Method. The concept of Hierarchial Production Planning (HPP) was introduced in 1975 by A.C. Hax and H.C. Meal (3:718). The highest level of planning in HPP is the aggregate production plan. The aggregate production plan is the long range goals for production. The sub-levels of hierarchial structure represent the disaggregate production plans. Disaggregate production plans represent the mid-range production objectives. Within each sub-level, a method of determining an optimal solution is found. By determining the optimal solutions at the sub-levels, the outcome of the aggregate planning level will be optimal.

Hax and Meal proposed three levels of aggregation in their model: 1) items; 2) product types, and; 3) families (3:718). Items are "the end products delivered to the customers" (3:718). For example, at the Chevrolet Division of General Motors Company the end products are Chevrolet Nova four door sedans. Product types are groups of items having similar unit costs,direct costs (excluding labor), holding costs, and production rates (3:718). Product types are Chevrolet Impalas, Chevettes, and Novas. Families "are groups of items pertaining to a same product type and sharing similar setups" (3:718). A family is the Chevrolet Division.

Within each of these levels of aggregation, an optimization process occurs to minimize costs and meet customer demand. The result will minimize the costs to General Motors and maximize the profits. Bitran adopted this three-level product structure for his research (3). However, he advised that a "specific disaggregation hierarchy depends on the actual setting being considered" (3:718). Production scheduling for multiple products at Owen-Corning Fiberglas (OCF) is an example of this comment (8).

Burch and Oliff used a three level hierarchial process to solve the multiple product scheduling at OCF. However, the levels were not characteristic of the item, product type, and family approach taken by Bitran, Hax, and Meal. At the first level, a production-switching rule was used to determine aggregate inventory levels, production levels, and work force sizes. The second level determines lot sizes, line assignments, and inventory levels for individual products using linear programming. The final level determines final job sequencing by use of a heuristic developed by Oliff and Burch (8:25). The three levels are integrated into each other with each level feeding the inputs of the next level. This development is characteristic of the current use of HPP (25).

The applicability of HPP to the tank allocation process is limited. The combat capability equation (1.1) and physical distribution of tanks subject to the constraints can be represented by two hierarchial levels. The determination of a tank fleet combat capability would be the aggregate level. The distribution of tanks would be the lower level. However, the major problem still would be the determination of a method by which to allocate tanks to the units in an "optimal" manner within the sub-levels.

<u>Transportation Method of Linear Programming</u>. Bowman showed in 1955 that production-scheduling problems may be solved by the transportation method of linear programming (5) (6:100). In Bowman's model, the objective function coefficients in the transportation problem represent the costs of production and storage. Production periods represent the source of supply (See Figure 2.1). Each production period consists of the maximum number of units which can be produced during an i^{th} sales period on overtime and regular time. Each time period's sales requirement is a destination. Since it is not possible to produce a unit in one period and sell it in a previous period, a "high" cost is assigned to those cells of the transportation table (6:100). On-hand inventory is also included in the transportation table. In order to use the transportation method, the total overtime and regular time production capacity is equal to the total

Production Periods (Source)	*Sales Periods (Destination)*						
	Sales$_1$	Sales$_2$	Sales$_3$	Sales$_n$	Inventory$_n$	Slack	Total Capacities
Inventory$_0$	0	C_I	$2C_I$	$(n-1)C_I$	nC_I	0	I_O
Regular$_1$	C_R	$C_R + C_I$	$C_R + 2C_I$	$C_R + (n-1)C_I$	$C_R + nC_I$	0	R_1
Overtime$_1$	C_O	$C_O + C_I$	$C_O + 2C_I$	$C_O + (n-1)C_I$	$C_O + nC_I$	0	O_1
Regular$_2$		C_R	$C_R + C_I$	$C_R + (n-2)C_I$	$C_R + (n-1)C_I$	0	R_2
Overtime$_2$		C_O	$C_O + C_I$	$C_O + (n-2)C_I$	$C_O + (n-1)C_I$	0	O_2
Regular$_3$			C_R	$C_R + (n-3)C_I$	$C_R + (n-2)C_I$	0	R_3
Overtime$_3$			C_O	$C_O + (n-3)C_I$	$C_O + (n-2)C_I$	0	O_3
Regular$_n$				C_R	$C_R + C_I$	0	R_n
Overtime$_n$				C_O	$C_O + C_I$	0	O_n
Total Requirements	S_1	S_2	S_3	S_n	I_n	*	

*Slack total = $I_0 + R + O - S - I_n$.

Notation:

I_i = Inventory at the end of the i^{th} time period.
R_i = Maximum number of units which can be produced during i^{th} time period on regular time.
O_i = Maximum number of units which can be produced during i^{th} time period on overtime.
S_i = Number of units of finished product to be sold (delivered) during i^{th} time period.
C_R = Cost of production per unit on regular time.
C_O = Cost of production per unit on overtime.
C_I = Cost of storage per unit per time period.

Source: Operations Research

[1] Developed by E. H. Bowman, in "Production Scheduling by the Transportation Method of Linear Programming," *Operations Research* (Feb. 1956), pp. 100-103.

Figure 2.1. Production Scheduling by Transportation Method

Production Periods (Source)	Sales Periods (Destination)						
	Sales$_1$	Sales$_2$	Sales$_3$	Sales$_n$	Inventory$_n$	Slack	Total Capacities
Inventory$_0$	0	C_I	$2C_I$	$(n-1)C_I$	nC_I	0	I_O
Regular$_1$	C_R	$C_R + C_I$	$C_R + 2C_I$	$C_R + (n-1)C_I$	$C_R + nC_I$	0	R_1
Overtime$_1$	C_O	$C_O + C_I$	$C_O + 2C_I$	$C_O + (n-1)C_I$	$C_O + nC_I$	0	O_1
Regular$_2$		C_R	$C_R + C_I$	$C_R + (n-2)C_I$	$C_R + (n-1)C_I$	0	R_2
Overtime$_2$		C_O	$C_O + C_I$	$C_O + (n-2)C_I$	$C_O + (n-1)C_I$	0	O_2
Regular$_3$			C_R	$C_R + (n-3)C_I$	$C_R + (n-2)C_I$	0	R_3
Overtime$_3$			C_O	$C_O + (n-3)C_I$	$C_O + (n-2)C_I$	0	O_3
Regular$_n$				C_R	$C_R + C_I$	0	R_n
Overtime$_n$				C_O	$C_O + C_I$	0	O_n
Total Requirements	S_1	S_2	S_3	S_n	I_n	*	

*Slack total = $I_0 + R + O - S - I_n$.

Notation:

I_i = Inventory at the end of the i^{th} time period.

R_i = Maximum number of units which can be produced during i^{th} time period on regular time.

O_i = Maximum number of units which can be produced during i^{th} time period on overtime.

S_i = Number of units of finished product to be sold (delivered) during i^{th} time period.

C_R = Cost of production per unit on regular time.

C_O = Cost of production per unit on overtime.

C_I = Cost of storage per unit per time period.

Source: *Operations Research*

[1]Developed by E. H. Bowman, in "Production Scheduling by the Transportation Method of Linear Programming," *Operations Research* (Feb. 1956), pp. 100-103.

Figure 2.1. Production Scheduling by Transportation Method

number of sale's requirements (5).

Bowman concluded that the method could be extended to several products (6:101). In the tank allocation process, the types of tanks (M60, M60A1, M60A3, and M1) represent the products. The most important point of Bowman's paper was the extension of the transportation framework to include time periods (6:102). Bowman used transportation framework in the classroom and did not apply to an actual industry problem. In 1970, C. David Sadleir extended Bowman's model to an actual industry problem (35).

Sadleir applied the transportation method to a production planning problem of a large footwear manufacturer in England. He was successful in implementing the transportation methodology. It resulted in a substantial savings in costs for the manufacturer (35:393). He faced several problems in adapting the transportation method. Additional constraints forced the modification of the transportation methodology, however, it still remained intact. Other problems faced were the derivation of costs and identifying demand (35:396-397).

In the tank allocation process, the cost is a measure of the degradation from the maximum achievable combat capability of a unit. The "best" tanks should be distributed to units with the smallest degradation in combat effectiveness. The number of tanks required by a unit represent the demand and the source is number of each type of tank available during a particular time period.

The transportation method of linear programming proposed by Bowman and implemented by Sadleir is the most feasible approach for allocating the tanks to units. It provides a better quantitative measure of assigning tanks to units according to their combat capability and not the total fleet capability. The aspect of time periods is not implemented in the linear programming formulation, but accomplished by solving several iterations of the tank problem. The availability of software for linear programming makes this approach easy to implement.

III. Methodology

Decision Support System for Tank Allocation Process

The automation of the tank allocation process involves the design and development of a decision support system. A decision support system is a tool which aids the decision-maker in solving a specific problem (41). In the tank allocation process, the decisionmaker is the Directorate of Combat Development (DCD). The specific problem is the tank allocation process. The tool being developed is an automated computer program which improves upon the current heuristics by "optimally" allocating tanks to units to maximize combat effectiveness.

A decision support system has three components: (1) a data base; (2) an interface with the user; and (3) a model base (9:28-29). The present data base for the tank allocation process consists of the current inventory by type of tank, production rates over time, number and organization of units, and the loss exchange ratios of U.S. versus threat tanks. The data base is captured on a Lotus 1-2-3 program. The tank fleet capability is calculated by an independent BASIC program, and then input into the LOTUS 1-2-3 spreadsheet. The interface with the user is a personal computer (PC) which runs and displays the Lotus 1-2-3 spreadsheet screens, and executes the BASIC program. DCD can manipulate and display the data within the Lotus 1-2-3 program and also vary the data of the BASIC program. The current model base is the manual application of the heuristics of the tank allocation process. It has not been automated, as explained earlier. However, the results of the manual process are stored on a LOTUS 1-2-3 spreadsheet. The essential step in the development of an automated decision support system for the tank allocation process is a model base which can interactively determine fleet capability and distribute the tanks to the units.

The Model Base

The development of the model base for the tank allocation process depends upon the accomplishment of two objectives: (1) the identification of an appropriate measure of effectiveness for combat capability, and (2) an algorithm to optimally allocate tanks to units. A measure of effectiveness is the combat capability measure developed by Remias (33). The combat capability measure of Remias provides a quantitative cost function which facilitates the use of the constrained transportation problem of linear programming to allocate the tanks to units in an optimal manner. Within the constrained transportation problem, the maximization of combat capability is achieved by minimizing the degradation of units from being equipped with less than the "best" tank.

Combat Capability Measure

The current measure used for determining fleet capability is Equation (1.1):

$$\text{Fleet Combat Capability} = \Sigma\ \Sigma\ \Sigma\ (LER_{ijk} * B_i * R_j * M_k)$$

There are several limitations to this equation. First, both tank studies, the Army Tank Program Analysis and Army Investment Strategy studies, derived the loss exchange ratios from a battalion level combat simulation. The results were obtained from the analysis of several iterations of thirty minute engagements of loss of forces at battalion level from a CARMONETTE model (11) (12) (13). The analysis should use at least a division level simulation to obtain the loss exchange ratios. Tanks are distributed to division size forces in the tank allocation process and are expected to fight for longer than thirty minutes.

A second limitation of Equation (1.1) is the that the loss exchange ratios do not account for the time sensitive nature of the battlefield (33). Time affects the mobilization of available fighting forces. This fact is particularly applicable to a war in Europe. Certain units are capable of fighting immediately, while other units must deploy and draw their equipment (i.e. POMCUS stocks) or transport their equipment over the oceans. A more appropriate measure of combat capability is the analysis of division level engagements simulated over a period of days where units could be deployed into the battle at various times consistent with deployment schedules. This analysis would provide a better estimate as to which units should receive the "best" tanks.

A third limitation is the inherent non-linearity of Equation (1.1). The determination of optimal solutions involving non-linear relationships often requires the use of complex and time-consuming solution techniques such as convex programming and quadratic programming. Although this requirement is not essential in determining a "cost" of assigning tanks to a specific unit in this research effort, a linear relationship is more desirable than a non-linear one.

A final limitation is the result of a dimensional analysis of Equation (1.1). The desired output from this equation should be the number of Red tanks destroyed, given the composition of the Blue force. The output, however, is not. The following example demonstrates this result:

Scenario: An M60A3 tank force of 2000 tanks engages a T-72 tank force of 5000 tanks. The Blue force is in defensive positions for 50% of the engagement. The loss exchange ratio of the T-72 to M60A3 is 1.5:1. The total number of Blue tanks is 10000 and the total number of Red tanks is 35000.

Dimensional analysis of equation (1.1) yields:

$$\frac{(1.5)\ \text{T-72}}{(1)\ \text{M60A3}} * \frac{(2000)\ \text{M60A3}}{(10000)\ \text{Blue Tanks}} * \frac{(5000)\ \text{T-72}}{(35000)\ \text{Red Tanks}} * \frac{5}{10}$$

The equation reduces to:

$$\frac{(1.5)\ (\text{T-72})\ (\text{T-72})}{(70)\ (\text{Blue Tanks})\ (\text{Red Tanks})}$$

Now if it is assumed that T-72 = Red Tanks, then the equation reduces to the following:

$$\frac{(1.5)\ \text{T-72}}{(70)\ (\text{Blue Tanks})}$$

The value determined is a fractional exchange ratio of T-72 to Blue tanks (33). It does not measure the combat capability of the Blue tank force to destroy Red tanks. Furthermore, this value is added to other values of different types of Red and Blue tanks. This results in a meaningless value. The measure of combat capability proposed by Remias does measure the number of Red tanks destroyed.

Remias proposes the following equation for unit combat capability:

$$\text{Unit Capability} = \Sigma\ \Sigma\ \Sigma\ Z * \int (A_{ijk} * B_i * R_j * M_k)\ dt \quad (3.1)$$

where:

Z = A time sensitive discount factor of a unit's ability to fight a battle

A_{ijk} = Attrition rate of Red tank (j) against Blue tank (i) in mission (k)

B_i = Number of tank (i)

R_j = Percentage of Red tank (j) in total Red fleet.

M_k = Percentage of time Blue units are conducting mission (k)

(32:32)

Equation (3.1) is based on Lanchester attrition equations. These equations were first proposed by F.W. Lanchester in his work, "Aircraft in Warfare: The Dawn of the Fourth Arm - No. V., the Principle of Concentration" (24). Lanchester type equations are the standard for force-on-force attrition models in combat analysis today (40). The basic Lanchester equation for engaged weapon systems over time is:

Y Casualties = X Firers * Attrition Rate * Delta T (3.2)

where:

X Firers = Average number of Blue shooters in the battle

Attrition Rate = Average rate at which a single Blue shooter kills a Red system

Delta T = Length of the engagement (expressed in terms consistent with the attrition rate)

(18:1-17)

Equation (3.2) is limited because it focuses on combat between homogeneous "X" and "Y" units. Equation (3.1) is the result of further research by Lanchester and others to incorporate heterogeneous combat into the equations. Equation (3.1) also introduces several important advantages that are not considered in Equation (1.1). The most important advantage is the situationally dependent value of a unit.

Situationally Dependent Value of a Combat Unit. The situationally dependent value of units is currently being studied at the Naval Postgraduate School in Monterey, California (29). The premise is that each unit has a basic inherent value to wage war. The basic inherent value is "that value possessed by a maneuver unit, in contact, as a direct result of the unit's ability to conduct operations" (29:4). The determination of a unit's basic inherent value is dependent on a situationally dependent value. A situationally dependent value is its basic inherent value decremented by an exponential factor (Z) based on the availability of that unit over time before it can influence the battle directly (29:6). In other words, units which are not directly engaged at the start of a battle still have the capability to wage war at some point in the future (33:29). This fact applies to units designated to deploy and be issued

POMCUS stocks. It also applies to units in the Continental United States (CONUS) destined to deploy to Europe in the advent of an outbreak in hostilities with the WARSAW Pact (See Figure 3.1) (34).

The basic inherent value of a unit at the start of an engagement, at time t(0), can be expressed with the following equation:

$$V_{actual} = V\ (s(\ t(0)\ )) \qquad (3.3)$$

where:

V = inherent value of the unit

s = state of the unit at time (t)

If the unit is not available for combat until some time in the future where t > t(0), then the inherent value of the unit is discounted back to the present to represent the actual availability of the unit. This value is the situationally dependent value of the unit. It can expressed by the following equation:

$$V = (s(\ t(0)\ ))\ e^{-C\ (t-t(0))} \qquad (3.4)$$

where:

$$e^{-C\ (t-t(0))} \qquad (3.5)$$

defines the discount factor and C is the decay constant that is used to determine the present value of a combat unit that is available in the future (33).

The solution of expression (3.5) is straightforward. An assumption is made that combat units that are available in 90 days have a negligible value of 0.05. This assumption is a value judgement of the decisionmaker, and is completely

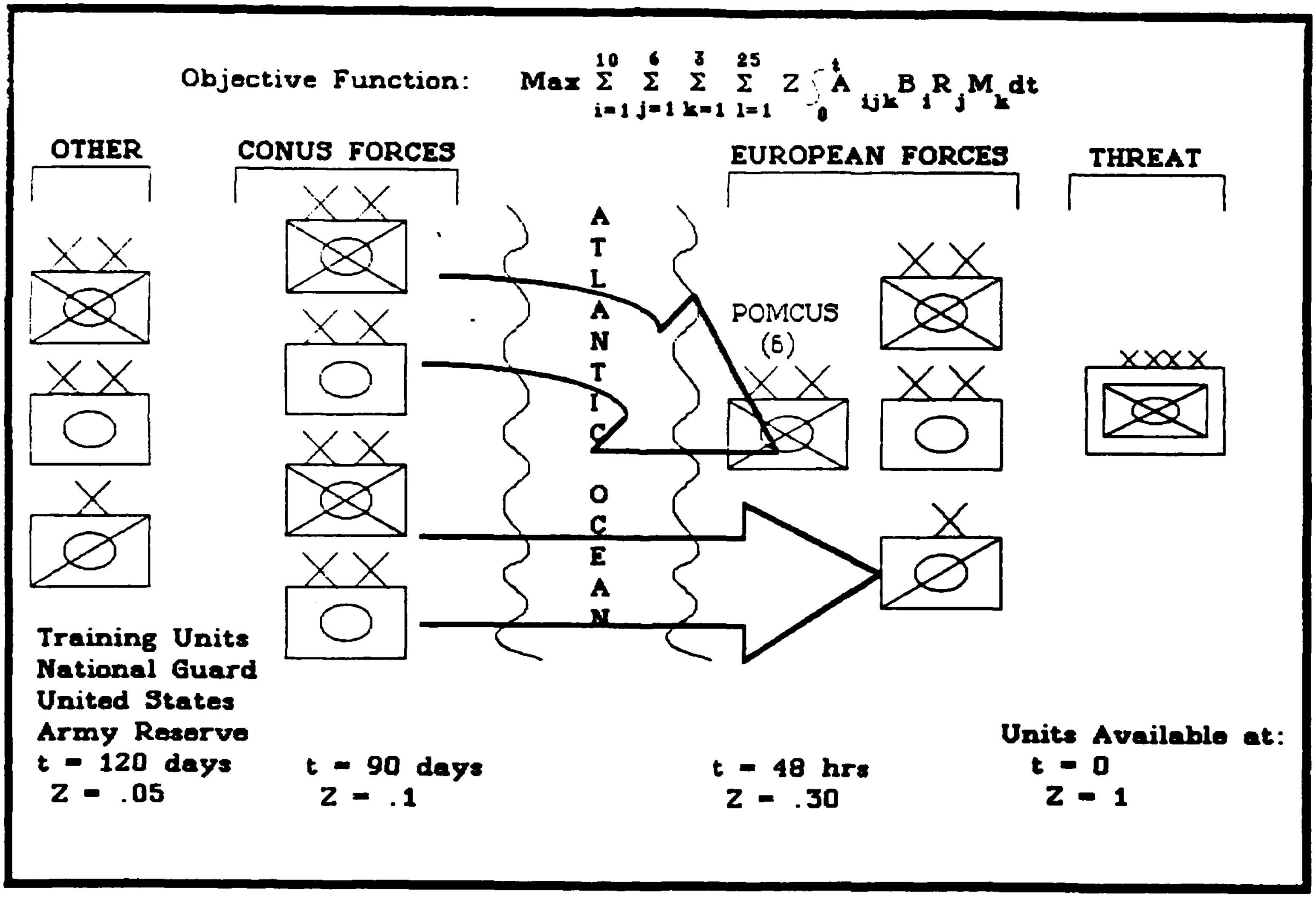


Figure 3.1. Discount Factor (Z) of Units

arbitrary for this illustration. The value of the decay constant C is then determined by solving:

$$\exp(-90*C) = 0.05$$

which reduces to:

$$C = \ln(0.05)/-90 = 0.0333$$

Once the decay constant is determined, the present values for all units can be determined. For example, a POMCUS unit can be operational in 30 days. The discount factor is:

$$Z = \exp(-0.033 * 30) = .368$$

Similarly, a frontline unit's discount factor is:

$$Z = \exp(-0.033 * 0) = 1$$

Z represents a fraction of a unit's future combat capability. Its value is proportional to the amount of time required before a unit can enter the battlefield. This time value methodology captures the priority ranking of units currently represented as a heuristic of the manual process (11) (12).

One limitation of the time value methodology for the tank allocation process is the inability to differentiate between units in Korea and Europe. Both units may have the same situationally dependent value. It will, therefore, be the judgement of the decisionmaker to determine unit priorities. It is assumed for this research effort that the primary mission is to defend Europe.

Dimensional Analysis Advantage. A dimensional analysis of Equation (3.1) yields a meaningful result: the number of

Red tanks destroyed. The following example demonstrates the compatibility of Equation (3.1):

Scenario: An Blue tank force of 200 M1 tanks and 200 M60A3 engage a Red force composed of 500 T-62 and 300 T-72. The total number of Red tanks is 3500. The Blue force is in offensive operations 50% of the time. The attrition rate of M1 to T-72 is 1:1.5, and M1 to T-62 is 1:3. The attrition rate of M60A3 to T-62 is 1:2, and M60A3 to T-72 1.5:1. The Blue tank force is a frontline unit (i.e. Z = 1).

In determining the combat capability of the Blue force, the combat capability of each type of Blue tank (i) in unit (j) must first be calculated. Once this calculation is performed, the combat capabilities of each type of Blue tank are added together to obtain the unit combat capability. The sum of all units' combat capabilities represent the Blue force capability. It is assumed for the previous scenario that the Blue force consists of two units (M60A3 and M1). Dimensional analysis yields:

Blue Force Capability = M60A3 Capability + M1 Capability

where:

$$\text{M60A3} = 1 * \frac{(2)\ \text{T-62}}{(1)\ \text{M60A3}} * 200\ \text{M60A3} * \frac{(500)\ \text{T-62}}{(3500)\ \text{Red Tanks}} * (.5)$$

$$+ 1 * \frac{(1)\ \text{T-72}}{(1.5)\ \text{M60A3}} * 200\ \text{M60A3} * \frac{(300)\ \text{T-72}}{(3500)\ \text{Red Tanks}} * (.5)$$

$$= 28.6 + 5.7 = 34.3\ \text{Red Tanks (Assuming Red Tanks = T-62 = T-72)}$$

$$\text{M1} = 1 * \frac{(3)\ \text{T-62}}{(1)\ \text{M1}} * 200\ \text{M1} * \frac{(500)\ \text{T-62}}{(3500)\ \text{Red Tanks}} * (.5)$$

$$+ 1 * \frac{(1.5)\ \text{T-72}}{(1)\ \text{M1}} * 200\ \text{M1} * \frac{(300)\ \text{T-72}}{(3500)\ \text{Red Tanks}} * (.5)$$

$= 42.9 + 12.9 = 55.8$ Red Tanks

Therefore, the total Blue Force combat capability is 90.1 (34.3 + 55.8) Red tanks destroyed for this scenario. It is important to note that this number represents less than one-third of the unit's total capability. The remaining capability results from its defensive and delay capabilities.

The dimensional analysis of Equation (3.1) gives the number of Red Tanks destroyed. Equation (3.1) provides a meaningful measure of combat capability whereas Equation (1.1) does not. The integral of Equation (3.1) represents the duration of the war. Since a war lasts an equal amount of time for all units, the integral can be eliminated.

Constrained Transportation Problem of Linear Programming

By using the situationally dependent combat capability explained in the preceding section, a constrained transportation problem can be formulated to maximize the fleet's capability by minimizing the degradation due to distributing less than the "best" tanks to units (34). The constrained transportation problem for the tank allocation problem is set up as follows:

MINIMIZE $$F = \Sigma \, \Sigma \, C_{ij} * X_{ij} \qquad (3.6)$$

SUBJECT TO:

$$\Sigma \, X_{ij} = S_i \qquad (3.7)$$

$$\Sigma \, X_{ij} = D_j \qquad (3.8)$$

$$\Sigma \, S_i = \Sigma \, D_j \qquad (3.9)$$

$$X_{mn} = X_{st} \qquad (3.10)$$

$$X_{uv} = TB \quad (3.11)$$

$$X_{ij} \geq 0 \quad (3.12)$$

where:

C_{ij} = Degradation of unit (j)'s combat capability due to "tank" and "unit" costs

X_{ij} = Number of type tank (i) to unit (j)

S_i = Total number of type (i) tanks available

D_j = Number of tanks required by unit (j)

TB = Fixed number of tanks needed for training base

X_{mn}, X_{st} = Different units which receive the same type of tanks

i = tank type

j = unit

(10:260)

The Coefficients of the Objective Function

The C_{ij}'s of Equation (3.6) are the per tank reduction of unit (j)'s combat capability due to it being assigned type (i) tanks rather than the "best" tank, and the reduction due to its location on and off the battlefield (34). C_{ij} is a coefficient for X_{ij} of tank (i) in unit (j). Equation (3.1) is modified to obtain the C_{ij}'s. This modified equation is:

$$C_{ij} = \Sigma \; \Sigma \; Z * A_{ijk} * R_j * M_k \quad (3.13)$$

Equation (3.13) represents the combined attrition rate for the three missions (attack, defend, and delay) of a specific type of tank (i). Consider the following attrition rates for Blue Tank 1 against Red Tanks 1,2, and 3 in attack, defend, and delay missions. The attrition rate matrix is multiplied by the percentage of time that Blue Tank 1 conducts the three missions:

Attack	Defend	Delay	*		R1	R2	R3
0.5	0.5	0.0		Attack	1.30	1.20	0.74
				Defend	1.45	1.26	0.80
				Delay	1.38	1.23	0.77

This results in the following matrix, representing a combined attrition rate against each type of Red tank:

R1	R2	R3
1.375	1.230	0.77

The combined attrition matrix is then multiplied by the percentage of each type of Red tank (j) in the fleet. In the example, there are three types of Red tanks:

R1	R2	R3					
1.375	1.230	0.77	*	R1	0.80	=	1.375
				R2	0.20		
				R3	0.00		

This computation results in a scaler value (1.375). The value represents the number of Red tanks destroyed per Blue Tank 1. This value is multiplied by the situationally dependent value (Z) to obtain the attrition coefficient for a particular unit and type tank. Once these coefficients are determined for each unit and type of Blue tank, the difference between the coefficient of the "best" tank and the other tanks is calculated. This difference is the "cost" for a unit not being equipped with the "best" tank.

The other component of the "cost" of the C_{ij}'s is the difference between frontline units and POMCUS or CONUS units. For instance, given that the situationally dependent values of Units "X" and "Y" are Z = 1.0 and Z = .40, respectively, the attrition coefficients for each unit equipped with Blue Tank 1 in the preceding example is 1.375 and 0.55. The difference between the two values (0.825) is the "cost" of assigning Blue Tank 1 to Unit "Y" rather than Unit "X". This cost is added to the Unit "Y" coefficient. By minimizing these unit "costs" and tank "costs" of the preceding paragraph, the optimal distribution is obtained.

Constraints of the Transportation Problem

Equation (3.7) is the number of each type of tank available for allocation. It represents the supply aspect of the transportation problem. As Bowman stated in his paper, the transportation method can accommodate multiple products (6). Equation (3.8) is the number of tanks required by each unit, or the demand of the transportation problem. Ideally, each unit would like the "best" tank possible; however, this goal is not possible because of the limited number of the "best" tanks which are available. Therefore, the constrained transportation problem optimally allocates the next "best" tank possible.

In order to use the constrained transportation methodology, supply must equal demand (5) (6). This equality is represented by Equation (3.9). In the tank allocation process, supply will always exceed demand. There will always be more tanks available to be issued to units than there are units to be filled. The excess tanks are obsolete tanks which are going to be taken out of the inventory. The excess supply can be accommodated in the constrained transportation problem by assigning tanks to a "dummy" unit. The degradation from maximum combat capability for the "dummy" unit is assigned a "high" attrition coefficient.

Equation (3.10) is a constraint specific to the tank allocation process. Certain units must receive the same type of tanks as other units. These units represent the pre-stocking of equipment (POMCUS) for wartime missions at various locations throughout the world. Upon the outbreak of war a unit will be deployed and be issued the same equipment it had for training at its home station.

Equation (3.11) represents another constraint specific to the tank allocation process. It establishes a specific number of tanks needed to maintain a school training base in order to train new recruits for the Armor force. It also provides tanks for further research and development of new concepts and tactics, and future enhancements of armored vehicles.

The flexibility of the constrained transportation methodology permits the inclusion of additional constraints that may arise in the future. The additional constraints can be easily formulated into the constrained transportation methodology. The quantity of type (i) tanks may vary from period to period. This variance is a function of either: 1) production rate of type (i) tanks, in which case S_i increases, or 2) in the case of older tanks, the rate at which they are dropped from the inventory. However, the two rates are equal, because the total fleet inventory (Σ D_i) is constant.

The handling of multiple time periods and the ripple-down effect are solved simultaneously by the constrained transportation methodology. Each "transportation table" represents one time period (See Figure 3.2). In order to determine the allocation of tanks over a twenty-year planning period, the methodology maximizes the combat capability for each period and is iterated over twenty years to determine the total allocation of tanks. This process maximizes the per period capability, but not the capability over the twenty-year period. If constraints change in any one period, the "transportation table" for that specific period is adjusted. Once a unit receives new tanks for a period, the older model tanks are assigned to other units based on their respective attrition costs. Finally, the minimum time requirement for new tanks is accomplished by fixing the newly acquired tanks assigned to a unit for several periods. This is handled by an equality constraint to the problem formulation.

Specific Computer Packages Used for the Solution

The transportation problem is a special case of linear programming (20:129). The constrained transportation problem for the tank allocation process is solved via linear programming. The linear programming package used for this research

FOR YEAR = 1995

	UNIT#1	UNIT#2	UNIT#3	UNIT#4	•••	UNIT #25	NUMBER TANKS AVAILABLE
M1E1	0	0	1.5	2.1		1.5	360
M1	.44	.44	1.4	1.8		1.4	2102
M60A3	.83	.83	1.3	1.5		1.3	3387
M60A1	1.31	1.31	1.2	1.2		1.2	1709
DEMAND	315	141	63	141		3862	7558

Figure 3.2. Transportation Problem

effort is the LPMIP83 Linear Programming System (39). This particular package has the capability of interacting with the Lotus 1-2-3 program.

The combat capabilities of 25 units and their associated attrition coefficients are calculated using two FORTRAN programs. The degradation in combat capability is then input into the LPMIP83 program as the cost coefficients to solve the tank distribution. The X_{ij}'s are then re-entered into the FORTRAN combat capability program to determine the fleet combat capability.

The merits and disadvantages of various programming languages was not a factor in selecting the FORTRAN programming language. Rather, it was used because of the author's knowledge of that specific programming language.

Data for Methodology

The data used for the methodology is representative of actual data at DCD. Specific data is not used in order to avoid the compromise of classified information. The distribution of tanks was determined for 25 units over a ten year period. Two production options are analyzed. The Blue force has four different tanks in its inventory; the Red fleet has three. The attrition rates are contrived; however, they are representative of actual data.

IV. Findings and Analysis

Assumptions and Scenario

The distribution plans presented in Appendixes H and I were determined for two production options. They are the result of the application of the linear programming formulation of the constrained transportation methodology presented in Appendix F. The attrition rate coefficients (C_{ij}'s) of the objective function were calculated from the FORTRAN program presented in Appendix B. Sample output of this program is presented in Appendix C. The combat capability for each unit and the total fleet was calculated by the FORTRAN program presented in Appendix A. Data sets used by both FORTRAN programs are presented in Appendix E. The initial inventory of the tank fleet used for this analysis is presented in Appendix H (page H-1).

The area of operations for this research effort was Europe. This choice is relevant because of the U.S. commitment to NATO. The methodology, however, is not limited to Europe. It is the role of the decisionmaker to establish priorities, based on his military judgement. The duration of the battle was assumed to be 180 days. This assumption is critical when considering the deployment schedules of POMCUS and CONUS units to Europe. Although the methodology will account for those units which take longer than 180 days to deploy, the time discount factor of these units will be extremely low. This effect will cause an extremely high "cost" to be associated with these units.

For this analysis, the Blue force consists of 25 units. Units 1 through 9 are considered frontline units and have a time discount factor of Z = 1. POMCUS units (Units 10 and 25) are available in 30 days and have a discount factor of Z = .40. CONUS units (Units 11 through 19) are available in 60 days, and Army National Guard (NG) units (Units 20 through 24) are available in 90 days. CONUS and NG units have a time discount factor of Z = .15 and Z = .05, respectively. The "dummy" unit was Unit 26 and was considered to have "high" cost of 500. Z was determined under the assumption that combat units available in 90 days have an almost negligible present value of 0.05. The calculations of Z for the units, based on this assumption, are found in Appendix K.

The attrition rates for the offensive, defensive, and delay missions are presented in Appendix J. The attrition rates reflect the expected number of Red tanks (j) destroyed per Blue tank (i) per day (33:48). The defensive attrition rates are partially based on the Systems Effectiveness Model inputs to the battalion level simulation used the Army Investment Strategy study (11). However, these rates represent loss exchange ratios rather than true attrition rates. Actual attrition rates are available from the U.S. Army Concepts Analysis Agency (CAA); however, they were not used in this study due to security restrictions. Therefore, the attrition rates used are hypothetical and are used only to facilitate the demonstration of the methodology.

The values of the offensive attrition rates will generally be lower than the defensive rates. Units are more susceptible to hostile fire when they are moving on an offensive mission. In the defense, units occupy prepared positions. The prepared positions afford cover and concealment from enemy fire. Delay attrition rates will represent values between the offensive and defensive rates, since delay missions consist of both defensive and offensive missions. The mission profile associated with the attrition rates for this analysis was assumed to be 50% offensive missions and 50% defensive missions. This assumption is consistent with current analysis being conducted at DCD (31).

The Red tank fleet is assumed to be composed of three tanks. The percentages of these tanks in the fleet for the ten year period are presented in Appendix G. The Blue tank fleet consists of four tanks. Blue tank 4 is considered the "best" and newest tank in the fleet. The order of increasing combat capability for the Blue fleet is Blue 1, Blue 2, Blue 3, and Blue 4.

Two production options were compared for a ten year period. The production rate for both options until 1992 was 240 Blue 3 tanks per year and 120 Blue 4 tanks per year. The first year of production for Blue 4 was 1988. Twenty of these tanks were sent to training base units and were not considered available for issue in 1988. For Option 1 after

1992, the production rate for Blue 3 tanks was stopped and full production of Blue 4 tanks begun. The production rate of Blue 4 tanks was increased to 360 tanks per year. For Option 2, the production rate of 240 Blue 3 tanks per year and 120 Blue 4 tanks per year was continued.

Analysis of Output

The results of the initial linear programming formulation for 1988 shifted the tanks according to combat capability to the units with the lowest "cost" or the frontline units (1-9). This resulted in a increased combat capability of the tank fleet (7890.271 verus 6976.06). Alternate optimal solutions exist for all the yearly distribution plans. This is consistent with linear programming since units have the same attrition "cost" associated with them. As long as the decisionmaker decides to shift the distribution of tanks from the solution obtained to units with the same "cost", the plan will remain optimal. For example in 1988, the alternate optimal solution was to assign the 100 Blue 4 tanks to Unit 1 instead of Unit 2. The objective function value remains unchanged.

The "dummy" unit was assigned a zero cost for the Blue 1 tanks in the formulation. This effect causes the Blue 1 tanks to be forced out of the fleet. The other tanks of the unit were assigned a cost of 500, as mentioned earlier. It is the intent of the methodology and force planners to keep the other tanks (Blue 2, Blue 3, and Blue 4) in the tank fleet. Blue 1 is considered to be the "oldest" tank in the fleet.

The attrition costs for Blue 1 and Blue 2 tanks of the POMCUS and CONUS towards the end of the ten-year plans are similar values. This effect is due to the increasing percentage of the Red 3 tanks which enter the force in the latter years. Since the Red 3 tank is the "best" tank for the opposing force, the effect of POMCUS and Conus units receiving Blue 1 and Blue 2 is negligible. On the other hand, the attrition cost of frontline units for these same tanks reflects a higher value. Sample calculations of C_{ij}'s for several units are presented in Appendix D.

The solution values (X_{ij}'s) are integer values. This fact is due to the coefficient of all constraint variables reflecting a value of one. This is a characteristic of the transportation method (20:123). It is a particularly "attractive" aspect of using this methodology.

An analysis of the right hand constraints can determine the effect of various production rates and their impact on minimizing attrition costs. The analysis was very limited, because of the use of only representative data. For 1988, the upper bound for Blue 4 tanks was 141. The lower bound was 0.0. This result implies that the production of up to 141 tanks has no effect on minimizing attrition costs. Likewise, the production of 0.0 tanks increases the objective function. A similar analysis of the other types of tanks in the inventory can also be conducted.

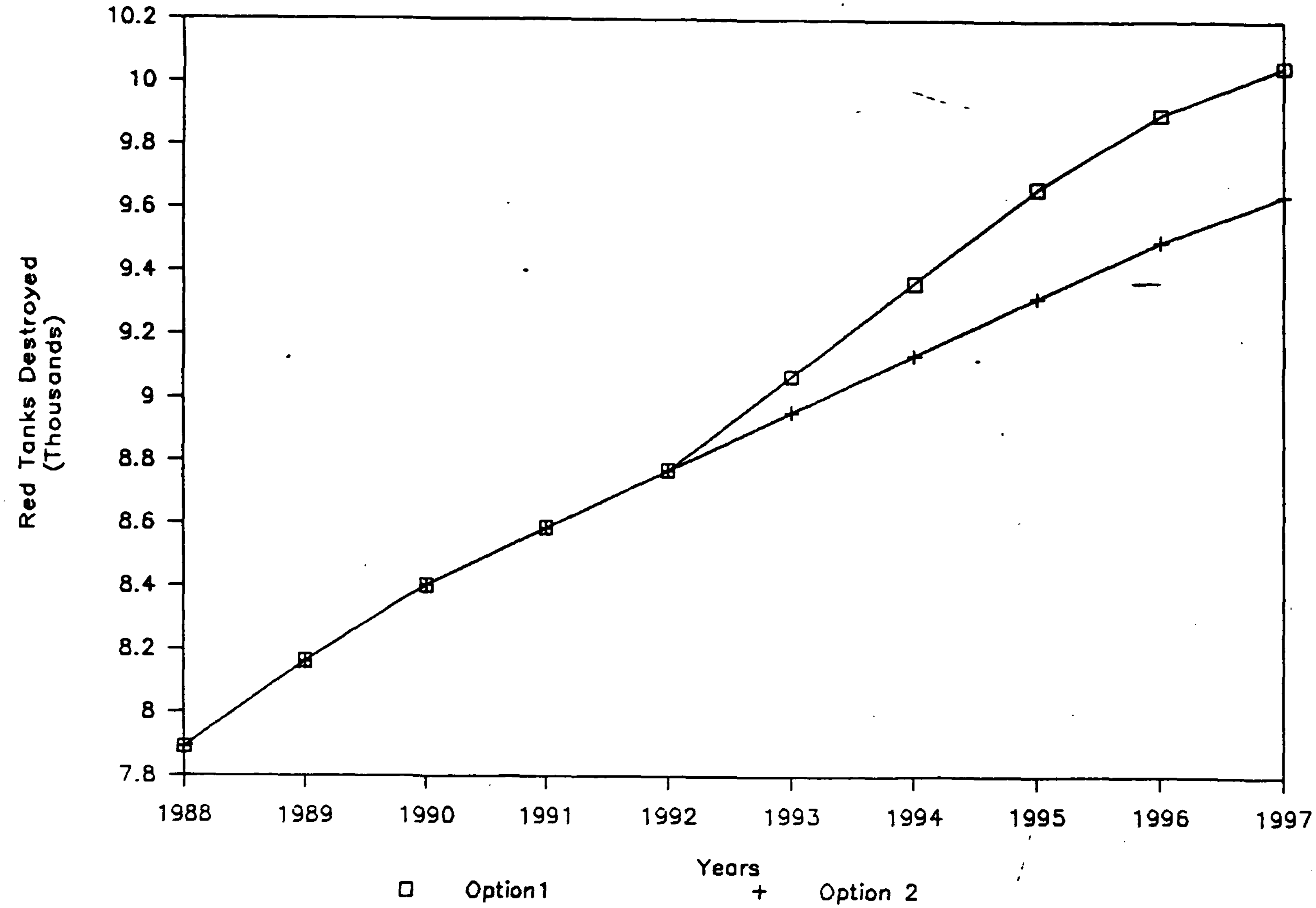
Analysis of Production Options

In all cases, the combat capability of both options increased as the ten-year plan was computed (See Figure 4.1). Option 1, however, reached to a higher level than Option 2. The reason for this effect was the increased production rate of Blue 4 tanks. The methodology gives the decisionmaker the ability to analyze various production options. Furthermore, it appears that the methodology of annual optimization also produces optimal results over the entire ten year period.

Heuristics of the Current Manual Process

The heuristics of the current manual process are captured by the constrained transportation methodology. The linear programming formulation of the "transportation table" fills the units from top to bottom, right to left, in order, as new tanks are available. The minimum time requirement of new tanks will never become a problem unless the production rate is excessively large. If this does occur, however, those units which are affected can be fixed by assigning tanks to them as an equality constraint. "Specialty" tanks, those tanks that the decisionmaker wants only a limited number assigned and built, can also be handled as an equality constraint. The priorities of units are accomplished by the time discount factor. This eliminates the need to rank order units.

FLEET CAPABILITY



Sensitivity Analysis of Attrition Costs

The certainty assumption of linear programming states that all parameters of the model are known constants. This does not usually occur in the real world. Therefore, a sensitivity analysis of the parameters should be conducted to determine which parameters are sensitive to change (20:26). However, a meaningful sensitivity analysis of the attrition costs cannot be conducted because of the absence of actual data.

Traditional economic theory implies that production costs should decrease as the number of units produced increases (26:120). This is not the case with the tank allocation process. The attrition costs will not vary because of an increased production rate (increasing S_i's). The cost is based on the type of tank rather the number of tanks. This is in keeping with the linear programming assumption of proportionality (10:69).

Compatibility of Software

One of the initial research objectives was to combine the combat capability measure and tank distribution method into one interactive model base for the user. This objective was not accomplished. The LPMIP 83 program does interface with Lotus 1-2-3. However, the ability of Lotus 1-2-3 to accept computer input of programming languages is limited. The macro capability of the Lotus 1-2-3 is limited to simple operations of copy and recurrent addition formulas. Futhermore, the magnitude of the matrix multiplication of the attrition coefficients cause the formulation of equations in Lotus 1-2-3 to be a lengthy and time consuming process. One advantage of the LPMIP 83 program is that it can build data files. These files can in turn be interpreted by programming languages. Further research needs to be conducted in this area.

V. Conclusions and Recommendations

Conclusions

One of the original objectives of this research effort was the development of an interactive model base for the tank allocation process. This objective was not accomplished. However, the constrained transportation methodology has structured the process to such an extent that effective analysis can be accomplished. The methodology uses a meaningful measure of combat capability for allocating tanks to units. It can be extended to other heterogeneous elements such mechanized infantry or artillery units with further research. Furthermore, the combat capability measure (Equation 3.1) is not indifferent to which unit receives which tanks; it provides the constrained transportation methodology with a cost function which allocates tanks to units by maximizing combat capability.

One limitation of Equation 3.1 is the ability to differentiate between units assigned to several theaters of operations. The methodology, however, is not theater dependent. It is the role of the decisionmaker to determine global priorities.

The constrained transportation methodology captures the heuristics of the current manual process. First, the priority of units is captured by the use of the time discount factor. Secondly, the relative effectiveness of each type of tank is captured by the attrition costs. Thirdly, the requirement to equip specific units is handled by equality constraints. The ripple-down effect is captured by the resource constraint (S_i) of the transportation method. Finally, the aspect of time periods is accomplished by the iterations of the linear programming formulation.

The presence of alternate optimal solutions could be avoided if one time phases the frontline units in Europe to the battlefield rather than assuming that t = 0 for all of the units. In reality, frontline units deploy at different times. The time intervals between these units is obviously not as long as those associated with POMCUS or CONUS units. This time difference for the units in Europe would not significantly affect the total fleet capability. However, it would enhance the current "ranking" heuristics.

The absence of real data limited the sensitivity analysis of attrition costs and resource constraints. Further research into these aspects needs to be conducted. However, the use of the methodology to analyze production options is easily accomplished as demonstrated in Chapter IV. This lack of real data also does not allow the comparison of constrained transportation methodology with the current approach.

The methodology does take less time than the current approach. Analysis of both options took less than two hours to perform. The time taken for each production option could be further reduced by the total integration of computer software.

The total integration of computer software was not accomplished as mentioned earlier. The availability of new software which can incorporate a spreadsheet, programming language, and linear programming needs to be explored. A new product which shows some promise of this capability is "What'sBest" developed by the General Optimization Inc. of Chicago. "What'sBest" uses both the Lotus 1-2-3 spreadsheet and the Linear Discrete Optimization Program (LINDO) package. A preliminary review of available literature shows promise.

Another limitation of the methodology is ability to handle the issue of unit packages of tanks. The problem is that several units do not have established unit packages. The use of integer programming to enhance this limitation of the constrained transportation methodology needs to be explored.

Recommendations

The methodology developed in this research effort further enhances the ability of the Directorate of Combat Development (DCD) to improve the combat capability of the Armor force by allocating tanks to units in an optimal manner. The methodology structures the tank allocation process into a process which can be understood and permits analysis of the variables which influence the tank allocation process. This analysis provides valuable information for the future development of the tank fleet through the comparison of several production options.

Further research of the sensitivity of the attrition rates which are used for the attrition cost formulation needs to be conducted. This research depends on the availability of actual data used for the tank allocation process. A sensitivity analysis of the production options can also be conducted with this data.

COMBAT CAPABILITY PROGRAM

```
C TANK CAPABILITY PROGRAM
C PROGRAMMER: WILLIAM G. ADAMS
C***********************************************************
C INPUT VARIABLES
C***********************************************************
C
C UNIT(25,13) ARRAY; ATTRIBUTES = 10 TYPES OF TANKS, DISCOUNT
C                                 FACTOR, MISSION PROFILE
C                                 (ATTACK, DEFEND, DELAY),
C                                 25 UNITS
C
C OATTRIT(10,6) ARRAY; ATTRIBUTES =OFFENSIVE ATTRITION RATES
C                                  OF 10 BLUE TANKS AGAINST 6
C                                  RED TANKS
C
C DATTRIT(10,6) ARRAY; ATTRIBUTES = DEFENSIVE ATTRITION RATES
C
C LATTRIT(10,6) ARRAY; ATTRIBUTES = DELAY ATTRITION RATES
C
C OFFCAP = UNIT OFFENSIVE CAPABILITY; COUNTER
C
C DEFCAP = UNIT DEFENSIVE CAPABILITY; COUNTER
C
C DELCAP = UNIT DELAY CAPABILIYT; COUNTER
C
C TOTOFF(25) ARRRAY = TOTAL OFFENSIVE CAPABILITY FOR UNIT
C
C TOTDEF(25) ARRAY = TOTAL DEFENSIVE CAPABILITY FOR UNIT
C
C TOTDEL(25) ARRAY = TOTAL DELAY CAPABILITY FOR UNIT
C
C UNCAP(25) ARRAY = TOTAL COMBINED (OFFENSIVE+DEFENSIVE
C                                   +DELAY) UNIT CAPABILITY
C
C THREAT(6) ARRAY = PERCENTAGE OF TYPE (RED TANK IN RED TANK
C                   FLEET
C
C I = ROW
C J = COLUMN
C
C***********************************************************
      PROGRAM TANK
      REAL UNIT(25,8), OATTRIT(4,3),DATTRIT(4,3), LATTRIT(4,3)
         REAL THREAT(3),UNCAP(25), TOTOFF(25), TOTDEF(25)
         REAL TOTDEL(25)
         REAL OFFCAP, DEFCAP, DELCAP, TOTCAP
      INTEGER I,J,K
C***********************************************************

C
C INITIALIZE ALL ARRAYS
```

```
C
C***********************************************************
C
        DO 5 I=1,25
        UNCAP(I) = 0.0
        TOTOFF(I)= 0.0
        TOTDEF(I)= 0.0
        TOTDEL(I)= 0.0
 5      CONTINUE
C
        TOTCAP = 0.0
C
C***********************************************************
C
C READIN EXTERNAL DATA SETS
C***********************************************************
C***********************************************************
C READIN THE UNIT DATA SET
C***********************************************************
     OPEN(UNIT=10,FILE='UNIT.DAT',STATUS='UNKNOWN')
     DO 10 I=1,25
           READ(10,*)(UNIT(I,J),J=1,8)
 10     CONTINUE
C
C***********************************************************
C READIN OFFENSIVE ATTRITION RATES
C***********************************************************
     OPEN(UNIT=20,FILE='OATTRIT.DAT',STATUS='UNKNOWN')
     DO 20 I=1,4
           READ(20,*)(OATTRIT(I,J),J=1,3)
 20     CONTINUE
C
C***********************************************************
C READIN DEFENSIVE ATTRITION RATES
C***********************************************************
     OPEN(UNIT=30,FILE='DATTRIT.DAT',STATUS='UNKNOWN')
     DO 30 I=1,4
           READ(30,*)(DATTRIT(I,J),J=1,3)
C
 30     CONTINUE
C
C***********************************************************
C READIN DELAY ATTRITION RATES
C***********************************************************
     OPEN(UNIT=40,FILE='LATTRIT.DAT',STATUS='UNKNOWN')
     DO 40 I=1,4
              READ(40,*)(LATTRIT(I,J),J=1,3)
C
 40     CONTINUE
C
C***********************************************************
C READIN THREAT FLEET PERCENTAGES BY TYPE TANK
```

```
C***********************************************************
      OPEN(UNIT=50,FILE='THREAT.DAT',STATUS='UNKNOWN')
      DO 50 I=1,3
            READ(50,*) THREAT(I)
 50      CONTINUE
C
C***********************************************************
C DO THE COMPUTATIONS
C***********************************************************
C
      DO 90 I=1,25
               DO 80 J=1,4
                     DO 70 K=1,3
                  OFFCAP=UNIT(I,J)*OATTRIT(J,K)*THREAT(K)*
     +                                UNIT(I,5)*UNIT(I,6)
C
                  DEFCAP=UNIT(I,J)*DATTRIT(J,K)*THREAT(K)*
     +                                UNIT(I,5)*UNIT(I,7)
C
                  DELCAP=UNIT(I,J)*LATTRIT(J,K)*THREAT(K)*
     +                                UNIT(I,5)*UNIT(I,8)
C
C
                           TOTOFF(I)=TOTOFF(I) + OFFCAP
                           TOTDEF(I)=TOTDEF(I) + DEFCAP
                           TOTDEL(I)=TOTDEL(I) + DELCAP
C
C
 70                  CONTINUE
 80            CONTINUE
                           UNCAP(I)=TOTOFF(I) + TOTDEF(I) +
      +                             TOTDEL(I)
                           TOTCAP=TOTCAP + UNCAP(I)
 90      CONTINUE
C
C***********************************************************
C WRITE THE RESULTS
C***********************************************************
      OPEN(UNIT=60,FILE='UNCAP.DAT',STATUS='UNKNOWN')
                 WRITE(60,*) '    FLEET CAPABILITY BY UNIT'
      DO 110 I=1,25
           WRITE(60,*) I,UNCAP(I)
 110      CONTINUE
                 WRITE(60,*) 'THE TOTAL FLEET CAPABILITY'
                 WRITE(60,*) TOTCAP
C
C
      STOP
      END
```

ATTRITION COEFFICIENT PROGRAM

```
      PROGRAM COFF
      REAL UNIT(25,8),OATTRIT(4,3),DATTRIT(4,3),LATTRIT(4,3)
      REAL YEAR(3,10),BATTRIT(3,3),MSNPROF(3),BMSN(3)
      REAL PRODUCT1,TOTAL1,PRODUCT2,TOTAL2,COST(4)
      REAL BIGCOST(25,4)
      INTEGER I,J,K,L,M,N,P,Q,R,S,DATE
C
C
      OPEN(UNIT=10,FILE='UNIT.DAT',STATUS='UNKNOWN')
      DO 10 I=1,25
         READ(10,*) (UNIT(I,J),J=1,8)
 10   CONTINUE
C
      OPEN(UNIT=20,FILE='OATTRIT.DAT',STATUS='UNKNOWN')
      DO 20 I=1,4
         READ(20,*) (OATTRIT(I,J),J=1,3)
 20   CONTINUE
C
      OPEN(UNIT=30,FILE='DATTRIT.DAT',STATUS='UNKNOWN')
      DO 30 I=1,4
         READ(30,*) (DATTRIT(I,J),J=1,3)
 30   CONTINUE
C
      OPEN(UNIT=40,FILE='LATTRIT.DAT',STATUS='UNKNOWN')
      DO 40 I=1,4
         READ(40,*) (LATTRIT(I,J),J=1,3)
 40   CONTINUE
C
      OPEN(UNIT=50,FILE='YEAR.DAT',STATUS='UNKNOWN')
      DO 50 I=1,3
         READ(50,*) (YEAR(I,J),J=1,10)
 50   CONTINUE
C
C
C
C  IN THE FOLLOWING FOUR LOOPS, THE INCREMENTS ARE:
C             Q = THE NUMBER OF YEARS USED
C             N = THE NUMBER OF TANK UNITS
C             I = THE NUMBER OF DIFFERENT BLUE
C                 EQUIPMENT TYPES
C             J = THE NUMBER OF DIFFERENT RED
C                 EQUIPMENT TYPES
C
C  OUTPUT DATA IS WRITTEN TO THE FILE NAMED
C  YEARCOFF.DAT.
C
      DO 2000 Q=1,10
         OPEN(UNIT=60,FILE='YEARCOFF.DAT',STATUS='UNKNOWN')
         DATE = 1987 + Q
         WRITE(60,*) 'THE COST COEFFICIENTS ARE FOR ',DATE
         DO 1000 N=1,25
            DO 500 I=1,4
```

```
                DO 100 J=1,3
C
C  THE BATTRIT MATRIX IS THE TWO DIMENSIONAL ARRAY OF
C  ATTRITION RATES.  IT IS CONSTRUCTED FOUR TIMES,
C  ONCE FOR EACH BLUE EQUIPMENT TYPE.
C
                   BATTRIT(1,J) = OATTRIT(I,J)
                   BATTRIT(2,J) = DATTRIT(I,J)
                   BATTRIT(3,J) = LATTRIT(I,J)
 100            CONTINUE
C
C
C  THE MSNPROF VECTOR HOLDS THE ATTACK, DEFEND, AND
C  DELAY PERCENTAGES FOR A GIVEN UNIT.
C
             MSNPROF(1) = UNIT(N,6)
             MSNPROF(2) = UNIT(N,7)
             MSNPROF(3) = UNIT(N,8)
C
C
                DO 300 K=1,3
                   PRODUCT1 = 0.0
                   TOTAL1 = 0.0
                   DO 200 L=1,3
                      PRODUCT1 = MSNPROF(L) * BATTRIT(L,K)
                      TOTAL1 = TOTAL1 + PRODUCT1
 200               CONTINUE
C
C  THE BMSN VECTOR IS AN INTERMEDIATE HOLDING AREA FOR
C  COMPUTING THE COST COEFFICIENTS OF A UNIT.
C
                   BMSN(K) = TOTAL1
 300            CONTINUE
C
C
                PRODUCT2 = 0.0
                TOTAL2 = 0.0
                DO 400 M=1,3
                   PRODUCT2 = BMSN(M) * YEAR(M,Q)
                   TOTAL2 = TOTAL2 + PRODUCT2
 400            CONTINUE
C
C
C  THE COST VECTOR IS THE PRODUCT OF THE COEFFICIENT
C  TIMES THE DISCOUNT FACTOR OF A SPECIFIC UNIT.
C
              COST(I) = TOTAL2 * UNIT(N,5)
C
C
 500         CONTINUE
C
C
```

```
                DO 600 P=1,4
C
C  BIGCOST IS THE FINAL ARRAY CONTAINING ALL THE COST
C  COEFFICIENTS FOR EACH UNIT, BY TYPE OF TANK, FOR
C  A GIVEN YEAR.
C
                   BIGCOST(N,P) = COST(P)
 600            CONTINUE
 1000     CONTINUE
C
C READ TANK TYPES FROM LEFT TO RIGHT (BLUE1, BLUE2, BLUE3,
C BLUE4, ETC.)
          DO 1500 R=1,25
             WRITE(60,*) R,(BIGCOST(R,S),S=1,4)
 1500     CONTINUE
C
C
 2000 CONTINUE
C
C
      STOP
      END
```

ATTRITIION COEFFICIENT OUTPUT

THE COST COEFFICIENTS ARE FOR 1988

1	1.346000	1.808000	2.225000	2.701000
2	1.346000	1.808000	2.225000	2.701000
3	1.346000	1.808000	2.225000	2.701000
4	1.346000	1.808000	2.225000	2.701000
5	1.346000	1.808000	2.225000	2.701000
6	1.265240	1.699520	2.091500	2.538940
7	1.265240	1.699520	2.091500	2.538940
8	1.265240	1.699520	2.091500	2.538940
9	1.265240	1.699520	2.091500	2.538940
10	0.5384001	0.7232000	0.8900000	1.080400
11	0.2019000	0.2712000	0.3337500	0.4051501
12	0.2019000	0.2712000	0.3337500	0.4051501
13	0.2019000	0.2712000	0.3337500	0.4051501
14	0.2019000	0.2712000	0.3337500	0.4051501
15	0.2019000	0.2712000	0.3337500	0.4051501
16	0.2019000	0.2712000	0.3337500	0.4051501
17	0.2019000	0.2712000	0.3337500	0.4051501
18	0.2019000	0.2712000	0.3337500	0.4051501
19	0.2019000	0.2712000	0.3337500	0.4051501
20	6.7300007E-02	9.0400003E-02	0.1112500	0.1350500
21	6.7300007E-02	9.0400003E-02	0.1112500	0.1350500
22	6.7300007E-02	9.0400003E-02	0.1112500	0.1350500
23	6.7300007E-02	9.0400003E-02	0.1112500	0.1350500
24	6.7300007E-02	9.0400003E-02	0.1112500	0.1350500
25	0.5384001	0.7232000	0.8900000	1.080400

THE COST COEFFICIENTS ARE FOR 1989

1	1.338750	1.803750	2.217500	2.692500
2	1.338750	1.803750	2.217500	2.692500
3	1.338750	1.803750	2.217500	2.692500
4	1.338750	1.803750	2.217500	2.692500
5	1.338750	1.803750	2.217500	2.692500
6	1.258425	1.695525	2.084450	2.530950
7	1.258425	1.695525	2.084450	2.530950
8	1.258425	1.695525	2.084450	2.530950
9	1.258425	1.695525	2.084450	2.530950
10	0.5355000	0.7215001	0.8870001	1.077000
11	0.2008125	0.2705625	0.3326250	0.4038751
12	0.2008125	0.2705625	0.3326250	0.4038751
13	0.2008125	0.2705625	0.3326250	0.4038751
14	0.2008125	0.2705625	0.3326250	0.4038751
15	0.2008125	0.2705625	0.3326250	0.4038751
16	0.2008125	0.2705625	0.3326250	0.4038751
17	0.2008125	0.2705625	0.3326250	0.4038751
18	0.2008125	0.2705625	0.3326250	0.4038751
19	0.2008125	0.2705625	0.3326250	0.4038751
20	6.6937499E-02	9.0187512E-02	0.1108750	0.1346250
21	6.6937499E-02	9.0187512E-02	0.1108750	0.1346250
22	6.6937499E-02	9.0187512E-02	0.1108750	0.1346250
23	6.6937499E-02	9.0187512E-02	0.1108750	0.1346250
24	6.6937499E-02	9.0187512E-02	0.1108750	0.1346250

25	0.5355000	0.7215001	0.8870001	1.077000

THE COST COEFFICIENTS ARE FOR 1990

1	1.331500	1.799500	2.210000	2.684000
2	1.331500	1.799500	2.210000	2.684000
3	1.331500	1.799500	2.210000	2.684000
4	1.331500	1.799500	2.210000	2.684000
5	1.331500	1.799500	2.210000	2.684000
6	1.251610	1.691530	2.077400	2.522960
7	1.251610	1.691530	2.077400	2.522960
8	1.251610	1.691530	2.077400	2.522960
9	1.251610	1.691530	2.077400	2.522960
10	0.5326000	0.7198001	0.8840000	1.073600
11	0.1997250	0.2699250	0.3315000	0.4026000
12	0.1997250	0.2699250	0.3315000	0.4026000
13	0.1997250	0.2699250	0.3315000	0.4026000
14	0.1997250	0.2699250	0.3315000	0.4026000
15	0.1997250	0.2699250	0.3315000	0.4026000
16	0.1997250	0.2699250	0.3315000	0.4026000
17	0.1997250	0.2699250	0.3315000	0.4026000
18	0.1997250	0.2699250	0.3315000	0.4026000
19	0.1997250	0.2699250	0.3315000	0.4026000
20	6.6575006E-02	8.9975007E-02	0.1105000	0.1342000
21	6.6575006E-02	8.9975007E-02	0.1105000	0.1342000
22	6.6575006E-02	8.9975007E-02	0.1105000	0.1342000
23	6.6575006E-02	8.9975007E-02	0.1105000	0.1342000
24	6.6575006E-02	8.9975007E-02	0.1105000	0.1342000
25	0.5326000	0.7198001	0.8840000	1.073600

THE COST COEFFICIENTS ARE FOR 1991

1	1.324250	1.795250	2.202500	2.675500
2	1.324250	1.795250	2.202500	2.675500
3	1.324250	1.795250	2.202500	2.675500
4	1.324250	1.795250	2.202500	2.675500
5	1.324250	1.795250	2.202500	2.675500
6	1.244795	1.687535	2.070350	2.514970
7	1.244795	1.687535	2.070350	2.514970
8	1.244795	1.687535	2.070350	2.514970
9	1.244795	1.687535	2.070350	2.514970
10	0.5297000	0.7181000	0.8810000	1.070200
11	0.1986375	0.2692875	0.3303750	0.4013250
12	0.1986375	0.2692875	0.3303750	0.4013250
13	0.1986375	0.2692875	0.3303750	0.4013250
14	0.1986375	0.2692875	0.3303750	0.4013250
15	0.1986375	0.2692875	0.3303750	0.4013250
16	0.1986375	0.2692875	0.3303750	0.4013250
17	0.1986375	0.2692875	0.3303750	0.4013250
18	0.1986375	0.2692875	0.3303750	0.4013250
19	0.1986375	0.2692875	0.3303750	0.4013250
20	6.6212498E-02	8.9762501E-02	0.1101250	0.1337750
21	6.6212498E-02	8.9762501E-02	0.1101250	0.1337750
22	6.6212498E-02	8.9762501E-02	0.1101250	0.1337750

23	6.6212498E-02	8.9762501E-02	0.1101250	0.1337750
24	6.6212498E-02	8.9762501E-02	0.1101250	0.1337750
25	0.5297000	0.7181000	0.8810000	1.070200

THE COST COEFFICIENTS ARE FOR 1992

1	1.317000	1.791000	2.195000	2.667000
2	1.317000	1.791000	2.195000	2.667000
3	1.317000	1.791000	2.195000	2.667000
4	1.317000	1.791000	2.195000	2.667000
5	1.317000	1.791000	2.195000	2.667000
6	1.237980	1.683540	2.063300	2.506980
7	1.237980	1.683540	2.063300	2.506980
8	1.237980	1.683540	2.063300	2.506980
9	1.237980	1.683540	2.063300	2.506980
10	0.5268000	0.7164001	0.8780001	1.066800
11	0.1975500	0.2686500	0.3292500	0.4000501
12	0.1975500	0.2686500	0.3292500	0.4000501
13	0.1975500	0.2686500	0.3292500	0.4000501
14	0.1975500	0.2686500	0.3292500	0.4000501
15	0.1975500	0.2686500	0.3292500	0.4000501
16	0.1975500	0.2686500	0.3292500	0.4000501
17	0.1975500	0.2686500	0.3292500	0.4000501
18	0.1975500	0.2686500	0.3292500	0.4000501
19	0.1975500	0.2686500	0.3292500	0.4000501
20	6.5850005E-02	8.9550011E-02	0.1097500	0.1333500
21	6.5850005E-02	8.9550011E-02	0.1097500	0.1333500
22	6.5850005E-02	8.9550011E-02	0.1097500	0.1333500
23	6.5850005E-02	8.9550011E-02	0.1097500	0.1333500
24	6.5850005E-02	8.9550011E-02	0.1097500	0.1333500
25	0.5268000	0.7164001	0.8780001	1.066800

THE COST COEFFICIENTS ARE FOR 1993

1	1.309750	1.786750	2.187500	2.658500
2	1.309750	1.786750	2.187500	2.658500
3	1.309750	1.786750	2.187500	2.658500
4	1.309750	1.786750	2.187500	2.658500
5	1.309750	1.786750	2.187500	2.658500
6	1.231165	1.679545	2.056250	2.498990
7	1.231165	1.679545	2.056250	2.498990
8	1.231165	1.679545	2.056250	2.498990
9	1.231165	1.679545	2.056250	2.498990
10	0.5239000	0.7147000	0.8750001	1.063400
11	0.1964625	0.2680125	0.3281251	0.3987750
12	0.1964625	0.2680125	0.3281251	0.3987750
13	0.1964625	0.2680125	0.3281251	0.3987750
14	0.1964625	0.2680125	0.3281251	0.3987750
15	0.1964625	0.2680125	0.3281251	0.3987750
16	0.1964625	0.2680125	0.3281251	0.3987750
17	0.1964625	0.2680125	0.3281251	0.3987750
18	0.1964625	0.2680125	0.3281251	0.3987750
19	0.1964625	0.2680125	0.3281251	0.3987750
20	6.5487504E-02	8.9337505E-02	0.1093750	0.1329250

21	6.5487504E-02	8.9337505E-02	0.1093750	0.1329250
22	6.5487504E-02	8.9337505E-02	0.1093750	0.1329250
23	6.5487504E-02	8.9337505E-02	0.1093750	0.1329250
24	6.5487504E-02	8.9337505E-02	0.1093750	0.1329250
25	0.5239000	0.7147000	0.8750001	1.063400

THE COST COEFFICIENTS ARE FOR 1994

1	1.272250	1.747500	2.148250	2.610750
2	1.272250	1.747500	2.148250	2.610750
3	1.272250	1.747500	2.148250	2.610750
4	1.272250	1.747500	2.148250	2.610750
5	1.272250	1.747500	2.148250	2.610750
6	1.195915	1.642650	2.019355	2.454105
7	1.195915	1.642650	2.019355	2.454105
8	1.195915	1.642650	2.019355	2.454105
9	1.195915	1.642650	2.019355	2.454105
10	0.5089000	0.6990001	0.8593001	1.044300
11	0.1908375	0.2621250	0.3222375	0.3916126
12	0.1908375	0.2621250	0.3222375	0.3916126
13	0.1908375	0.2621250	0.3222375	0.3916126
14	0.1908375	0.2621250	0.3222375	0.3916126
15	0.1908375	0.2621250	0.3222375	0.3916126
16	0.1908375	0.2621250	0.3222375	0.3916126
17	0.1908375	0.2621250	0.3222375	0.3916126
18	0.1908375	0.2621250	0.3222375	0.3916126
19	0.1908375	0.2621250	0.3222375	0.3916126
20	6.3612498E-02	8.7375008E-02	0.1074125	0.1305375
21	6.3612498E-02	8.7375008E-02	0.1074125	0.1305375
22	6.3612498E-02	8.7375008E-02	0.1074125	0.1305375
23	6.3612498E-02	8.7375008E-02	0.1074125	0.1305375
24	6.3612498E-02	8.7375008E-02	0.1074125	0.1305375
25	0.5089000	0.6990001	0.8593001	1.044300

THE COST COEFFICIENTS ARE FOR 1995

1	1.227500	1.704000	2.101500	2.554500
2	1.227500	1.704000	2.101500	2.554500
3	1.227500	1.704000	2.101500	2.554500
4	1.227500	1.704000	2.101500	2.554500
5	1.227500	1.704000	2.101500	2.554500
6	1.153850	1.601760	1.975410	2.401230
7	1.153850	1.601760	1.975410	2.401230
8	1.153850	1.601760	1.975410	2.401230
9	1.153850	1.601760	1.975410	2.401230
10	0.4910000	0.6816000	0.8406000	1.021800
11	0.1841250	0.2556000	0.3152250	0.3831750
12	0.1841250	0.2556000	0.3152250	0.3831750
13	0.1841250	0.2556000	0.3152250	0.3831750
14	0.1841250	0.2556000	0.3152250	0.3831750
15	0.1841250	0.2556000	0.3152250	0.3831750
16	0.1841250	0.2556000	0.3152250	0.3831750
17	0.1841250	0.2556000	0.3152250	0.3831750
18	0.1841250	0.2556000	0.3152250	0.3831750

19	0.1841250	0.2556000	0.3152250	0.3831750
20	6.1375003E-02	8.5200004E-02	0.1050750	0.1277250
21	6.1375003E-02	8.5200004E-02	0.1050750	0.1277250
22	6.1375003E-02	8.5200004E-02	0.1050750	0.1277250
23	6.1375003E-02	8.5200004E-02	0.1050750	0.1277250
24	6.1375003E-02	8.5200004E-02	0.1050750	0.1277250
25	0.4910000	0.6816000	0.8406000	1.021800

THE COST COEFFICIENTS ARE FOR 1996

1	1.190000	1.664750	2.062250	2.506750
2	1.190000	1.664750	2.062250	2.506750
3	1.190000	1.664750	2.062250	2.506750
4	1.190000	1.664750	2.062250	2.506750
5	1.190000	1.664750	2.062250	2.506750
6	1.118600	1.564865	1.938515	2.356345
7	1.118600	1.564865	1.938515	2.356345
8	1.118600	1.564865	1.938515	2.356345
9	1.118600	1.564865	1.938515	2.356345
10	0.4760000	0.6659000	0.8249001	1.002700
11	0.1785000	0.2497125	0.3093375	0.3760125
12	0.1785000	0.2497125	0.3093375	0.3760125
13	0.1785000	0.2497125	0.3093375	0.3760125
14	0.1785000	0.2497125	0.3093375	0.3760125
15	0.1785000	0.2497125	0.3093375	0.3760125
16	0.1785000	0.2497125	0.3093375	0.3760125
17	0.1785000	0.2497125	0.3093375	0.3760125
18	0.1785000	0.2497125	0.3093375	0.3760125
19	0.1785000	0.2497125	0.3093375	0.3760125
20	5.9499998E-02	8.3237499E-02	0.1031125	0.1253375
21	5.9499998E-02	8.3237499E-02	0.1031125	0.1253375
22	5.9499998E-02	8.3237499E-02	0.1031125	0.1253375
23	5.9499998E-02	8.3237499E-02	0.1031125	0.1253375
24	5.9499998E-02	8.3237499E-02	0.1031125	0.1253375
25	0.4760000	0.6659000	0.8249001	1.002700

THE COST COEFFICIENTS ARE FOR 1997

1	1.152500	1.625500	2.023000	2.459000
2	1.152500	1.625500	2.023000	2.459000
3	1.152500	1.625500	2.023000	2.459000
4	1.152500	1.625500	2.023000	2.459000
5	1.152500	1.625500	2.023000	2.459000
6	1.083350	1.527970	1.901620	2.311460
7	1.083350	1.527970	1.901620	2.311460
8	1.083350	1.527970	1.901620	2.311460
9	1.083350	1.527970	1.901620	2.311460
10	0.4610000	0.6502000	0.8092000	0.9836001
11	0.1728750	0.2438250	0.3034500	0.3688500
12	0.1728750	0.2438250	0.3034500	0.3688500
13	0.1728750	0.2438250	0.3034500	0.3688500
14	0.1728750	0.2438250	0.3034500	0.3688500
15	0.1728750	0.2438250	0.3034500	0.3688500
16	0.1728750	0.2438250	0.3034500	0.3688500

17	0.1728750	0.2438250	0.3034500	0.3688500
18	0.1728750	0.2438250	0.3034500	0.3688500
19	0.1728750	0.2438250	0.3034500	0.3688500
20	5.7625003E-02	8.1275001E-02	0.1011500	0.1229500
21	5.7625003E-02	8.1275001E-02	0.1011500	0.1229500
22	5.7625003E-02	8.1275001E-02	0.1011500	0.1229500
23	5.7625003E-02	8.1275001E-02	0.1011500	0.1229500
24	5.7625003E-02	8.1275001E-02	0.1011500	0.1229500
25	0.4610000	0.6502000	0.8092000	0.9836001

Sample Calculations of Attrition Coefficients for Units

(1) Year = 1988

(2) Assume Blue 4 = Best Tank

(3) Attrition Costs for Unit 10 (POMCUS) are:

Blue 4 = Unit Cost

= 2.701 - 1.0804

= 1.62

Blue 3 = Unit Cost + Tank Cost

= (2.225 - .89) + (1.0804 - .89)

= 1.335 + .19

= 1.53

Blue 2 = Unit Cost + Tank Cost

= (1.808 - .7232) + (1.0804 - .7232)

= 1.085 + .36

= 1.44

Blue 1 = Unit Cost + Tank Cost

= (1.346 - .5384) + (1.0804 - .5384)

= .8076 + .542

= 1.35

DATA SETS FOR FORTRAN PROGRAMS

UNIT.DAT

0	0	315	0	1.0	0.5	0.5	0
0	0	0	141	1.0	0.5	0.5	0
0	0	0	63	1.0	0.5	0.5	0
0	0	0	141	1.0	0.5	0.5	0
0	0	0	378	1.0	0.5	0.5	0
0	0	0	63	1.0	0.5	0.5	0
0	0	0	378	1.0	0.5	0.5	0
0	0	299	16	1.0	0.5	0.5	0
0	0	27	0	1.0	0.5	0.5	0
0	0	1779	0	.4	0.5	0.5	0
252	0	0	0	.15	0.5	0.5	0
94	0	0	0	.15	0.5	0.5	0
126	0	0	0	.15	0.5	0.5	0
252	0	0	0	.15	0.5	0.5	0
315	0	0	0	.15	0.5	0.5	0
189	0	0	0	.15	0.5	0.5	0
34	92	0	0	.15	0.5	0.5	0
0	63	0	0	.15	0.5	0.5	0
0	252	0	0	.15	0.5	0.5	0
189	0	0	0	.05	0.5	0.5	0
299	0	0	0	.05	0.5	0.5	0
1371	0	0	0	.05	0.5	0.5	0
63	0	0	0	.05	0.5	0.5	0
149	0	0	0	.05	0.5	0.5	0
0	2980	882	0	.4	0.5	0.5	0

YEAR.DAT

.80	.75	.70	.65	.60	.55	.45	.30	.20	.10
.20	.25	.30	.35	.40	.45	.50	.60	.65	.70
0.0	0.0	0.0	0.0	0.0	0.0	.05	.10	.15	.20

OATTRIT.DAT

1.45	1.26	0.80
1.90	1.85	1.25
2.40	2.20	1.76
2.83	2.62	2.05

DATTRIT.DAT

1.30	1.20	.74
1.75	1.63	1.00
2.11	2.01	1.48
2.64	2.51	1.85

LATTRIT.DAT

1.38	1.23	0.77
1.82	1.70	1.10
2.27	2.09	1.62
2.71	2.58	1.96

THREAT.DAT

.80
.20
0

EXAMPLE OF PROBLEM FORMULATION FOR LP83 PROGRAM

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..TITLE

  TANK ALLOCATION PROBLEM

..OBJECTIVE MINIMIZE

 * DEVIATION FROM COMBAT CAPABILITY
  0 X11 + 0 X12 + 0 X13 + 0 X14 + 0 X15 + 0 X16 + 0 X17 +
  0 X18 + 0 X19 + 1.61 X110 + 2.27 X111 + 2.27 X112 +
  2.27 X113 + 2.27 X114 + 2.27 X115 + 2.27 X116 + 2.27 X117
  + 2.27 X118 + 2.27 X119 + 2.54 X120 + 2.54 X121 +
  2.54 X122 + 2.54 X123 + 2.54 X124 + 1.61 X125 + 500 X126
  + .47 X21 + .47 X22 +.47 X23 + .47 X24 + .47 X25 + .47 X26
  + .47 X27 + .47 X28 +.47 X29 + 1.51 X210 + 1.94 X211 +
  1.94 X212 + 1.94 X213 + 1.94 X214 + 1.94 X215 + 1.94 X216
  + 1.94 X217 + 1.94 X218 + 1.94 X219 + 2.11 X220 +
  2.11 X221 + 2.11 X222  + 2.11 X223 + 2.11 X224 + 1.51 X225
  + 500 X226 + .88 X31 + .88 X32 + .88 X33 + .88 X34 +
  .88 X35 + .88 X36 + .88 X37 + .88 X38 + .88 X39 +
  1.43 X310 + 1.66 X311 + 1.66 X312 +   1.66 X313 +
  1.66 X314 + 1.66 X315 + 1.66 X316 + 1.66 X317 + 1.66 X318
  + 1.66 X319 + 1.75 X320 + 1.75 X321 + 1.75 X322 +
  1.75 X323 + 1.75 X324 + 1.43 X325 + 500 X326 + 1.35 X41 +
  1.35 X42 + 1.35 X43 + 1.35 X44 + 1.35 X45 + 1.35 X46 +
  1.35 X47 + 1.35 X48 + 1.35 X49 + 1.33 X410 + 1.33 X411 +
  1.33 X412 + 1.33 X413 + 1.33 X414 + 1.33 X415 + 1.33 X416
  + 1.33 X417 + 1.33 X418 + 1.33 X419 + 1.33 X420 +
  1.33 X421 + 1.33 X422 + 1.33 X423 + 1.33 X424 + 1.33 X425
  + 0 X426

 ..CONSTRAINTS

  * AMOUNT OF BLUE4 TANKS AVAILABLE
  S BLUE4: X41 + X42 + X43 + X44 + X45 + X46 + X47 + X48 +
           X49 + X410 + X411 + X412 + X413 + X414 + X415 +
           X416 + X417 + X418 + X419 + X420 + X421 + X422 +
           X423 + X424 + X425 + X426 = 5133

  * AMOUNT OF BLUE3 TANKS AVAILABLE
  S BLUE3: X31 + X32 + X33 + X34 + X35 + X36 + X37 + X38 +
           X39 + X310 + X311 + X312 + X313 + X314 + X315 +
           X316 + X317 + X318 + X319 + X320 + X321 + X322 +
           X323 + X324 + X325 + X326 = 3387

  * AMOUNT OF BLUE2 TANKS AVAILABLE
  S BLUE2: X21 + X22 + X23 + X24 + X25 + X26 + X27 + X28 +
           X29 + X210 + X211 + X212 + X213 + X214 + X215 +
           X216 + X217 + X218 + X219 + X220 + X221 + X222 +
```

```
          X223 + X224 + X225 + X226 = 2342

* AMOUNT OF BLUE1 TANKS AVAILABLE
S BLUE1: X11 + X12 + X13 + X14 + X15 + X16 + X17 + X18 +
         X19 + X110 + X111 + X112 + X113 + X114 + X115 +
         X116 + X117 + X118 + X119 + X120 + X121 + X122 +
         X123 + X124 + X125 + X126 = 700

* DEMAND OF UNIT 1
S DEM1: X41 + X31 + X21 + X11 = 315

* DEMAND OF UNIT 2
S DEM2: X42 + X32 + X22 + X12 = 141

* DEMAND OF UNIT 3
S DEM3: X43 + X33 + X23 + X13 = 63

* DEMAND OF UNIT 4
S DEM4: X44 + X34 + X24 + X14 = 141

* DEMAND OF UNIT5
S DEM5: X45 + X35 + X25 + X15 = 378

* DEMAND OF UNIT 6
S DEM6: X46 + X36 + X26 + X16 = 63

* DEMAND OF UNIT 7
S DEM7: X47 + X37 + X27 + X17 = 378

* DEMAND OF UNIT 8
S DEM8: X48 + X38 + X28 + X18 = 315

* DEMAND OF UNIT 9
S DEM9: X49 + X39 + X29 + X19 = 27

* DEMAND OF UNIT 10
S DEM10: X410 + X310 + X210 + X110 = 1779

* DEMAND OF UNIT 11
S DEM11: X411 + X311 + X211 + X111 = 252

* DEMAND OF UNIT 12
S DEM12: X412 + X312 + X212 + X112 = 94

* DEMAND OF UNIT 13
S DEM13: X413 + X313 + X213 + X113 = 126

* DEMAND OF UNIT 14
S DEM14: X414 + X314 + X214 + X114 = 252
```

```
* DEMAND OF UNIT 15
S DEM15: X415 + X315 + X215 + X115 = 315

* DEMAND OF UNIT 16
S DEM16: X416 + X316 + X216 + X116 = 189

* DEMAND OF UNIT 17
S DEM17: X417 + X317 + X217 + X117 = 126

* DEMAND OF UNIT 18
S DEM18: X418 + X318 + X218 + X118 = 63

* DEMAND OF UNIT 19
S DEM19: X419 + X319 + X219 + X119 = 252

* DEMAND OF UNIT 20
S DEM20: X420 + X320 + X220 + X120 = 189

* DEMAND OF UNIT 21
S DEM21: X421 + X321 + X221 + X121 = 299

* DEMAND OF UNIT 22
S DEM22: X422 + X322 + X222 + X122 = 1371

* DEMAND OF UNIT 23
S DEM23: X423 + X323 + X223 + X123 = 63

* DEMAND OF UNIT 24
S DEM24: X424 + X324 + X224 + X124 = 149

* DEMAND OF UNIT 25
S DEM25: X425 + X325 + X225 + X125 = 3862

* DEMAND OF UNIT 26 (DUMMY UNIT)
S DEM26: X426 + X326 + X226 + X126 = 360
```

RED FLEET COMPOSITION
(percent of fleet by year)

Weapon System	Year	1988	1989	1990	1991	1992
RED 1		.80	.75	.70	.65	.60
RED 2		.20	.25	.30	.35	.40
RED 3		.00	.00	.00	.00	.00

Weapon System	Year	1993	1994	1995	1996	1997
RED 1		.55	.45	.30	.20	.10
RED 2		.45	.50	.60	.65	.70
RED 3		.00	.05	.10	.15	.20

Blue Fleet Distribution Option 1
(Initial)

YEAR: 1987

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1		252	63		595.7911
2		141			254.9280
3		63			113.9040
4		141			254.9280
5		378			683.4240
6	63				84.79800
7	378				508.7880
8	315				423.9900
9	27				36.3420
10	504	960	315		1245.976
11			252		84.1050
12			94		31.3725
13	63	63			29.8053
14		252			68.3424
15	315				63.5985
16		189			51.2568
17	126				25.4394
18		63			17.0856
19		252			68.3424
20	189				12.7197
21		189	110		29.3231
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	3350	444	68		2185.26

TOTAL FLEET CAPABILITY.............................6976.06

Blue Fleet Distribution Option 1

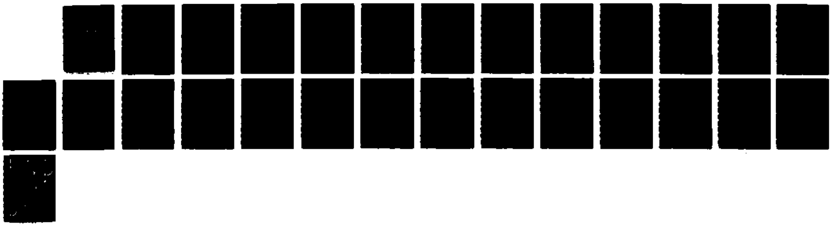
YEAR: 1988

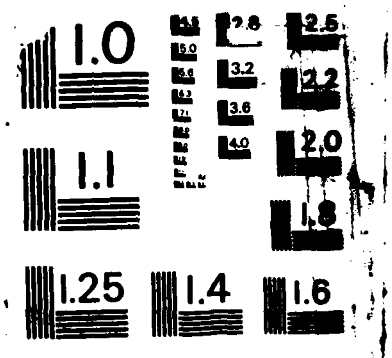
UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2			41	100	361.3250
3			63		140.1750
4			141		313.7250
5			378		841.0500
6			63		140.1750
7		237	141		742.2210
8		315			569.5200
9		27			48.8160
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2833	1029			2269.46

TOTAL FLEET CAPABILITY............................7890.271

AD-A180 227 A METHODOLOGY FOR AUTOMATION OF TANK ALLOCATION(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING W G ADAMS MAR 87 AFIT/GST/ENS/87M-1 2/2

UNCLASSIFIED F/G 15/6 NL





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Blue Fleet Distribution Option 1

YEAR: 1989

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4			125	16	321.3410
5			378		841.0500
6			63		140.1750
7			378		841.0500
8		192	123		620.8110
9		27			48.8160
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2473	1389			2335.99

TOTAL FLEET CAPABILITY.............................8164.03

Blue Fleet Distribution Option 1

YEAR: 1990

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4			6	136	378.4610
5			378		841.0500
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.07500
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2113	1608	141		2426.04

TOTAL FLEET CAPABILITY............................8402.52

Blue Fleet Distribution Option 1

YEAR: 1991

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5			263	115	895.7900
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1753	1608	501		2552.61

TOTAL FLEET CAPABILITY..............................8586.22

Blue Fleet Distribution Option 1

YEAR: 1992

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5			143	235	952.9100
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1393	1608	861		2679.19

TOTAL FLEET CAPABILITY............................8769.92

Blue Fleet Distribution Option 1

YEAR: 1993

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7			224	154	914.3541
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1033	1608	1221		2805.76

TOTAL FLEET CAPABILITY.............................9067.85

Blue Fleet Distribution Option 1

YEAR: 1994

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7				378	1020.978
8			179	136	765.6110
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	673	1608	1581		2932.34

TOTAL FLEET CAPABILITY..............................9365.79

Blue Fleet Distribution Option 1

YEAR: 1995

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			161	154	774.1790
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7				378	1020.978
8				315	850.8150
9				27	72.9270
10			1779		1583.310
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	313	3387	162		2762.18

TOTAL FLEET CAPABILITY............................9663.72

Blue Fleet Distribution Option 1

YEAR: 1996

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1				315	850.8150
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7				378	1020.978
8				315	850.8150
9				27	72.9270
10			1580	199	1621.200
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	205	47			54.1359
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25		3340	522		2880.07

TOTAL FLEET CAPABILITY.............................9899.40

Blue Fleet Distribution Option 1

YEAR: 1997

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1				315	850.8150
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7				378	1020.978
8				315	850.8150
9				27	72.9270
10			1220	559	1689.744
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	34	92			31.8150
18		63			17.0856
19		252			68.3424
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25		2980	882		2940.12

TOTAL FLEET CAPABILITY..........................10052.94

Blue Fleet Distribution Option 2

YEAR: 1988

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2			41	100	361.3250
3			63		140.1750
4			141		313.7250
5			378		841.0500
6			63		140.1750
7		237	141		742.2210
8		315			569.5200
9		27			48.8160
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2833	1029			2269.46

TOTAL FLEET CAPABILITY..........................7890.271

Blue Fleet Distribution Option 2

YEAR: 1989

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4			125	16	321.3410
5			378		841.0500
6			63		140.1750
7			378		841.0500
8		192	123		620.8110
9		27			48.8160
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2473	1389			2335.99

TOTAL FLEET CAPABILITY............................8164.03

Blue Fleet Distribution Option 2

YEAR: 1990

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4			6	136	378.4610
5			378		841.0500
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.07500
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	2113	1608	141		2426.04

TOTAL FLEET CAPABILITY.............................8402.52

Blue Fleet Distribution Option 2

YEAR: 1991

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5			263	115	895.7900
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1753	1608	501		2552.61

TOTAL FLEET CAPABILITY............................8586.22

Blue Fleet Distribution Option 2

YEAR: 1992

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5			143	235	952.9100
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1393	1608	861		2679.19

TOTAL FLEET CAPABILITY............................8769.92

Blue Fleet Distribution Option 2

YEAR: 1993

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5			23	355	1010.030
6			63		140.1750
7			378		841.0500
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	1033	1608	1221		2805.76

TOTAL FLEET CAPABILITY..............................8953.61

Blue Fleet Distribution Option 2

YEAR: 1994

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7			344	34	857.2340
8			315		700.8750
9			27		60.0750
10		1779			1286.573
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	673	1608	1581		2932.34

TOTAL FLEET CAPABILITY............................9137.31

Blue Fleet Distribution Option 2

YEAR: 1995

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7			224	154	914.3541
8			315		700.8750
9			27		60.0750
10			1779		1583.310
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	252				50.8788
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25	313	3387	162		2762.18

TOTAL FLEET CAPABILITY............................9321.00

Blue Fleet Distribution Option 2

YEAR: 1996

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7			104	274	971.4741
8			315		700.8750
9			27		60.0750
10			1779		1583.310
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	126				25.4394
18	63				12.7197
19	205	47			54.1359
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25		3340	522		2880.07

TOTAL FLEET CAPABILITY.............................9499.27

Blue Fleet Distribution Option 2

YEAR: 1997

UNIT	BLUE1	BLUE2	BLUE3	BLUE4	CAPABILITY
1			315		700.8750
2				141	380.8410
3				63	170.1630
4				141	380.8410
5				378	1020.978
6				63	170.1630
7				378	1020.978
8			299	16	708.4910
9			27		60.0750
10			1779		1583.310
11	252				50.8788
12	94				18.9786
13	126				25.4394
14	252				50.8788
15	315				63.5985
16	189				38.1591
17	34	92			31.8150
18		63			17.0856
19		252			68.3424
20	189				12.7197
21	299				20.1227
22	1371				92.2683
23	63				4.2399
24	149				10.0277
25		2980	882		2940.12

TOTAL FLEET CAPABILITY..............................9641.39

ATTRITION RATES

TABLE I

Offensive Attrition Rates

Blue 1 against Red 1 = 1.30
Blue 1 against Red 2 = 1.20
Blue 1 against Red 3 = 0.74

Blue 2 against Red 1 = 1.75
Blue 2 against Red 2 = 1.63
Blue 2 against Red 3 = 1.00

Blue 3 against Red 1 = 2.11
Blue 3 against Red 2 = 2.01
Blue 3 against Red 3 = 1.48

Blue 4 against Red 1 = 2.64
Blue 4 against Red 2 = 2.51
Blue 4 against Red 3 = 1.85

TABLE II

Defensive Attrition Rates

Blue 1 against Red 1 = 1.45
Blue 1 against Red 2 = 1.26
Blue 1 against Red 3 = 0.80

Blue 2 against Red 1 = 1.90
Blue 2 against Red 2 = 1.85
Blue 2 against Red 3 = 1.25

Blue 3 against Red 1 = 2.40
Blue 3 against Red 2 = 2.20
Blue 3 against Red 3 = 1.76

Blue 4 against Red 1 = 2.83
Blue 4 against Red 2 = 2.62
Blue 4 against Red 3 = 2.05

TABLE III

Delay Attrition Rates

Blue 1 against Red 1 = 1.38
Blue 1 against Red 2 = 1.23
Blue 1 against Red 3 = 0.77

Blue 2 against Red 1 = 1.82
Blue 2 against Red 2 = 1.70
Blue 2 against Red 3 = 1.10

Blue 3 against Red 1 = 2.27
Blue 3 against Red 2 = 2.09
Blue 3 against Red 3 = 1.62

Blue 4 against Red 1 = 2.71
Blue 4 against Red 2 = 2.58
Blue 4 against Red 3 = 1.96

Discount Factor Calculations

(1) Assume units available in 90 days have a negligible value of 0.05.

(2) exp(-90 * C) = 0.05

C = ln(0.05)/-90

= .0333

(3) a. Units 1 - 9 have t = 0

Z = exp(-.033 * 0) = 1

b. Units 10,25 have t = 30

Z = exp(-.033 * 30) = .40

c. Units 11 - 19 have t = 60

Z = exp(-.033 * 60) = .15

d. Units 20 - 24 have t = 90

Z = exp(-.033 * 90) = .05

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VITA

Captain William G. Adams was born on 14 January 1957 in Renton, Washington. He graduated from Renton High School in 1975, and received an appointment to the United States Military Academy at West Point. Upon graduation from West Point in June 1979, Captain was commissioned as an Armor officer. He was subsequently assigned to the First Armored Division in Ansbach, West Germany. Captain Adams has served as a tank platoon leader, scout platoon leader, tank company executive officer, and tank company commander. His military schooling includes the Armor Officer Basic Course, Airborne School, Ranger School, and the Armor Officer Advance Course. Upon his completion of the Armor Officer Advance Course at Fort Knox, Kentucky in July of 1985, Captain Adams entered the Air Force Institute of Technology at Wright-Patterson AFB, Ohio.

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