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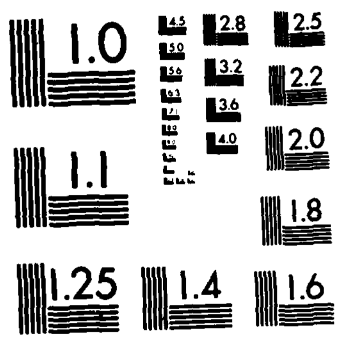
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Twelfth Annual

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Volume II

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P000 625	CONFORM/SPECIFOR.
P000 626	VGATES II.
P000 627	Force Analysis Simulation of Theater Administrative and Logistic Support (FASTALS).
P000 628	Generalized Engineer Estimating Routine and Tabulator of Requirements (GENERATOR) Project.
P000 629	Decision Analysis for XM578 APFSDS Cartridge Development Program.
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VOLUME II

Conceptual Design for the Army-in-the-Field Study, Phase III (CONAF-III)

Colonel John R. Brinkerhoff

US Army Concepts Analysis Agency

1. CONAF III - General

a. The Conceptual Design for the Army-in-the-Field Study, Phase III (CONAF III) is an annual mid-range Department of the Army force planning exercise designed to provide support for Army Staff development of the Program Objective Memorandum (POM). CONAF III is specifically designed to influence POM 76-80 and the FY 76 Army budget request. CONAF III will be accomplished by the US Army Concepts Analysis Agency during 1973. CONAF III is sponsored by the Assistant Chief of Staff for Force Development. Guidance and review are provided by a Study Advisory Group chaired by the ACSFOR which includes representatives of each Army staff agency.

b. This paper presents the objectives and mission of CONAF III, the CONAF III Methodology, and the substantive projects to be covered during CONAF III.

2. CONAF III - Objectives and Mission

a. The objectives of the CONAF III Study, as stated in the Department of the Army Study Directive and amended by the Study Advisory Group in April 1973, are as follows:

(1) Evaluate the 21 Army division forces to ascertain the best mix emphasizing employment in the European Theater.

(2) Develop and evaluate within approved resource constraints alternative designs for the Army's division forces which will accomplish forecasted Army tasks and missions for the period 1976 through 1986.

(3) Develop and evaluate resource levels and forces reflecting increments and decrements from approved projected levels.

b. Significant additional study guidance provided CAA by the Department of the Army includes the following:

(1) Assist the Army Staff in the development of POM 76-80.

(2) Achieve out-year forces by evolutionary development from existing organizations.

(3) Consider trade-offs among men, materiel, and R&D funds.

(4) Recommend priorities for development and procurement of major weapons systems.

(5) Evaluate impact of the "BIG FIVE" weapons systems on force effectiveness.

(6) Develop easy to understand indicators of force effectiveness.

(7) Insure model improvements are compatible with an eventual hierarchy of models.

(8) Use the period 1976 through 1986 for design and evaluation of forces.

c. Upon receipt of this guidance and the study objectives, CAA analyzed and restated its mission as follows:

> The mission of CONAF III is to provide study reports that will assist the Army staff in the development of POM 76-80. The objective is to maximize division forces' combat power in the mid-range time frame based on realistic projections of resource constraints, materiel available, and the international situation. In addition, CONAF III is interested in the timely integration of combat developments--new concepts and organizations--into the division forces.

d. The restated mission of CONAF III emphasizes that the primary task is to give assistance to the Army Staff in preparation of a valid Program Objective Memorandum to serve as the basis for FY 76 budget formulation. A secondary emphasis is on integration of new concepts and organizations into the Army through the budgetary process. Not all of the objectives of tasks outlined above for CONAF III can be accomplished during the study because of a time, resource, or state-of-the-art limitation. For example, it will not be possible to examine increments or decrements to the Approved Force during CONAF III. Similarly, it is unlikely that models presently available will allow effective determination of incremental benefits of the "BIG FIVE" weapons systems to the force structure. Despite these limitations, however, much work will be accomplished and has already been accomplished during CONAF III.

3. <u>CONAF Methodology</u>. The CONAF approach to mid-range force planning and development is a significant departure from previous approaches and deserves careful examination. In addition, powerful new tools and techniques are being developed in support of the CONAF Study. This section of the paper explains the CONAF approach step by step as a general methodology applicable to all CONAF studies. This section will also cover specific aspects of methodology to include the CAA Unit Data File, the CAA evaluation system, the costing technique, and the CONAF evaluation model (CEM).

4. <u>The CONAF Approach</u>

a. The CONAF approach is to start with the Approved Force; project the Approved Force through the period of interest making modernization and other changes in accordance with current decisions; then to define alternative force structures for selected years at equal cost; and evaluate the relative capabilities of the equal cost force alternatives. Finally, courses of action which would bring about an increased capability of alternate forces are made known to the decision maker for his consideration.

b. This general approach tnat CONAF espouses is a remarkable change from previous mid-range force planning exercises. The normal approach in the past has been to start with a threat and a strategy and establish from these an objective or required force structure. Subsequently, the objective force structure was never achieved in the budgeting and programing portions of the planning, programing, and budgeting system, thereby leaving a gap between requirements and capabilities which could not be audit-trailed or even well understood. This discontinuity has been recognized in the force development community for sometime, and the recognition of the problem led directly to the initiation by the Combat Developments Command in 1970 of the CONAF studies. The idea of CONAF, then as now, is to start planning from the real world and project to the future on a firm basis of known force structure, known resources, known technology, known costs and already approved courses of action. Transformation of the Approved Force into an objective force can, of course, be accomplished, possibly by incrementing the approved resource and force levels.

5. Detailed Methodology

a. The CONAF is accomplished in six basic steps:

(1) The start point for each annual CONAF study will be the force as defined at the end of the budget fiscal year in the President's budget force. This force is completely defined annually in the January Budget and Manpower Guidance in terms of units, resources, and costs. Detailed composition of the force is available from the DA Structure and Composition System (SACS).

(2) The force is projected through the end of the period of interest (in this case 74-86) and described at the end of each fiscal year in gross terms. In projecting the Approved Force, the effects of decisions already made as reflected in the President's budget are portrayed in the force. No new decisions are made. The intent is to see how the Army would be constituted as a result of decisions already made. During this step a "bow wave" may occur. A bow wave is an increase in costs due to the unforeseen consequences of current decisions. The effect of a bow wave is to increase program year costs above projected constraints. If a bow wave is discovered, this fact is transmitted to the Army Staff for additional guidance. Once decisions are made as to how to eliminate the portion of the program which exceeds costs and strengths, the force is adjusted until it meets those constraints.

(3) The force is adjusted to eliminate the bow wave, and the "true" force is projected for the mid-range period of interest. Combat modules

are defined at the end of each fiscal year. All units are defined for specific years throughout the period. For CONAF III the force will be defined in complete troop list detail at end FY 74, end FY 76, end FY 79, and end FY 86. The troop list at end FY 74 is given. The troop list is defined for end FY 76 because that is the target year for the CONAF III study to influence. End FY 79 is defined fully to provide a year in the middle of the period of interest to evaluate current procurement and budgetary decisions. End FY 79 is also the objective year for the JSOP FOREWON 1973 exercise which is being conducted simultaneously with CONAF III. End FY 86 is defined in detail to provide an insight into the effects of decisions made in the context of FY 79. We must be able to understand the out-year effects of mid-range decisions.

(4) Alternative equal cost forces are designed for critical mid-range points. For CONAF III these equal cost forces will be defined for end FY 79 and end FY 86.

(5) The equal cost forces are compared in terms of capability relative to the Approved Force which is used as a standard. Forces which deliver less capability than the Approved Force at equal cost are discarded. Forces which appear to deliver increased capability for equal cost are subjected to additional evaluation to determine how the increased capability can be obtained. Specifically, the idea is to determine what budgetary decisions need to be made in FY 76 to provide the increased capability in FY 79 and FY 86.

(6) Increments and decrements to resource levels and capabilities are established. The increments to the Approved Force in terms of resources and capability allow the Army's objective force to be constructed on the basis of the Approved Force. The resulting objective force is completely defined in terms of units, resources, and costs and can be achieved by adding specified packages of units to the Approved Force. Decrements to the Approved Force are useful in estimating the adverse impact of bulk unspecified reductions to the Army budget by either the Executive Branch or the Congress.

b. This is the general outline for all CONAF studies.

6. The Unit Data File

a. The Unit Data File (UDF) is a comprehensive data base within the Concepts Analysis Agency created for use within the CONAF studies. It includes a listing of all units in the Army approved program and new conceptual units devised by TRADOC. Essential characteristics or attributes of each unit are included in the automated data base. Some of these attributes are strengths, equipment, costs, capabilities, weights and cubes, and logistics support factors. The UDF allows the force designer to pick and choose the units he wishes to use in designing a particular force. It also allows a compilation of data useful to the evaluation of forces. The Unit Data File will include all Active, Army Reserve, National

Guard, and Army of the United States units in or projected for the Army total forces.

b. The evaluation system invented by CAA CONAF Evaluation Methodology for use in CONAF III integrates the functioning of several existing models into a coherent overall system. Figure 1 is a block diagram of the system developed by CAA for CONAF III.

(1) A force design is provided as the input to the overal ystem. The approved force is, of course, always included as an altern ive force design.

(2) The force design troop list is the input to a model k . as the Preliminary Force Designer—Strategic Allocation Model (PFD-SAM). The PFD-SAM is a group deployment model which allows Divisions, ISIs and SSIs to be deployed to the theater of interest by constrained airlift/sealift resources.

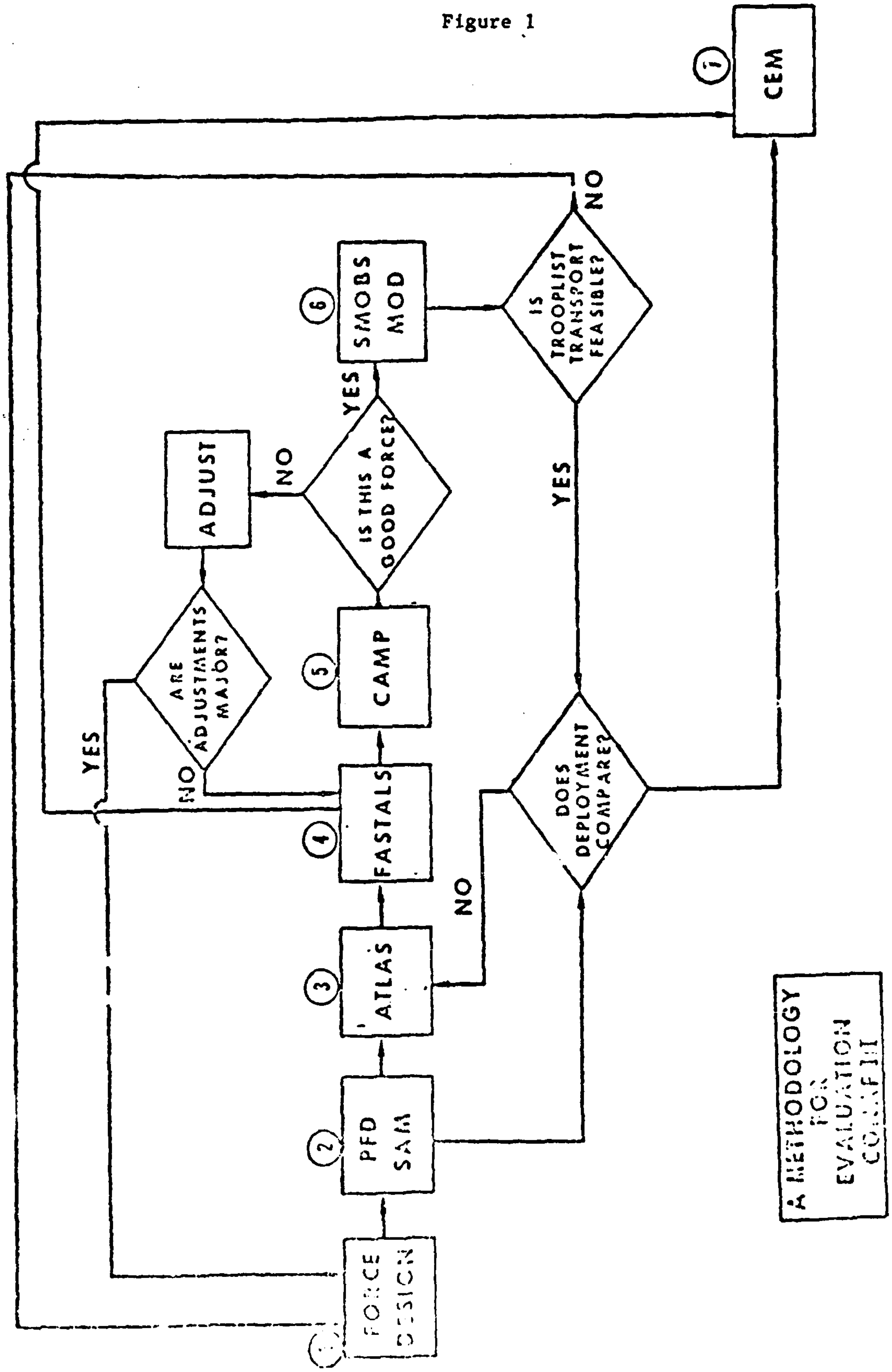
(3) The output of the PFD/SAM Model is the input to the ATLAS Model. The ATLAS is a theater-level combat simulation based upon firepower potential. The output of the ATLAS is used for evaluating the force and also provides the inputs to the FASTALS Model.

(4) The FASTALS Model for a given scenario and set of combat modules establishes the requirements for support modules (units). The output from the FASTALS Model is a troop list of all units in a force. This establishes the "requirements."

(5) The requirements troop list produced by the ATLAS-FASTALS phase of the system are then compared with the available units in the CAMP Model, and the overages and shortages are noted. After going through the CAMP routine, the force is evaluated by asking, "Is this a good force?" A good force is defined as one which meets manpower constraints, cost constraints, and is "balanced" (properly supported administratively and logistically). If the force does not pass this test to be a "good force," the troop list is sent back for adjustments. If the adjustments are minor, they may be made on the spot and, in this event, the force will return to the FASTALS Model after a few unit changes are made. If the adjustments are major or cannot be accommodated by the designer easily, the entire force is sent back to the force designer for a complete redesign, such as substituting support modules for combat modules. The procedure is repeated until a good force is obtained.

(6) Once a good force is obtained, it is sent to the SMOBSMOD, which deploys each unit individually to the theater of interest in accordance with a time-phased deployment list. The next question to be asked is whether the troop list is feasible from the standpoint of strategic mobility. If troop list transport is not feasible, once again the force designer is asked to redo his force until it can be deployed. If the troop list can be deployed by projected airlift/sealift resources, the

Figure 1



FORCE DESIGN
2
PFD SAM
3
ATLAS
4
FASTALS
5
CAMP
6
SMOBS MOD
7
CEM
ADJUST
ARE ADJUSTMENTS MAJOR?
IS THIS A GOOD FORCE?
IS TROOPLIST TRANSPORT FEASIBLE?
DOES DEPLOYMENT COMPARE?
YES
NO
A METHODOLOGY FOR EVALUATION

detailed deployment is compared with the rough deployment brought about by the PFD-SAM. If the two deployment schedules do not agree, another war game must be run in the ATLAS to reconfirm the results of the detailed deployment module.

(7) Once the troop list is declared deployable and discrepancies between the two deployment modules are reconciled, the force is available as the input to the CONAF Evaluation Model. An additional set of inputs to the CONAF Evaluation Model is obtained directly from the FASTALS Model; these are the logistics policies and factors which determine, for example, resupply rates in the CEM. This overall methodology assures that the forces are feasible in terms of deployability, cost, and other resource constraints.

7. Costing Methodology. A primary interest in CONAF is to employ a costing methodology which is simple, accurate, and easy for the force designer to use. The CONAF costing methodology is to apply to each unit in the Army the direct costs in the OMA, MPA, and PEMA appropriations. Other costs are prorated if necessary, and indirect costs are noted. Indirects costs are reflected in the total Army force structure with the unit which accomplishes the indirect function or mission, thus the unit costs employed in CONAF do not represent the total cost of having a unit but only those costs which are directly involved in placing the unit in the force structure. In order to facilitate this concept, operating and MPA costs for each unit are obtained from the Office of Comptroller of the Army. With respect to PEMA, a unit is charged with the cost of new equipment only. The sunk costs of the inherited inventory are omitted. Each unit having a new piece of equipment is treated as a variation of the fundamental unit type and has its own distinctive cost. The budget is charged with the total obligational authority in the year in which the money is obligated. This, of course, precedes the actual introduction of the item of equipment into the force by the appropriate funded delivery period or lead time. Costs for CONAF III are in constant 1974 dollars undiscounted. Forces costs are simply the sum of included unit costs under this methodology.

8. CONAF Evaluation Model

a. The CONAF Evaluation Model (CEM) is a theater-level combat simulation which was created by General Research Corporation (GRC) in connection with earlier CONAF studies. It is the primary, although not the only, evaluation tool to be used in CONAF III. It is very similar to the ATLAS theater level combat simulation in that it is based on firepower potential and force ratios of relative firepower potential to determine rates of FEBA movement. However, it also includes additional features of combat at the brigade/regimental level, decision routines at brigade, division, and corps level, and an extensive logistics sub-model. These improvements allow discrimination among various tactics and provide a means to evaluate residual unit state during or at the end of the battle. The CEM is currently in its third version and has been undergoing sensitivity analysis since July. It is completely documented, and plans are underway to convert the CEM to the CAA computer starting in January 1974. The idea would be to employ CEM operationally in CAA while simultaneously experimenting with the model in its GRC version.

b. CONAF methodology is a judicious blend of old and new ideas and tools. It is an attempt to apply the systems approach to the design and evaluation of Army forces. While the primary production of CONAF III is not intended to be an improved methodology, certainly any improvements in methodology will bear fruit in later years. Accordingly, considerable effort is being expended to improve the logic, the data, and the integration of the various facets of force development into a coherent whole.

9. CONAF III Substantive Project

a. CONAF III is devoted to the examination of the US Army under the "NATO First" Scenario specified in the Defense Program and Planning Guidance. Essentially the "NATO First" Scenario envisages a defense by NATO forces against a conventional Warsaw Pact in the mid-range time frame. The scope of the CONAF III study includes all of the 21 DFE in the Approved Force structure. This study has been divided into three phases:

(1) Phase 1. Data definition, 15 Jan 73-7 Aug 73.

(2) Phase 2. Evaluation of the Approved Force, 8 Aug-19 Oct 73.

(3) Phase 3. Evaluation of alternative forces, 20 Oct 73-1 Mar 74.

b. Phase 1 is devoted to defining the Approved Force for the period of interest. Starting with the end FY 74 force structure, the major combat units and combat modules are projected for the end of each fiscal year through the end of FY 86. The entire troop list is defined for end FY 76, 79, and 86. The approach taken in this phase is to determine what the Army is currently programed to be as a consequence of decisions already made. The Concepts Analysis Agency, during this phase, will not make judgments or decisions unless it is found that the Department of the Army has not already decided upon a particular matter. The force will be modernized in accordance with currently planned procurement schedules for equipment under development or procurement. Known program changes in troop units will be made in the force. At the same time a definitive investigation will be made of all currently approved factors, assumptions, and policies which operate within the framework of the "NATO First" Scenario, and a base case will be established to serve as the foundation for evaluation during Phase 2. The products of Phase 1 will be a General Situation Report in which all data pertinent to the base case scenario will be published, and a Force Data Book which will describe quantitatively the approved Army force structure.

c. Phase 2 is the evaluation of the capability of the Approved Force to execute the base case "NATO First" Scenario. Phase 2 builds on and incorporates the results of Phase 1. The technique of Phase 2 is to create semi-independent study groups to pursue seven separate but related problems associated with the capability of the Approved Force. These seven projects are: Warfighting; Warsaw Pact tank threat; barriers; echelons above division; logistical support; ammunition supply; and readiness and deployment.

(1) Evaluation of the warfighting capability of the Approved Force is fundamental. All other studies contribute to this evaluation. Warfighting capability is the measure of the success of the opposing forces in battle as opposed to other measures of overall worth such as deterrent value or political considerations. Warfighting capability will be evaluated using both the ATLAS theater level simulation and the CONAF Evaluation Model. In addition, subjective judgmental evaluation will be accomplished by members of the study team.

(2) A major aspect of the Soviet threat is the reported overwhelming preponderance of Soviet tanks. A study group will attempt to evaluate the capability of the Approved Force to counter this threat. Subsequently, an effort will be made to devise better ways of countering the Soviet threat. Laying out this problem from a capabilities viewpoint, we believe, will provide useful insights into the overall problem.

(3) Although barriers are widely recognized as being valuable adjuncts to the land forces, the exact value of barriers is a matter of some controversy. The barrier study group will define current doctrine and capability for barrier construction and attempt to determine how this barrier construction influences the course of the battle. Subsidiary studies will determine how barriers are currently simulated in combat modules and how this simulation can be made more realistic. This study is being accomplished in cooperation with the Engineer Strategic Studies Group. What we are after in the barrier study is essentially some insights into how much barriers contribute to the warfighting outcome.

(4) Doctrine for organization of the Army-in-the-Field in the echelons above division has recently been changed to eliminate the field army as a logistical and administrative headquarters. The functions formerly performed by the field army and corps are to be combined into the corps. This change necessitates evaluation of the impact of the new concept on the Army force structure. Allocation rules for units formerly assigned to the field army will have to be revised, and the distribution of units among theater army and corps will have to be accomplished. The proper numbers of Army corps needs to be determined. This work in CONAF is not intended to provide doctrine for the new echelons above division organization but to provide a conceptual framework for the development of such doctrine by TRADOC.

(5) The logistics study group will examine the capability of the Approved Force to support the included combat modules under the conditions of the base case scenario. This study is expected to provide insights as to what policy changes would be advantageous to the Army in either assuring adequate logistics support for the existing Approved Force or subsequently improving the combat worth of the division forces.

(6) Ammunition is particularly important to the combat worth of the force. The ammunition project involves comparison of ammunition consumption requirements with ammunition consumption capability. The expected expenditure of ammunition (EEA) used in combat simulation models will be compared with the ammunition procured, distributed, and made available for firing. If capability is not in balance with requirements, methods of adjusting the system to eliminate the discrepancy will be determined.

(7) The final substudy is concerned with the evaluation of the readiness of the Approved Force to meet the projected deployment schedules for Army units. Also included will be consideration of M-day stationing for active and Reserve Components units. Readiness standards and objectives will be investigated to see if they are realistic and reasonable. Methods for improving readiness of division force units will be considered

d. The seven substudies described briefly above constitute the heart of Phase 2. Of course, as we proceed in Phase 1 and Phase 2, other problems of equal importance may arise, and we would hope to study them as they occur to us. Some of the value of Phase 2 may be the discovery of quite obvious errors which have simply never been noticed before.

e. Phase 3 will involve the design at equal cost of alternative force structures for the base case "NATO First" Scenario. One or more of the alternative designs may in one respect or another provide increased capability at equal cost. When this occurs, we will investigate that situatio to determine the decisions needed to be taken now to provide the improved capability at a future date. The exact nature of the force alternatives has not yet been determined; however, at this time we believe it would be worthwhile to investigate tank-heavy force and an attack helicopter heavy force and compare them with the currently approved force. The results of Phase 3 are intended to provide a vehicle for the incorporation of new concepts and of new organizations into the Army force structure.

10. Summary

a. The purpose of CONAF III is to provide study reports of value to the Army Staff in the preparation of the Program Objective Memorandum for 1976. To the extent that the CONAF effort is successful, and we believe it is going to be successful, the Army will have at hand the answers to these kinds of questions:

(1) How many divisions should the Army have?

(2) What is the proper mix of divisions in the Army?

(3) How many main battle tanks should the Army buy?

(4) What is the value of an air cavalry combat brigade?

(5) What is the proper deployment schedule under the NATO First Scenario?

(6) What is the proper role of cavalry?

(7) What is the impact of changing logistical policies on the force effectiveness:

b. CONAF III is designed to provide analytical support to the Army Staff in coming to grips with the fundamental problem of force development --determining the right numbers and types of units to be in the Army.

AD P000625

CONFORM/SPECIFOR

Mr. Richard H. Gramann
General Research Corporation

INTRODUCTION

This paper has a twofold purpose: first, it describes the recently developed constrained force model, CONFORM, currently operational and in use at the United States Army Management System Support Agency for structuring theater forces for the outyears. The model is designed to enable the force planner to establish troop lists with TOE units within constrained troop levels while minimizing any support shortfalls that occur.

The second purpose is to describe briefly the current effort in the SPECIFOR project at GRC. SPECIFOR stands for Specification for Improved Force Structuring Models. The purpose is to apply to the structuring of peacetime Army forces the same optimizing technique so that the near-time or the current peacetime forces can be structured for wartime requirements and yet satisfy the many peacetime constraints.

CONFORM—Background

The support force planner seeks that level of support sufficient to satisfy all requirements generated within a theater of operations. He plans for enough medical and engineer units, for example, so that all casualties would be quickly returned to duty or properly treated and the required construction would be performed on time. The support planner has at his disposal an increasing number of innovative techniques to assist him in his planning tasks. In recent years computerized procedures that generate or roundout a total troop list from a specified combat force mix have been developed. The numbers of support units, often accounting for more than half the theater troop strength, are determined using allocation rules established by support specialists from each Army branch. These allocation rules are derived from estimated workloads generated within the theater, the existence of other units in the force and other theater structure parameters. These support units are allocated so as to match the set of capabilities of the support forces to the set of requirements generated by the total theater force. The number of unit allocation factors for all support categories often exceeds five thousand for a single theater force, making the support allocation process a large and complicated task. It is further complicated because each time a support unit is added to the force, further requirements for additional support are generated. The computerization of this roundout process, with the chain of demand support relations, is one of the innovative tools now available to the support planner. Two models recently developed to perform this task are the Modular Force Planning System (Battalion Slice) and the Force Analysis Simulation of the Theater Administrative and Logistic Support (FASTALS) models.

The Battalion Slice utilizes the input-output concept from economics to roundout the support force while FASTALS cycles through the allocation procedure until all requirements are satisfied and a balanced troop list is obtained. Battalion Slice provides an average or "steady state" troop list; FASTALS time-phases the introduction of support forces and distributes them geographically within the theater. Both models incorporate the allocation rules established by the support force specialists. For a specified scenario and theater and a given set of combat units, the force planner can obtain a troop list complete with all required support units with either model. The force planner is assured that all allocation rules are satisfied and that no support category will be deficient relative to the stated requirements.

Problem Areas

While the development of these two models has greatly advanced the state-of-the-art in support force planning, problems still remain for the force planner. When he is faced with the need to consider resource constraints, authorized troop ceilings and possible support shortfalls, his difficulties come sharply into focus. When the troop list must conform to an authorized troop ceiling, when tradeoffs of selected support units for additional combat units must be made, when the combat-to-support ratio must be altered, and when the allocation rules need re-examination, then the force planner needs more computerized assistance. With the requirement-oriented roundout models he has no assurance he has the least costly troop list, nor does he know where efficient adjustments can be made to improve the troop list.

In support force analysis and planning, when constraints must be satisfied, the force planner must do the best he can to satisfy the various support needs while not violating any of the imposed constraints. Tradeoffs are sought in initial planning that delete some units from the alternative troop lists and possibly exchange others in order that the constraints can be satisfied. The selection of the units in this substitution process is made among the various combinations of units until the most efficient or "cost effective" mix of elements is attained. The problem at this stage is to avoid trial and error methods, i.e., the trying of a number of changes to find the one that yields the best results. The constrained optimization approach using linear programming is a natural tool for performing this search. This approach enables the force planner to adjust the mix of support units in such a way that the total support shortfalls are minimized and the imposed constraints are satisfied. This approach led to the development of CONFORM.

Goal Programming

Goal programming, a key feature of the CONFORM, is a special type of linear programming. Although the term goal is sometimes used in place of the term constraint there should be a distinction made between the two terms. Goals refer to the planners desires while constraints refer to conditions imposed on the planner.

In ordinary linear programming only one goal is represented in the objective function to be maximized or minimized. For example, the desire or goal might be to maximize combat potential or to minimize total force strength. If there are multiple goals, then the goals not incorporated into the objective function are treated as constraints of the problem. The solution is then selected from the set of all solutions that satisfy the constraints and maximizes or minimizes the objective function.

In goal programming, multiple goals can be incorporated into the objective function. Further, each goal is related to a target value that is judged satisfactory by the planner. In CONFORM the deviations from these target values are minimized. The flexibility of goal programming allows the planner to treat multiple goals even when these goals may be conflicting and hence cannot all be fully satisfied. By setting targets for the planners goals, and minimizing the deviation from these targets, the difference (shortfall) between the resulting value of a given goal and its target value may be considered itself a measure of performance in satisfying the requirements.

CONFORM takes as input all the support allocation rules of the A and B matrices of the Battalion Slice model. The A matrix is an array of factors or coefficients relating the direct support needs of all the combat units in the troop list. The B matrix consists of the allocation factors relating the support units to support needs of the support units themselves. (Included in this latter array are coefficients for the so-called dummy units that serve as a convenient means for the generation of support units that are dependent on other force characteristics such as population, maintenance equivalents, cargo movement, POL consumption, hospital beds, etc.) These allocation rules are either fixed coefficients which usually do not change from run to run, e.g., "one battalion headquarters per four companies," or they are parametrically derived from planner inputs, workload estimates or other environment data.

The Battalion Slice model computes the first order support requirements, then the second order support requirements after the first order support has been added, then the third order support requirements, etc. This calculation is truncated after a sufficient number of iterations insures that no significant amount of support is still required. A complete listing is then printed that includes the name, SRC and quantity of each unit in the theater force. A troop list of this kind, along with the related A and B matrices, is then supplied to CONFORM.

The matrix generator of CONFORM processes the data of the A and B matrices into a format suitable for use in a linear program. It has been shown that the support roundout process can be made equivalent to a linear program. CONFORM then makes a calibration run that reproduces exactly the original troop list.

With the completion of a successful calibration run, the model user is confident that all inputs are verified and consistent. A calibration run is successful if the troop list produced by CONFORM is identical unit-by-unit to the original troop list. The user then can proceed to modify this original troop list employing the various options and features of CONFORM.

Model Options and Features

CONFORM has been designed to give the force planner assistance in a variety of force planning problem areas. These areas include the design of peculiar combat force mixes with various constraints on the support force; modifying combat or support mix ratios; reducing troop strength efficiently; examining allocation rules; performing equal cost tradeoffs; minimizing support shortfalls that occur when imposed constraints are satisfied. In these and other applications of CONFORM, the user selects a combination of the model options for the particular purpose at hand. This option selection in simplest terms reduces to the choice of constraints and the selection of an objective function to be used in a particular run of CONFORM.

Constraints

The choices of all possible constraints available to the use of CONFORM are too numerous for a single exhaustive listing. Since there are usually five to six hundred different types of units in a typical troop list, a constraint could conceivably be placed on any combination of these units, their strengths, their costs (or other indicators), various aggregates and mixes, or their allocation rules. The following three lists of words approximately described the variety of constraints.

CONSTRAINT SELECTION

ALL	SUPPORT	
TOTAL	NOTIONAL	COST(S)
SELECTED	COMBAT	ALLOCATION RULES(S)
MIX OF	AGGREGATE	TYPE(S)
EVERY	UNIT	STRENGTH(S)
	FORCE	INDEX(S)

To use this list, a selection is made in sequence from each column and the resulting phrase describes in words a candidate constraint. Examples are: Total force strength may be reduced; total force cost may be held fixed; selected aggregate costs may be constrained (e.g., the total annual operating cost for all medical units cannot exceed X million dollars); mix of combat types may be preserved (e.g., the ratio of armor to infantry units must equal 3 to 1); mix of support strengths may be increased (e.g., the ratio of medical personnel to overall force strength could be increased by 5 percent). Many special constraints are created using "Selected Unit Type." Any single unit type of the force may be augmented, reduced in number, bounded, or completely deleted. And further optional units may be added that are not brought into the force through the normal allocation process.

The combinations of constraints are almost unlimited and as the user gains more experience with CONFORM, he will become more adept at selecting innovative and useful combinations to suit his needs.

Objective Functions

In mathematical programming any combination of allowable values for the variables that causes none of the constraints to be violated constitutes a feasible solution. To pass from a feasible to an optimal solution, that feasible combination is sought that optimizes (minimizes or maximizes) the objective function.

In CONFORM the objective function can be selected using the same list of words above preceded by the word minimize or maximize. Examples are: minimize total force strength; maximize selected combat indices (e.g., maximize the total antitank firepower score of the force); maximize total combat strength.

One additional type of objective function is available in CONFORM and contributes to one of the key aspects of the model. This is the minimization of deviations from some established targets or stated requirements. Whenever the user allows tolerances on any or all of the support allocation rules so that the various constraints can be satisfied, he may set the tolerance at a specified level (i.e., 20 percent) and then minimize the overall deviation from the original support requirements given by the allocation rules. The objective function, in this case, is chosen to minimize support deviations. The result would be an alternative force whose overall support shortfalls (deviations) were minimized and no single allocation rule violated more than the specified tolerance. The deviations or shortfalls that are minimized in the objective function also may be weighted to produce a priority listing of support requirements to be satisfied. Natural weighting factors, for example, are the strengths of the units. With strengths as weighting factors, the above objective function becomes the minimization of total support strength deviations.

This special type objective function can also be used with combat units as well as support units. If a requirement has been set for the combat units (as is usually the case in a support roundout problem) but the user allows deviations from these combat requirements, then target values for the combat units are set and the objective function becomes to minimize combat unit (strength) deviations (shortfalls).

Model Input Description

Troop List—Capability Indices. Figure 1 is a schematic of the model. A proposed troop list with each unit's strength along with the allocation rules for the support units is processed into the proper format for the initial calibration run. Any desired capability indices are assigned to reflect the unit's capability in various functional areas. An index of combat potential, both antitank and antipersonnel, is assigned to the combat units. A recent study at the Engineer Strategic Study Group (ESSG) has developed combat unit capability measures for mobility, intelligence, and command and control.

Whenever force changes are made and the combat mix is altered these indices reflect the capability of the new force in these particular combat functional areas. Such capability indices can also be used in

CONFORM

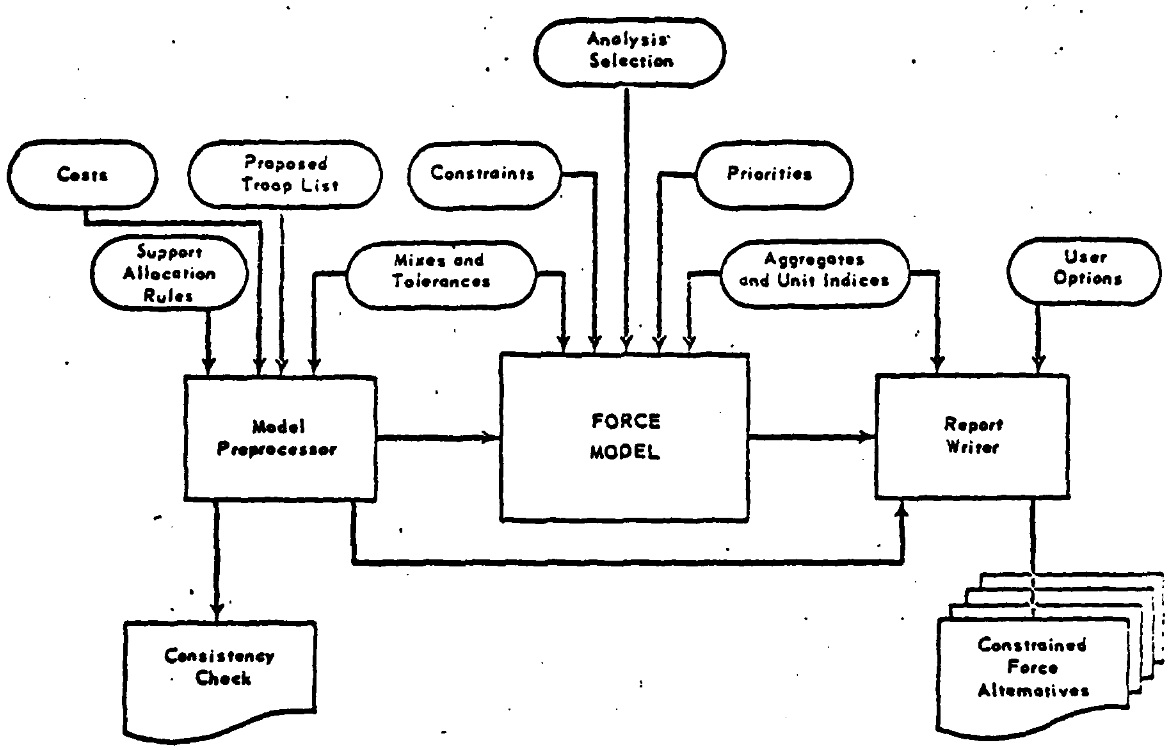


Fig. 1—Constrained Force Model

For use in force planning and analysis in:

- Developing or Designing constrained force alternatives
- Minimizing combat effectiveness indicator shortfalls
- Modifying or preserving combat or support mix/ratios
- Reducing efficiently force troop strengths
- Minimizing support shortfalls
- Adjusting or Adding tolerance to allocation rules
- Analyzing forcewide implications of combat or support changes
- Investigating trade-offs in combat/support ratio changes
- Performing equal cost trade-offs
- Studying changes in size of Division Force Equivalent

force design to obtain a force whose specifications are stated in terms of these capability indices. Whenever support capability indices are established for the various support categories, those too can then be used by CONFORM in developing alternative force structures whose specifications are described in terms of the support capabilities.

Cost Data. The interface with the Force Cost Information System (FCIS), formerly the Cost Analysis System (COSTALS), assigns costs to each of the units. These costs can be selected as any linear combination of PEMA, OMA and MPA, initial investment or annual operating costs.

Mixes, Aggregates, and Groups. The mix of combat units in the new alternative force may be specified as well as the mix of any support units. In many of the demonstration runs with CONFORM the combat strength was allowed to increase but in the same mix or proportion as the original troop list. The user may specify any mix of units to be preserved.

In examining the results of a force transformation, it is convenient for the user to see at a glance the changes brought about in various aggregates of units. All the support units in the same functional category are aggregated and presented in the summary report so that the user can quickly note the changes. There are 20 such support categories including medical, civil affairs, engineers, etc. The user may also create any other aggregates that he desires. Not only do those aggregates give the user quick information about force changes, but also they can be used to control the formulation of the new alternative force. In the constraint section above, one of the options is to constrain selected aggregate types. After the user specifies the aggregates he desires, he may treat these aggregates as single entities just as any other unit in the force.

A further option is to specify a relationship between two groups of units. For example, the strength of the group of all support units may be related to the strength of the group of all combat units thus specifying the combat-to-support ratio.

Allocation Rule Tolerance. The user may specify a tolerance on selected individual allocation coefficients for any support unit. If there is uncertainty in any of the allocation coefficients, this uncertainty can be reflected by allowing the coefficient to vary an appropriate percentage amount.

Deviations (Shortfalls and Longfalls). As discussed above in the section on the objective function, a special feature of the model is to minimize deviations from stated requirements. To set up this objective function the user must specify the type deviation (a force or requirements shortfall) to be minimized. A force shortfall (or longfall) is the difference between the value of a force characteristic (e.g., medical strength) in one troop list versus that in the alternative troop list. A requirements shortfall is the quantity of a given unit not present to satisfy the stated number required of that unit, e.g., if the allocation rules state that 36 combat engineer battalions are required and only 30 appear in the alternative troop list, there is a requirement shortfall of six units.

Report Writer Options. Seven reports are available with CONFORM. These include the Force Summary Report, Peacetime Cost and Strength Summary Report, Troop List, Unit Deviation Report, Unit Support Report, and Unit Allocation Report. The user may specify which of the reports he desires for each run of CONFORM. These reports are discussed in the next section.

Model Output Description

The needed end product for the force planner is a complete theater troop list. CONFORM produces this list in two different formats. The first is the same format as received from the Bn Slice model. The second is a listing of the units with their strengths along with the marginal values of each unit. In the calibration run these marginal values correspond to the support slices of each unit. The Bn Slice model produces these values for each combat unit. CONFORM produces the values for support units as well. The marginal values in the calibration run are useful since they reflect the incremental change in total force strength with the addition or deletion of each unit, i.e., the strength of the unit itself plus its support slice.

Since the general purpose of CONFORM is to produce constrained alternative forces that meet the specification of the planner, a Summary Report is also produced that describes the main characteristics of the alternative force. This summary report gives the total force strength and cost, total combat and support strength and cost, and the strength and cost of each of the 20 support categories. It also reports the force shortfalls and longfalls of all support categories, and the requirement shortfalls and longfalls of all support categories. The combat unit indicators are also recorded. The force planner thus has an overview of the entire force and sees where the principal resources are allocated.

Another summary report is produced that lists the peacetime costs, both initial investment and annual operating, of the entire force with a breakout of each of the 32 budget line items. A second cost summary page displays the present value of the initial investment plus 10 years operating cost. The undiscounted value along with the discounted value at various rates is presented.

A Unit Deviation Report is produced that displays the force deviations and requirements deviations of each unit in the alternative troop list. Whenever shortfalls occur in producing an alternative force, they are displayed in this report in terms of strength and unit types. Any requirement shortfalls reported can serve as risk indicators for the particular alternative force, i.e., it is a signal to the planner that some requirements are not being met.

The two final reports are related to the allocation process. The Unit Allocation Report lists each supporting unit of the force and beside it all those units in the force to which it is allocated. The allocation factor is given for each of these supported units so the model user can examine in detail how each support unit is allocated. Also reported in the unit allocation report of the calibration run is the effect on the total force strength of a 10 percent change in each of the allocation coefficients.

The Unit Support Report lists each unit in the force followed by the list of supporting units that are allocated directly to that unit. These support allocation reports provide visibility of the support planning process so that the force planner can better perform this allocation task. The reports provide the vehicle to improved allocation procedures.

Example of Use of CONFORM

The user's test that was performed at USAMSSA after the model was transferred, consisted of six computer runs as shown in Fig. 2. These runs were designed to exercise the model, demonstrate that it was fully operational on the Army's computer, provide illustrations of model output that highlighted the support allocation process, and display the impact on the support force when constraints were imposed.

The first one served as a base case, a 15-division force for the European theater. Run number 2 increased the number of each combat unit by 15 percent and allowed the normal roundout to occur unconstrained. Run number 3 then set a total force strength equal to that of the base case, allowing no allocation rule to be violated by more than 20 percent and minimized the support shortfalls that occurred. This is an example of a tradeoff where 15 percent more combat units are obtained and the support strength is reduced to keep the total force strength the same and the support shortfalls are minimized to 3 percent.

In run number 3 many of the required headquarters units were deleted so in run number 4 a new constraint was added setting the headquarters shortfall variable equal to zero. This means the tolerance on the allocation rules for just headquarters was changed to zero instead of 20 percent as with the other support units.

Run number 5, instead of being an equal strength tradeoff as was run number 3, was an equal cost tradeoff. That is, the total force cost was set equal to the base case.

The final run, number 6, leaves the combat units as in the base case, imposes a constraint on the total strength so that the DFE is reduced from 60,000 to 48,000 men. A constraint was also imposed on the number of engineers in the alternative troop list.

For each of these computer runs, a complete troop list was produced with a detailed list of all changes and shortfalls. Figure 3 summarizes the results of the six computer runs.

SPECIFOR

The Battalion Slice/CONFORM structuring system deals with the outyear wartime required theater forces with TOE units. The structuring process for the peacetime budget and budget plus one year force is separated from the outyear structuring process. The outyear planning tends to simplify the resource quantity and phasing problems of force transition while the in-year force accounting and management tends to ignore longer range impacts on the objective forces. SPECIFOR, Specifications for Improved Force Structure models smooths the discontinuity between peacetime and wartime force structuring.

Project SPECIFOR is developing a system that relates the structure, i.e., the allocation rule interrelationships, that are now present in the outyear force structuring models to the current force in the Force Accounting System (FAS). The FAS contains records for more than 8000 Army units in the current Active, National Guard and Reserve Components. A large number of these units are TDA and MTOE units rather than standard TOE units as used in the outyear planned forces.

At the present time there exist no allocation rules for those "on the ground" units analogous to the allocation rules for the TOE units in the wartime objective force. In short, there is no way to make changes systematically in the current force and determine the impact of these changes on the total force structure.

The basic problem in the near-time structuring of forces is to develop a force in detail, i.e., unit-by-unit level, which agrees with the gross force (division level) of the Form 1, a guidance memorandum issued by the Assistant Vice Chief of Staff Army. This detailed force must meet the various "fences" or constraints embodied on the Form 1. These are mainly manpower constraints of various kinds for division forces. The first step is to select an initial force which already has the detail that is desired. That force is obtained from the Force Accounting System in the form of a large computer printout. It is first checked by hand against various backup documents for errors. The force is then checked against a list of OSD controlled units to make sure these are included. If not, adjustments are made in the force.

The planned modernization of units are included next in the force. This consists of earmarking the conversion of a unit to more advanced equipment or possibly the inactivation of an old unit and activation of a new unit.

Next, the support units are examined for their adequacy in providing support to the force. This is done on an exception basis in which the selected initial force from the FAS is left unchanged, except in those cases where there is some reason to change it. These reasons include: differences of the force with respect to a standardized objective force, the need to satisfy the Form 1, and the recommendations of the force structuring proponents of each support category such as the medics and the engineers.

CONFORM
Constrained Force Model

USER'S TEST

RUN NO.	DESCRIPTION
1.	• Base Case: 15 Divisions; European Theater
2.	• 15% Increase in Combat Units • Unconstrained
3.	• 15% Increase in Combat Units • Total Force Strength = Base Case • 20% Tolerance on Support Allocation • Minimize Support Requirement Shortfalls
4.	Same as 3 Except • Set Hq Req. Shortfalls = Zero
5.	Same as 3 Except • Set Total Force Cost = Base Case
6.	Same as 4 Except • Reduce DFE from 60K to 48K • Engineers Constrained

Fig. 2

CONFORM
Constrained Force Model

Summary of USER's TEST RESULTS

RUN NO.	1	2	3	4	5	6
STRENGTH						
Combat	251,180	285,533	285,533	285,533	285,533	251,180
Support	653,014	737,180	618,661	618,661	616,368	468,820
Total	904,194	1,022,713	904,194	904,194	901,901	720,000
C/S Ratio	.385	.387	.462	.462	.463	.536
DFE	60,280	68,181	60,280	60,280	60,127	48,000
COST ($ mil)	9,366	10,604	9,433	9,443	9,366	7,553
SUPPORT SHORTFALLS						
Requirement	—	—	−19,775 (3%)	−43,896 (6.6%)	−21,711 (3.4%)	−14,738 (3%)
Force	—	+84,166 (12.9%)	−34,353 (5.3%)	−34,353 (5.3%)	−36,646 (5.6%)	−184,149 (28.2%)

Fig. 3

This structured force is next processed and updated with all the changes, and further error checks are made.

The aspects missing from this structuring process is an additional orientation to objective forces, an objective force, for example, with the combat units and rounded out with the support units in an unconstrained manner, with the support units that each support proponent says are required to be there, i.e., using allocation rules established by support proponents. Such a roundout for wartime objective force is currently performed by the models, FASTALS and the Battalion Slice. The allocation rules in these models have been established by the support proponents. The same structuring detail is needed for the budget and budget plus one year force. By creating a system for current forces using accepted support allocation rules, a balanced force structure can be generated.

Finally, the troop lists generated from such a system will be alternative forces designed for wartime requirements but structured so as to satisfy the many peacetime constraints.

AD P000626

VGATES II

Mr. W. Ivan Keller
General Research Corporation

VGATES II is a combat simulation model developed by the General Research Corporation. The model evaluates the performance of general purpose forces including US ground, tac air and naval forces together with similar forces from allied free world countries.

Time

Time is represented linearly day-by-day in VGATES II. Up to 220 days are available for a total conflict and this time may be subdivided into reporting periods as desired. A typical time structure is 180 days of combat divided into six 30-day periods and preceded by mobilization periods for RED and BLUE. Mobilization times are specified separately (i.e., may be different) for RED and BLUE.

Forces

Up to 15 BLUE force types may be represented, including land forces (usually notionalized division force equivalents), tac air forces (numbers of equivalent aircraft), naval forces (attack submarines, escorts, carriers (CVSG), VP squadrons, etc.) and mobility forces (notional airlift and notional sealift types).

A specified RED threat opposes the BLUE forces in the model. Up to 10 RED force types may be represented, similar to the BLUE, with the exception that RED does not employ mobility forces.

Force deployments of any size and type may occur on any specified day after mobilization (M-day). All forces are considered to be at the FEBA, or ready for combat on the day of deployment, except BLUE forces which are moved by the lift system. US forces deployed (or made available for deployment) at the CONUS will be moved to the FEBA by the lift system if and when sufficient mobility forces are available.

Mobility forces may be composed of airlift and/or sealift capacity with notional vehicle capacities for each type. A pool of available lift capacity for each lift type is maintained and depleted as forces from CONUS are deployed to the FEBA. Scheduling for deployment functions (loading, trip, unloading, return trip and movement to the FEBA) is depicted in Fig. 1. Each lift type requires two scheduling parameters: (1) the trip time, represented by X_1 in Fig. 1, which includes loading time and the one-way trip time, and (2) the time to the FEBA, represented by X_2 in Fig. 1, which includes unloading time and the time required to move the force from the port to the FEBA. The lift forces are assumed to be available for another deployment after $2X_1$ days (round trip time), when the appropriate pool is augmented. The US

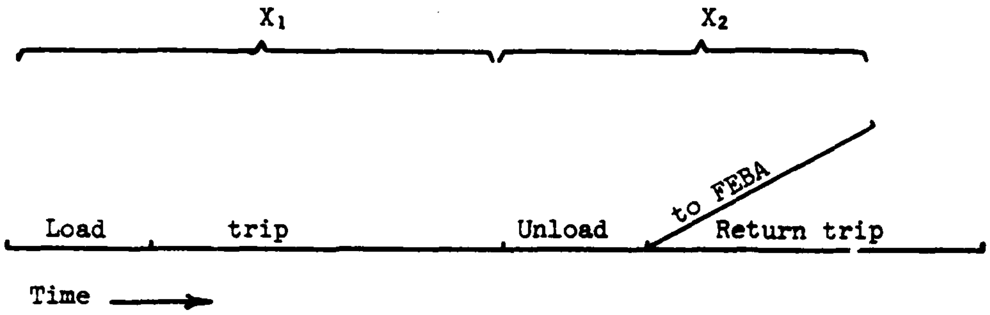


Fig. 1 -- Deployment Scheduling

ONUS forces deployed by lift are assumed to be available at the FEBA fter $X_1 + X_2$ days from the day of deployment. Attrition of mobility orces as discussed below, consumes both lift and division resources.

orce Attrition

A typical model structure for RED and BLUE forces is shown in Fig. 2. Each arrow in the diagram represents a unique time dependent attrition relationship in the model. Casualties caused by attrition are computed by the formula

BCAS(I) = B(I)*R(J)*RAB(J,I)*F(I)

where (for example:

BCAS(I) is the casualties to BLUE force I caused by Red Force J.

B(I) is the strength of BLUE force I.

R(J) is the strength of RED force J.

RAB(J,I) is a distribution factor, and

F(I) is the time dependent attrition factor for BLUE force I.

A similar formula is computed for each pair of RED/BLUE and BLUE/RED forces which interact according to the force interaction diagram (Fig. 2). These computations are repeated daily from the beginning of the conflict (D-day).

The distribution factor, RAB(J,I), in the above formula, modifies the attrition to account for the relative contributions of other RED forces which may also attrit BLUE I. Fig. 3 shows for example that 80 percent of the casualties to RED tac air are caused by BLUE tac air and the remaining 20 percent by BLUE land forces. The factor RAB accounts for this relative distribution.

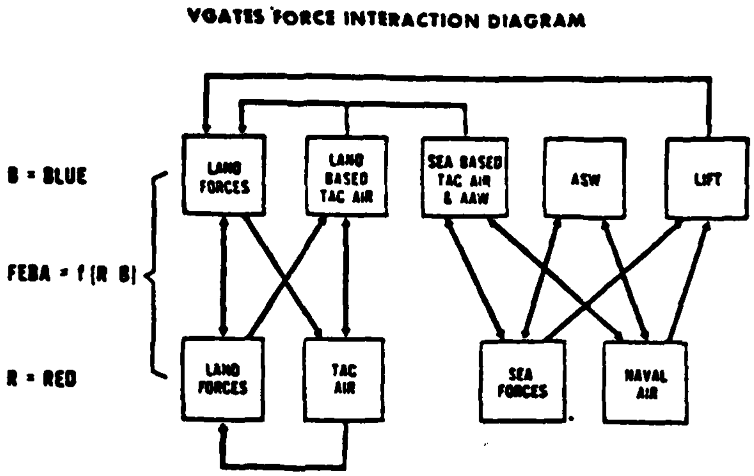


Fig. 2 -- Example VGATES II Force Interaction Diagram

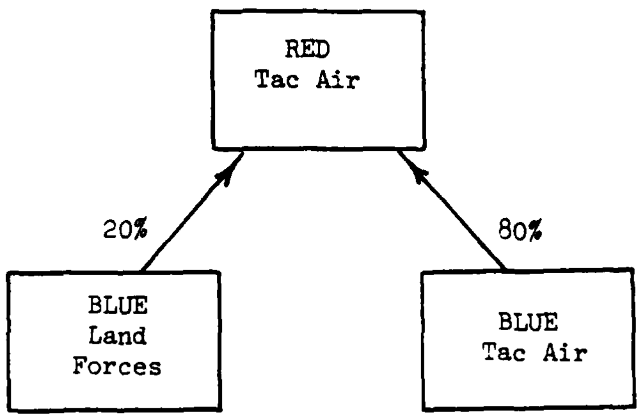


Fig. 3 -- Example Distribution of Attrition Among Opposing Forces

Force Ratio

Each force has a combat weighting factor, comparable in most cases with a normalized firepower score. At the end of each combat day after deployments and casualties are accounted for, a total combat weight is computed for each side. The strength of each force multiplied by its combat weight (which may be zero) is summed for RED and for BLUE separately. Then the force ratio, RED divided by BLUE, is computed. This force ratio drives the movement of the expected FEBA in VGATES.

Probability Functions

In the current VGATES II model probability functions may be used to represent the location of the FEBA relative to specified defense lines. The probability of holding a defense line is computed from a function such as the one depicted in Fig. 4.

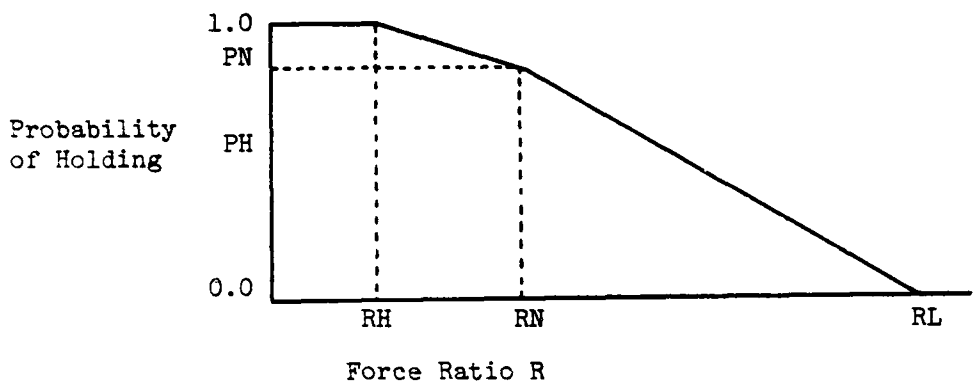


Fig. 4 -- Defense Line Holding Probability Function

In this example the ordinate PH represents the probability of holding the defense line while the abscissa R is the force ratio (RED/BLUE). RH is the force ratio at which BLUE is certain to hold the line; RN is the nominal holding ratio associated with PN, the nominal holding probability; and RL is the ratio at which BLUE is certain to lose the defense line. A probability PH(I,t) for holding is determined by such a function for each defense line I at time t. The probability of being <u>on</u> defense line I at time t may then be computed by:

$$PB(I,t) = PH(I,t)*PB(I,t-1) + (1-PH(I-1,t))*PB(I-1,t)$$

In words PB(I,t) is the probability of being on defense line I and holding, plus the probability of being on defense line I-1 and not holding.

If the distance from some reference point (BLUE rear) to defense line I is D(I), then the location of the expected FEBA E(t) may be computed by:

$$E(t) = D(1)*PB(1,t) + D(2)*PB(2,t) + \ldots + D(N)*PB(N,t).$$

Note that using this formulation precludes any forward movement of the FEBA for the BLUE forces--i.e., BLUE can only hold or withdraw, they cannot attack and regain lost ground. The VGATES II model has been applied to current Army studies in which BLUE forces are always smaller than the opposing RED threat. Of course, a simple modification in the computation of PB(I,t) above and additional probability data for advancing would allow forward FEBA movements.

Calibration

Force attrition rates described above are derived through a calibration process in which the day-by-day force levels and casualties are made to match precisely with observed results taken from other models or other studies. Naval attrition may be based on Navy studies such as NARAC-G; air attrition may come from Air Force studies and ground attrition from Army studies and/or models.

Figure 5 shows a sample input data set which specifies both the force levels and the FEBA locations for six time periods. The line numbered 086 shows the relative FEBA locations, including the initial location of 100. Lines 087 through 092 specify the strengths of both BLUE and RED forces at the end of each of six time periods. Each line specifies one force type with the prefix 10 or 0 indicating a BLUE type and the prefix 5 indicating a RED type.

```
086 100. 89. 70. 57. 49. 36. 25.
087 10 6    30    46    46    46    49    49
088  0 8    57    56    56    55    54    53
089  014    24    23    23    22    21    21
090  0 4  1653   864   424   240   115    69
091  5 3  2302  1185   538   290   115    56
092  5 4    36    34    28    24    20    17
```

Fig. 5—Example Set of FEBA Observations/
Force Observations

Calibration of the attrition rates is done automatically by VGATES II based on the observations just described. Through an iterative convergence algorithm, attrition rates are selected which produce precisely the observed strength and associated casualty levels. The FEBA report may also be calibrated automatically. This is accomplished by solving a system of linear equations for a set of FEBA transformation factors which are used in place of the D(I) in the computation of the expected FEBA.

VGATES II Output

VGATES output includes a force strength report, a force casualty report and a time phased FEBA location report.

Figure 6 shows a sample force strength report at 30-day intervals. The RED and BLUE combat weights and the force ratio are reported as well.

Figure 7 shows a sample force casualty report also at 30-day intervals.

Figure 8 shows a sample FEBA movement report. Note that all of these reports may be produced as often as every day for the combat period beginning at D-day or day 0.

Figure 8 also shows an example of a probability report which is useful when the FEBA has not been calibrated automatically as described above.

Operating Statistics

The VGATES II model has been exercised at the Army Concepts Analysis Agency (CAA) in a user test in which combat in both the NATO and the NEA theaters have been simulated. Calibration data came from the Navy NARAC-G study for the naval campaign and from FOREWON 72 exercise data for the tac air, land and mobility forces as well as the FEBA movement.

VGATES II is an interactive quick response model. It executes a complete 180 simulation in about 10 seconds wall time on the Army UNIVAC 1108 computer at CAA. A full calibration run takes less than one minute CPU time. Written in FORTRAN, VGATES II occupies about 20,000 words of core storage.

```
METOFOR   NATO I,II,III                              •••UNCLASSIFIED•••

III•C•6                    NATO  METOFOR TEST  JUN 73
DAY  FORCE   ••••••••STARTING  STRENGTH••••••••   SUM            RATIO
                     1       2      3      4      5      WTD.STR
                      6       7      8      9      10
                       11      12     13     14     15

  0   BLUE         .00     6.00   30.282804.00     .00 SB=424.56    .00
                882.02      .00  285.50     .00   1.72
                 57.20      .00     .00  138.00
       RED       47.00  23.003540.00  134.00       .00 SR=377.92424.56
                   .00
 30   BLUE         .00    12.23   30.561818.50     .00 SB=   3.20   1.59
                818.25      .00  215.51     .00   1.72
                 57.20      .00     .00   46.42
       RED       77.00  23.002170.21  101.78       .00 SR=   5.10
                   .00
 60   BLUE         .00    13.27   30.56  892.77    .00 SB=   3.17   1.67
                826.48      .00  212.73     .00   1.72
                 57.20      .00     .00   44.86
       RED       77.00  29.001078.75   81.69       .00 SR=   5.29
                   .00
 90   BLUE         .00    13.27   30.56  438.52    .00 SB=   3.11   1.70
                818.67      .00  209.77     .00   1.72
                 57.20      .00     .00   43.21
       RED       77.00    29.00  421.31   66.50    .00 SR=   5.27
                   .00
120   BLUE         .00    15.58   30.56  274.05    .00 SB=   3.31   1.59
                793.41      .00  209.76     .00   1.72
                 57.20      .00     .00   41.45
       RED       77.00    29.00  221.64   53.11    .00 SR=   5.27
                   .00
150   BLUE         .00    18.70   30.56  193.94    .00 SB=   3.61   1.46
                822.08      .00  206.35     .00   1.72
                 57.20      .00     .00   41.44
       RED       77.00    29.00  134.97   42.82    .00 SR=   5.26
                   .00
180   BLUE         .00    20.94   30.56  102.18    .00 SB=   3.83   1.38
                822.08      .00  206.34     .00   1.72
                 57.20      .00     .00   39.42
       RED       77.00    29.00   59.26   33.99    .00 SR=   5.26
                   .00
```

Fig. 6 -- Sample VGATES II Strength Report

```
DAY   FORCE            CUMULATIVE CASUALTIES OF FORCE
                       1          2          3          4          5
                       6          7          8          9         10
                      11         12         13         14         15

 30
         BLUE        .00        .00        .001438.50           .00
                   27.14        .00    69.99        .00         .00
                     .00        .00      .00      91.58
          RED        .00        .001399.79        32.22         .00
                     .00
 60
         BLUE        .00        .00        .002403.23           .00
                   32.57        .00    72.77        .00         .00
                     .00        .00      .00      93.14
          RED        .00        .002521.25        52.31         .00
                     .00
 90
         BLUE        .00        .00        .002896.48           .00
                   32.57        .00    75.73        .00         .00
                     .00        .00      .00      94.79
          RED        .00        .003208.69        67.50         .00
                     .00
120
         BLUE        .00        .00        .003099.95           .00
                   34.34        .00    75.74        .00         .00
                     .00        .00      .00      96.55
          RED        .00        .003438.36        80.89         .00
                     .00
150
         BLUE        .00        .00        .003219.06           .00
                   38.96        .00    79.15        .00         .00
                     .00        .00      .00      96.56
          RED        .00        .003555.03        91.18         .00
                     .00
180
         BLUE        .00        .00        .003349.82           .00
                   38.96        .00    79.16        .00         .00
                     .00        .00      .00      98.58
          RED        .00        .003660.73       100.01         .00
                     .00
```

Fig. 7 -- Sample VGATES II Casualty Report

VGATES Output

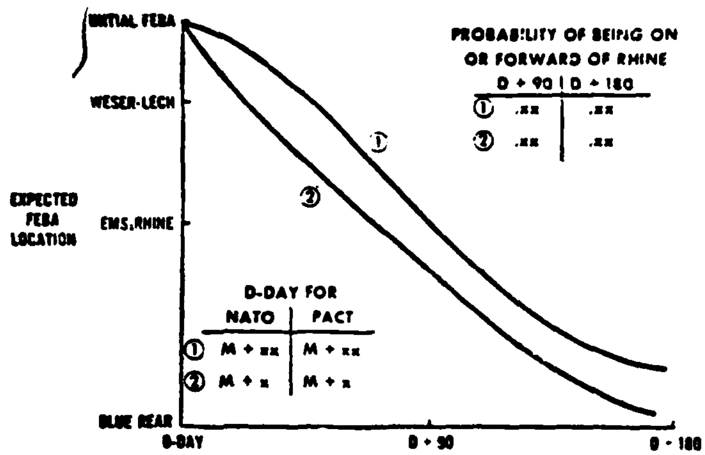


Fig. 8 -- Example FEBA Plot with Probabilities

Force Analysis Simulation of Theater Adimistrative and Logistic Support (FASTALS)

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1. Introduction

a. Purpose. The purpose of the Force Analysis Simulation of Theater Administrative and Logistic Support (FASTALS) Model is to compute the combat service support requirements that are associated with a hypothesized military operation. Ultimately the output from the model is a balanced and time-phased troop list of units which have been geographically distributed in a theater of operations. This troop list identifies all the combat, nondivisional combat, and support to combat units employed in a single theater of operations to accomplish a projected mission.

b. Support to Combat Unit Requirements. The support to combat units are those which are required to provide the logistic and administrative support of the tactical operations. It is the task of FASTALS to develop geographic and time-phased support to combat unit requirements for postulated deployments in a theater of operations. The major elements of support are maintenance, construction, supply, transportation, storage, troop hospitalization, and troop replacement. Requirements for units which serve these functions are derived from the workloads these units must perform. These workloads are determined in FASTALS as a function of the combat force deployment, theater environmental conditions, and the tactical operations plan as detailed by the scenario input to the system.

c. Balanced Troop List. A troop list including all three types of units is said to be balanced when the individual units that comprise the list are capable of accomplishing the various workloads generated by the total force.

d. Time-Phasing of Troop Lists. Time-phasing of troop lists means that for each time period in the simulation a complete troop list is computed. Unit arrivals in the theater can then be determined by analyzing the troop lists; for a given type of unit, the differences in the numbers required in successive time periods represent the new arrivals in the theater.

e. Technical Information. The proponent for the FASTALS Model is the Office of the Assistant Chief of Staff for Force Development. The model runs on a UNIVAC 1108 computer. It uses 47,000 bits or core storage and averages 3.5 minutes of computer time per run. Run initiation to printout delivery usually takes about 60 minutes. Storage of programs and data base is on disks with a 9-track tape backup. Remote terminals are used for the majority of data base updates and program executions.

2. Input

a. Combat Simulation Data. The FASTALS Model uses the results of a combat simulation as the starting point for the roundout process. The combat results may be developed from a manual combat simulation and input to FASTALS on cards, or the combat data may be input on a tape which is created by processing the results of A Tactical, Logistical and Air Simulation (ATLAS) run. Combat data required for the FASTALS simulation include identification of all combat units to include strength, location, and unit identification number; the deployment schedule of these units; the location of units within the theater; the intensity of tactical activity of each unit by day expressed as intense, normal, reduced, or reserve; and the location of the forward edge of the battle area (FEBA) each day. These data define the basic support parameters of the combat units.

b. Theater of Operations. In order to simulate a theater of operations with FASTALS, the user must provide data which defines the theater geographically and the organizational echelons that are in existence by time period.

(1) The geographical aspects of the theater are defined by sectors and physical regions.

(a) A sector is a portion of the theater that contains a unique axis of logistic activity. Thus, each sector is considered as an independent area of logistic activity with support units allocated on this premise. This means that a unit assigned to one sector cannot use any excess capability to fulfill the requirements of an adjacent sector. Thus, the number of sectors in a theater can have a significant impact on the number of support forces required for a given combat situation.

(b) A physical region is a unique geographical segment of one or more sectors. It serves as a basis for locating the position of the objects and activities such as FEBA movements and location of prepositioned supplies and equipment within the theater. If a physical region spans more than one sector, it is called a common physical region. Common physical regions denote areas located in the support axis of more than one sector. Essentially, common physical regions merge two or more independent sectors into a single sector. Common physical regions are usually used to represent this base echelon in a theater. The maximum number of physical regions is currently 20.

(2) Logical regions (LRs) correspond to the echelons of the Army structure (LR 1 = Division, LR 2 = Corps, LR 3 = Field Army, LR 4 = COMMZ Forward, LR 5 = COMMZ Rear, and LR 6 = Offshore Base). The geographical positions of each echelon in the theater of operations in

any time period is specified by superimposing the applicable logical region over the specified physical region. One logical region may encompass one or more physical regions. However, no more than one logical region may be placed in a physical region.

(3) The location of physical region boundaries is affected primarily by two factors: First, physical regions can be controlled by only one of the opposing forces. Therefore, the FEBA cannot be positioned in the middle of a physical region with the implied dual control of the region. Thus, depth of physical regions determines the resolution of the FEBA. Second, the FASTALS Model simulates the theater transportation activity by tracking the movement of units and supplies between regions. Intra-regional movement is not addressed by the model. Thus, the transportation network is governed by the number of physical regions designated within the theater. The desirable features of a large number of physical regions with the resulting high FEBA resolution must be weighed carefully against the increased amount of input data necesssary to define the transporation network. Generally, the depth considered adequate for a region is that distance required to accommodate an Army criterion such as corps or division. The physical regions are usually centered around main supply depots/logistic centers; thus, when the main supply depot is lost, the entire physical region is considered to be under enemy control.

c. Prepositioned Equipment. Since the unit deployment weight has a significant impact on the transportation workload, all unit equipment that is prepositioned in the theater is input into FASTALS. This equipment, expressed in tons, is located by physical region, and, to be more specific, is located in the geographic area to which the units will deploy rather than in the area where the equipment may be actually stored. Therefore, when a unit is to be deployed the model will search the physical regions currently included in the appropriate echelon. Available prepositioned equipment will be credited against the unit deployment weight, thereby reducing the unit equipment workload placed on transportation units.

d. Theater War Reserve Stocks. Prepositioned supplies, i.e., theater war reserve stocks, are also input to the model. These supplies are located by physical region and are positioned in the same geographical area as where they are actually stored. The supplies are utilized in a similar manner as prepositioned equipment in that prepositioned supplies will be used before the requirement for supplies from offshore bases is generated.

e. Engineer Support Requirements. Construction requirements computed in FASTALS are essentially those performed by the engineer construction battalion. This unit is responsible primarily for COMMZ construction requirements; however, the model methodology will allow certain engineer tasks in the combat zone to be assigned to the construction battalion.

(1) It is recognized that existing facilities within a theater will be used wherever feasible, thereby reducing some engineer effort. These existing facilities are input to the FASTALS Model as construction assets in each physical region. A total of twelve categories, such as refrigerated storage, troop camps, POL storage, etc., are identified. The assets are expressed in terms of workload unit, i.e., short tons for storage assets and fixed beds for hospitals.

(2) There are a total of 23 engineer tasks and associated workloads. The model computes the man-hours required for each of those tasks per time period. In actual practice not all the tasks would have equal priority. Therefore, the planner inputs engineer task completion percentages for each time period. Thus, construction of administrative space could be deferred during the early time periods so that increased effort can be devoted to such tasks as repair of road damage or port maintenance. Through judicious use of these percentages, maximum benefit can be achieved from the construction battalion and the minimum number of units necessary to accomplish the work will be deployed.

f. Supply Data. The ten classes of supply have been grouped into six categories for the FASTALS simulation. The supplies were grouped together based on similar storage requirements, similar transportation requirements, and similar distribution/issue procedures. Category 1, Reefer, includes refrigerated Class I supplies. Category 2, Light Supplies, includes nonrefrigerated Class I, Classes II, VI, and VIII, plus packaged Class III. Category 3 equates to bulk Class III. Categories 4 and 5 equate to Classes IV and V, respectively. Supply Category 6 encompasses Classes VII and IX, major end items and repair parts.

(1) Within FASTALS, the materiel routine produces the consumption and stockage requirements in the simulated theater. Divisional consumption is based on consumption factors, expressed in pounds per man per day, input in the form of combat consumption tables for each intensity of combat (intense, normal, reduced, and reserve). With the assistance of DA Staff consultants from the Office of the Deputy Chief of Staff for Logistics, consumption tables containing factors for each category of supply, by combat postures, have been developed for each type division.

(2) Nondivisional consumption is accomplished by assigning each nondivisional unit to a population subset. Standard consumption factors are then input for each population subset. The subsets accumulate population strength by physical region and time period, which multiplied by the applicable consumption factor, generates the consumption. This consumption, in contrast to divisional consumption, is not influenced by the combat posture.

(3) To calculate the level of supplies to be stocked in each physical region of the theater, the supply planner must input supply policies given in number of days of supply. In addition to determining the level of stocks, the user also specifies the stocks required at each echelon (division, corps, Army, etc.) of the distribution chain.

For each unique stock level (e.g., 30-day supply level) that is required the planner must input a matrix indicating the distribution of these stocks.

g. Transportation Data. Transportation is a significant aspect of FASTALS because of the number of workloads to which it contributes, the number of units that are allocated based on transportation workloads, and the amount of input required.

(1) The transportation network consists of links (notional representations of connections between two points on a map) and paths (series of links) which are assigned transportation modes (highway, pipeline, railroad, etc.). Since a path can consist of links of various modes of transport, the mode assigned to the path should be the mode that dominates the path in terms of distance except for a path containing a pipeline link or a POL port link, in which case the path mode will be designated pipeline or POL port.

(2) The major consideration in structuring the transportation network is the path's region of destination. Each physical region must have at least two paths that terminate in it. Thus the first step in structuring the network is designation of the links. This is done by reapplying the question, "How are the region's requirements for resupply to be satisfied?" beginning with the forward region and working toward the rear. Once all the links are defined by link number, mode, distance in miles, and initial capacity in short tons, then the paths are designated. Each physical region must have at least one unit deployment path beginning at a theater debarkation port and terminating at the region. A deployment path is distinguished from a resupply path by its designation as mode "O." Thus, a region's resupply is drawn over paths from adjacent regions, whereas unit deployments are drawn directly through the ports. Use of deployment paths for resupply of a given region would cause the routine to bypass intermediate regions having stocks intended for support of the given region, thus causing supplies to be brought into the theater when assets are still available.

h. D-Day Units. Another data element necessary to describe the theater of operation is a list of units in the theater on D-Day. This will include units with home station in the theater as a result of mobilization.

i. Unit Allocation. Units may be allocated in FASTALS manually; allocated as a function of the theater's organizational structure (Theater Structure Variable) (e.g., one AG personnel services company (Type A) is allocated per Field Army); allocated based on the existence of other units in the theater (e.g., one MP Physical Security Company is allocated on the existence of a Special Ammunition Company); or allocated based on a capability to accomplish a workload generated by units in the theater (e.g., one light maintenance company is allocated for every 357.5 daily direct support automotive maintenance man hours generated). All the rules may be used in combination with other rules except for the manual rule which must be used singly.

(1) The manually played units must be input by the planner along with all units that are in the theater on D-day.

(2) There are currently nine theater structure variables (TSV) on which selected units may be allocated. These variables include the standard echelons, such as number of corps or number of Field Armies in the theater, plus the number of 50-mile increments in COMMZ (on which a signal operations battalion is allocated). The value of each of these variables must input for each time period.

(3) The allocation factors for the rules based on TSV, existence, and workload are contained in the FASTALS Master File.

j. FASTALS Master File. The FASTALS Master File (FMF) shown in Figure 1 is the Basic Data Bank for the FASTALS Model and contains all the data necessary to completely describe each unit that may be employed by the model. The FMF contains the following data elements. (The paragraph numbers are keyed to Figure 1.)

(1) The Unit Identification Number (UIN) is a unique number assigned to identify each separate Standard Requirements Code (SRC)-logical region combination in the FMF. For example, a heavy equipment maintenance company (SRC 29137H20000), may be employed in the COMMZ, logical region 5, and in the Field Army Area, logical region 3. In each situation the unit will have a unique UIN.

(2) The logical region, 1 through 5, designates the echelon of employment of the unit.

(3) The unit's strength as contained in the Force Planning Information System (FPIS).

(4) The unit deployment weight, as shown in the FPIS, is a contributing factor to the number of terminal service companies required.

(5) The nonmobile equipment weight, based on the mobility specified in Section 1 of the TOE, contributes to the tonnage that must be moved by Transportation Corps truck companies.

(6) The population subsets which identify the unit personnel by population category, e.g., nondivisional population. The population subsets are used in calculating supply consumption and medical support.

(7) The unit description as contained in the Table of Organization and Equipment (TOE) to include the SRC and the strength and equipment level.

(8) The combining rule determines the use of the separate allocation bases. The sum of the units generated by the separate bases may be

```
                                                          ALLOC
                                              COMB ROUND  RULE
                                              RULE RULE   0-INPUT
                                              1-SUM 0-UP  1-TSV
                                         LAG/ 2-MIN 1-DN  2-EXIST
NIT LR  STR DEPNT NMENT  SUBSET CODES    LEAD 3-MAX 2-0.5 3-W/L   BASIS OF ALLOC  FR TO      SRC                LVL CODE
  AUTO MNT              SIG FLD MNT            A/C MNT                  (10)              UNIT DESCRIPTION
   EE    DS    GS     EE    DS    GS        DS    GS
 (1)  (2)  (3)  (4)  (5)  (6)                     (8)   (9)   (10)
55    1  267.  77.  73.   16  0  0  0  0   2   2   2   2    1.000 PER   7  0  0    12027H10000 (7)     11
183.0    2.1(11) 1.2(11) 166.3   .0(11)  .0(11)   .0(11)  .0(11)               AG CO ADJUTANT GENERAL AMBL DIV (7)

56    3   71.  32.  21.   15 16  0  0  0   2   2   0   1    1.000 PER   3  0  0    12067G71000         11
990.0    1.4   .7  111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE A

57    5   71.  32.  21.   15 16  0  0  0   2   2   0   1    1.000 PER   5  0  0    12067G71000         11
990.0    1.4   .7  111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE A

58    3  119. 129.  84.   15 16  0  0  0   2   1   2   3     .020 PER  22  1  3    12067G72000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE B

59    5  119. 129.  84.   15 16  0  0  0   2   1   2   3     .020 PER  22  4  5    12067G72000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE B

60    3  152. 130.  84.   15 16  0  0  0   2   1   2   3     .020 PER  22  1  3    12067G73000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE C

61    5  152. 130.  84.   15 16  0  0  0   2   1   2   3     .020 PER  22  4  5    12067G73000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE C

62    3  189. 134.  87.   15 16  0  0  0   2   1   1   3     .020 PER  22  1  3    12067G74000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE D

63    5  189. 134.  87.   15 16  0  0  0   2   1   2   3     .020 PER  22  4  5    12067G74000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE D

64    3  220. 137.  89.   15 16  0  0  0   2   1   2   3     .020 PER  22  1  3    12067G75000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE E

65    5  220. 137.  89.   15 16  0  0  0   2   1   2   3     .020 PER  22  4  5    12067G75000         11
888.0    3.4   2.1 111.8        .0    .0    .0    .0                              AG CO PERSONNEL SERVICE TYPE E
```

Figure 1--FASTALS Master File

designated or a code can be entered to select the minimum number of units generated by any single rule. The third alternative is to select the maximum number of units generated by any single rule.

(9) The rounding rule determines roundoff of units generated by the separate allocation rules. The model deploys units in whole integers. Therefore, any fraction can be designated to round up, to round down, or to round 0.5 up.

(10) The allocation rule includes an entry which shows the TSV, UIN, or workload upon which the allocation is to be based; an entry which specifies the ratio of allocation; and an entry which defines the logical regions in which the workload is to be counted for a workload oriented allocation rule. From one to ten allocation rules may be designated for a unit.

(11) The maintenance data recorded for each unit includes the daily maintenance man hour requirements generated for automotive and signal field radio equipment, plus the daily maintenance man-hour requirement generated per flying hour for all units equipped with aircraft.

k. Modes of Execution. The FASTALS Model may be executed in a requirements mode or in a constrained mode. In a requirements mode the support units are allocated and deployed as required, whereas in a constrained mode the number of units allocated or the time of deployment may be modified to meet an imposed limitation. One method of constraining a troop list is through the use of lag category profiles which are input by the planner. Each unit is assigned to one of fifteen categories. Within each category the deployment limiting profile is specified for each time period. The effect of the deployment profile would be to deploy only the percent specified of the required units. Thus the deployment of units can be delayed to facilitate deployment of higher priority units or to meet population constraints.

l. Additional Data. Additional scenario oriented data that must be input for the FASTALS execution include length and number of time periods, damage factors, casualty and disease nonbattle injury rates, and POW capture rates.

3. Execution

a. Model Logic. Simply described, the FASTALS problem is as follows: given a tactical situation in terms of unit deployments, logistic capabilities, and policies, determine the total force that is necessary to support the situation logistically. Figure 2 depicts the flow of logic which FASTALS employs to solve this problem.

b. Allocation Cycle. First, the combat/nondivisional combat units generated by the combat model are augmented by direct input units and by units that are implied by the organizational structure of the theater being analyzed (e.g., number of corps). Next, units that are required

1
COMBAT
&
Nondivisional Combat Units
(From Combat
Simulation)

2
DIRECT
INPUT UNITS
(Manual Allo-
cation Rule)

3
THEATER ORGANIZATION
(Unit Allocated Based
on Theater Structure)

4
UNITS BASED ON OTHER UNITS
(Existence Rule)

5
COMPUTE
PERSONNEL
WORKLOAD

6
COMPUTE
REPLACEMENT
WORKLOADS

7
COMPUTE
MEDICAL
WORKLOADS

COMPUTE
MATERIEL
WORKLOADS

9
COMPUTE
MAINTENANCE
WORKLOADS

10
COMPUTE
CONSTRUCTION
WORKLOADS

11
COMPUTE
TRANSPORTATION
WORKLOADS

12
ALLOCATE UNITS
BASED ON
WORKLOADS
(WL 1-26 as
Appropriate)

FASTALS

Figure 2--FASTALS Logic Flow

on the basis of the existence of other units in the theater are added to the list. The model then computes workloads generated by these units in terms of personnel, replacements, casualties, supplies, maintenance, construction, and transportation. These workloads are then used as a basis for adding more units such as hospitals, medium truck companies, etc. This new set of units generates another increment and so the cycling process begins. Additional units increase the workloads which in turn generate a requirement for more units. This cyclic process, steps 3 through 12, is continued until the model computes the same set of units (troop list) that were computed on the previous cycle.

4. Output

a. Time-Phased Reports. In addition to the unit deployment schedule (troop list) which includes the SRC, unit description, and time-phased deployment, the FASTALS output also includes time-phased reports listed by theater location. Some of the reports provide the consumption and stockage requirements for each category of supply and the tonnage carried over each link in the transportation net. Other reports describe the type of transportation used and the type of material hauled, the engineer construction requirements by type, the number of direct support and general support man-hours of automotive maintenance required, the number of fixed-bed hospitals in the theater, the number of casualties and replacements generated, and the population in terms of combat troops and nondivisional troops.

b. Supplemental Summary Reports. Various summaries can be produced rapidly to provide additional information. These summaries are:

(1) The comparison summary which is used to compare two FASTALS troop lists produced from the same basic set of scenario data with, for example, the consumption rates, supply policies, or casualty rates varied. The analyst is provided a printout summarizing the differences by time period and total between troop lists obtained.

(2) The category summary which provides a percentage breakout of the troop list by combat and support categories. The analyst uses these data to confirm proper troop list balance.

(3) The branch summary which provides the analyst with a branch percentage by time period display which is used to monitor proper proportion of the troop list for each branch category.

c. Analysis. These comprehensive output data allow the analyst to make objective assessments concerning the validity of a force. They also provide a firm base for subjective assessments of the effects of minor changes in constraints.

5. Selected Analysis. An unconstrained FASTALS execution develops a balanced troop list which includes the proper qualities and types of support units. However, as soon as constraints are applied, such as

lag category profiles, a balanced troop list can no longer be guaranteed. Three routines have been developed to analyze the impact on the maintenance, ammunition, and POL support capabilities of the troop list caused by the imposed constraints. These analyses are produced not only in report format but also as graphs which display the support requirements compared with the support capabilities as a constrained troop list.

a. Maintenance Routine. The maintenance routine identifies the direct support (DS) and general support (GS) maintenance man-hour backlog that may be created and compares the actual backlog with the allowable backlog. A total of eight graphs, four each for DS and GS, are produced.

b. Ammunition Routine. The ammunition routine analyzes the actual handling capability of the ammunition units deployed in relation to the total ammunition requirements of the theater.

c. POL Routine. The POL routine analyzes the issue and storage capability in relation to the total requirements. Additionally, the POL on hand, expressed in days of supply, is compared with that specified by the stockage pouch input by the planner.

6. Conclusion. Although the FASTALS Model was developed as part of the Forces and Weapons (FOREWON) System, it may be used in any force planning simulation where a balanced, time-phased, geographically distributed force is desired. Given a tactical situation, logistical capabilities and theater policicies, FASTALS will determine the total force which consists of the minimum number of each type of support to combat unit that is necessary to support the situation logistically. In summary, the principal features of the FASTALS Model are time-phasing, regional distribution, automated recycling, intra-theater dynamics, and verifiable output. The principal advantage for its use is that the force planner's time is now available for analyses of alternative forces.

AD P000628

GENERALIZED ENGINEER ESTIMATING ROUTINE AND TABULATOR OF REQUIREMENTS (GENERATOR) PROJECT

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GENERATOR is a deterministic computerized tool designed for use in conjunction with the Forces and Weapons (FOREWON) force planning system. The primary purposes for this project are to refine the engineer troop requirement by basing engineer effort on tasks within the combat and communications zones and to generate concurrently the Class IV (construction) materiel required to support Army force development plans. GENERATOR operation will insure that DA-level acquisition decisions regarding forces and Class IV materiel can be made simultaneously.

This planning tool was developed under the sponsorship of the Chief of Engineers and it will be operated within OCE.

The discussions presented below will be aimed at describing the following major elements of GENERATOR:

--The engineer functional modules concept for measuring facility requirements and engineer unit capabilities.

--Interface requirements with the FOREWON force planning system.

--The major logic details incorporated within the computerized submodels of GENERATOR.

--The Class IV materiel analysis for developing objective stocks.

--And finally, the uses made of this planning tool.

Force planning and development decisions will in the foreseeable future result from the operation of the adopted FOREWON computerized planning system. This system can generate alternative objective forces to include acquisition and operating costs in support of the Army Strategic Objective Plan (ASOP) and the Army Force Development Plan (AFDP).

The GENERATOR model will be operated parallel with the FOREWON system because of space limitations within the computer used by FOREWON, but it will be dependent upon outputs from FOREWON in order to produce meaningful results.

In order to see how GENERATOR will fit into the Army planning cycle, one must understand the relationship between force development and operational planning (as prescribed by current regulations). Acquisition of forces and certain resources follows analysis of various force alternatives (in an ASOP exercise) and imposition of budgetary constraints. On the other hand, Class IV materiel requirements for these forces are not identified until detailed theater analyses have been completed. Operational projects which contain Class IV materiel are established in a much later time frame than the acquired forces, thus producing an inconsistency in the planning process. This time lag between acquired forces and the procurement of Class IV materiel may be 2 years, or more under critical budgetary conditions. Furthermore, these Class IV requirements are established piecemeal by single theaters. A synthesis of these requirements, considering the multiregional aspects of the problem, is not part of the explicit analysis.

GENERATOR will be operated in conjunction with the FOREWON force planning system and will concurrently develop the Class IV materiel requirements to support the objective force designed by FOREWON. Once GENERATOR is in operation, DA-level acquisition decisions for forces and materiel can be made simultaneously.

The current method for determining engineer unit requirements is mainly based on allocation rules for most type units, the exception being the engineer construction battalion. In this case, facility requirements are identified within the COMMZ before being converted to effort requirements using a single-element analysis, namely aggregated man-hours. To establish unit requirements, the total effort requirements are identified and then divided by the man-hour capability for one battalion.

The principal shortcoming of the current process is that the analysis does not address the utilization efficiency of the battalion's major items of equipment. If, for instance, the construction of certain facilities creates a heavy demand for an equipment item (such as bulldozers), the process would only account for this requirement as additional man-hours. Therefore, this procedure would result in a mismatch between the statement of facility requirements and the engineer unit requirements identified for completing the construction.

A multidimensional characterization of engineer activity has been developed to refine the method for generating engineer troop requirements. This breakdown was developed around 23 major engineer functions, the most significant of which are: dozing, grading, hauling, paving, concrete operations, materiel production, crane-shovel operations, vertical construction skills, and combat engineer activity. These engineer functional modules measure both facility requirements and engineer unit capabilities in hours. This common base permits an explicit assessment of the match between facility requirements and unit capabilities.

It should be noted that all vertical construction skills are grouped into a single module. This grouping assumes that complete substitution is possible among the various journeyman skills in the COMMZ. Vertical construction skills are manpower oriented; e.g., carpenters, masons, electricians, welders, and pipeline specialists. This same analogy was made for the combat engineer activity module, which is applicable to the combat zone. Both of these modules are computed based on man-hour estimates.

All of the other functional modules were developed around a special purpose or major item of engineer equipment. Equipment operators and maintenance personnel are not addressed separately in this analysis, but are considered available as necessary to support the engineer functional modules. Minor items of equipment are also omitted from explicit analysis.

Labor and equipment estimates for approximately 350 facilities covered in the back-up data of the Army Facilities Components System (AFCS) have been converted to this modular concept for use with GENERATOR.

The AFCS is a detailed construction support system that provides completed designs for a full range of possible theater of operations facilities. This catalog includes hourly labor estimates by individual construction skill and item of equipment and indicates the bill of materials needed to construct each facility.

GENERATOR, in conjunction with FOREWON, will identify required engineer tasks in terms of facilities, such as: 500-bed hospitals, 5,000-short ton ammunition dumps, and 1,500-man troop camps.

To illustrate the process in generating engineer troop requirements, a simplified example is presented in Figure 1. One 1,500-man troop camp was selected for analysis.

TYPICAL ENGINEER FORCE ANALYSIS

INSTALLATION: 1,500 MAN TROOP CAMP, STANDARD 3, STEEL FRAME

MODULE DESCRIPTION	FACILITY RQMTS (MODULE HOURS/DAY)	ENGR CONST COMPANY CAPABILITIES (MODULE HOURS/DAY)	UTILIZATION EFFICIENCY (PERCENT)
CRANE-SHOVEL OP (3/4CY)	8	30	27
CONCRETE OP	14	30	47
VERTICAL CONST SKILLS	490	488	100
HAULING (5T DUMP)	73	88	83
HAULING (18CY SCRAPER)	29	59	50
DOZING	23	59	39
GRADING	20	44	46

ESTIMATE IS BASED ON ONE ENGINEER CONSTRUCTION COMPANY COMMITTED FOR 25 DAYS.

Figure 1

The labor and equipment estimates for each of the 24 facilities that make up this installation were analyzed, and seven unique modules were identified. Total module requirements were established by accumulating for the actual number of facilities. It was determined that an engineer construction company can provide these same seven modules at the rates shown in the second column. Assuming a 25-day construction period, the average daily module requirements are those indicated in the first column. The last column shows the utilization efficiency for each module. The GENERATOR computerized process, of course, will be accumulating module requirements for many installations of different types and doing so on a time-phased basis.

In matching engineer units to computed requirements, only certain units will be considered. The combat zone units are: the nondivisional combat battalion, light equipment company, and the bridge companies. The units in the COMMZ are: the construction battalion, construction support company, port construction company, and the pipeline construction support company. Each of these type units have been analyzed to ascertain their capabilities considering the 23 engineer functions.

An optimizing routine is used to develop the most efficient overall mix of engineer units. Utilization efficiencies are reported by module for the total engineer force and for each type unit. An important by-product of this analysis will be insights into design eccentricities of the engineer units included in the analysis. After several cycles of the ASOP and other force planning exercises, the utilization efficiencies for the various modules can be examined to determine trends within the engineer force as a whole and within each type unit considered. If certain modules appear to be driving the solution for most cases, an increased capability for these modules would be in order. Conversely, if certain modules are persistently under-utilized, a reduced unit capability should be provided.

The general flow of the major analyses within the FOREWON system is shown in Figure 2. A thumbnail description of FOREWON is provided at this point, and more details are given later in the discussion of interface between GENERATOR and FOREWON.

DCSOPS or ACSFOR prescribe the exercise plan of analysis in detail. It contains the exercise objectives, guidance, ground rules, and constraints--to include imposed budgetary limitations. The primary result from the FOREWON system is the design of an objective force in support of the ASOP or AFDP.

The preliminary force designer (PFD) is a major model in the FOREWON system. It is a large-scale model which analyzes an entire design group of multitheater operations (DGMTO) and assesses the distribution of gross forces and intertheater strategic lift requirements. Because of its scope, all representations in the PFD are highly aggregated.

Two typical multitheater operations (MTO) are shown in Figure 3, and they illustrate the makeup of a DGMTO. The US national strategy dictates the number of active single theater operations that constitute one MTO.

Currently, one major and one minor contingency are being considered as simultaneous requirements; of course, CONUS reserve and nonactive forward deployments are other concurrent troop requirements to be considered. The final objective force designed by the FOREWON system is capable of satisfying any one MTO that is included within a design group of up to five MTO.

FOREWON SYSTEM

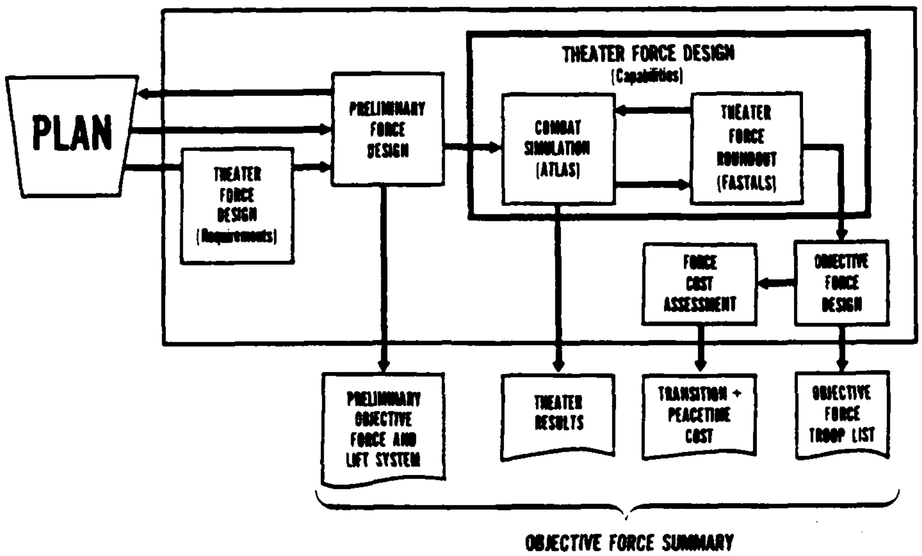


Figure 2

DESIGN GROUP OF MULTITHEATER OPERATIONS

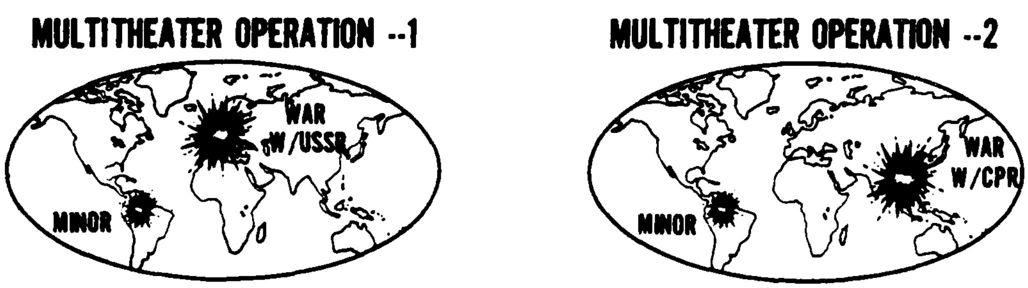


Figure 3

The PFD considers the given MTO structures and develops the distribution of forces among active, reserve, and unmanned units based on established mobilization criteria. The PFD also develops a strategic lift analysis and a closure schedule for division forces in each of the major contingencies.

After applying the PFD, each major contingency is then subjected to the detailed theater force design which includes FOREWON's two principal models--combat simulation (or ATLAS) and force roundout (or FASTALS). ATLAS simulates tactical activity to determine the combat and certain combat support forces in the troop list. Using the ATLAS results, FASTALS determines a balanced, time-phased combat service support troop list as a function of the stipulated combat force and its activities in the theater combat simulation.

By selectively combining the troop lists developed for each of the single theater analyses, the objective force designed will have the capability of satisfying any one MTO postulated within the design group.

An objective force cost analysis is also developed by FOREWON. All costs reflect peacetime requirements and are based on the transition from a force-in-being to the objective force designed by FOREWON. Costs include operating and maintaining forces over stipulated time periods and the PEMA requirements for the conversion to the objective force.

Interface requirements between the FOREWON and GENERATOR systems influence the two theater force design models: ATLAS and FASTALS. Each major contingency analyzed using the ATLAS and FASTALS models will also be evaluated using GENERATOR.

The combat simulation is run first, and these results are used by the GENERATOR engineer combat model to develop both time-phased engineer units and the Class IV materiel requirements to support their activities. The engineer unit requirements developed by the combat model (namely, combat battalions, light equipment companies, and bridge companies) and estimated requirements based on experience factors for the major engineer COMMZ units (i.e., construction battalions, construction support companies, port construction companies, and pipeline construction support companies) are input to the first run of the FASTALS model. The engineer routine in FASTALS for developing numbers of construction battalions will be suppressed prior to the first run. All engineer unit requirements other than those input will be developed within FASTALS by the routines in the roundout process.

To develop a troop list that satisfies all constraints requires several FASTALS runs (of 12 or 15 iterations each) with as much as 3 days lapse between runs. When the players determine that the model is approaching desired results, the GENERATOR COMMZ[1/] model is activated using the

1/ The principal routine in the GENERATOR COMMZ model will be very similar to the engineer routine now structured within FASTALS. Exceptions being that GENERATOR will address several other engineer units besides the construction battalion, and that unit requirements will be based on the functional module concept instead of aggregated man-hours.

acceptable workloads for engineer tasks as developed by FASTALS. The results from the COMMZ model are in terms of time-phased engineer units and Class IV materiel requirements to support the construction efforts. This output is used to revise the initial estimate of engineer COMMZ units made for the first run of FASTALS and will be provided prior to the final run. Our goal is to run the COMMZ model and respond within one day with the final estimate of engineer COMMZ units. After GENERATOR has provided these inputs to FOREWON, th final troop list and objective force are developed without further engineer input. The time-phased Class IV materiel requirements resulting from both the combat and COMMZ models become input to the objective stocks analysis that will be discussed later.

Major elements of the ATLAS combat simulation are discussed below. Prior to conducting an ATLAS analysis, a detailed layout of the theater is developed which establishes sector boundaries, base lines within each sector, and type terrain within each sector referenced to the base line. The game is run and results are based on the relative firepower potentials of the red and blue forces and the impact of tactical air and logistics. Game results are developed daily for the scenario duration to provide for the introduction of new forces and to account for personnel replacements, changes in the tactical air mission assignments, and other logistic considerations. The daily results include the FEBA location, the tactical postures of both red and blue forces, and force summaries.

The GENERATOR combat model will use the theater layout developed for the ATLAS run and the output tape which provides daily results of the game. This combat model is made up of two major segments: the first addresses engineer place-dependent tasks in the preplanned category; and the second addresses those tasks which result from the dynamics of FEBA movements. Barriers and river crossings comprise the place-dependent tasks, while the FEBA dynamics-dependent tasks include defensive positions, hasty obstacles, protective structures, Army airfields, logistic installations, bridging, obstacle clearing, road construction, damage repair, maintenance, and limited contingency factors.

In the case of preplanned tasks where the ATLAS battle reaches a specified distance from the barrier or major river crossing, the program calls up the event and records the functional module requirements for its completion.

The tasks based on FEBA dynamics are generated considering theater assets, the movement rate of the FEBA, and the proximity to the preceding installation or position constructed. Contingency factors are included in the model to account for altered, deferred, aborted, or unforecast tasks which nondivisional combat engineers are called upon to support. Various levels of this type effort are addressed. For instance, a minimum factor is included during periods when barrier construction is at a peak and a maximum factor when the tactical situation deteriorates to disorderly retirement.

Support requirements from the sector analyses are totaled for the theater, and a 5-day time period average is established from which the engineer unit requirements are developed.

The current force planning procedure regarding construction battalions considers only minimum standards of construction and utilizes a construction policy for completion of tasks by time period. This establishes constrained facility requirements. As an example, the construction policy for troop camps states that none will be built during the first 30-day time period, and only 50 percent of the computed requirements will be satisfied during the following 60 days. Such a policy serves to set priorities in the construction sequence, so that a realistic engineer troop list is developed from the analysis. Peak facility requirements are normally identified about D+90, thus establishing the number of construction battalions. All unused unit capabilities beyond this point are assumed committed to upgrading facilities to higher standards of construction. Current procedures do not estimate the actual upgrading that is accomplished, since the basic concern has been to determine the number of required construction battalions in the force based only on minimum standards of construction.

In the GENERATOR analysis, the same general routine to establish peak unit requirements is followed; in addition, the process accounts for upgrading of facilities in order to identify Class IV materiel requirements for the entire scenario duration. A construction policy has been established in the upgrading routine so that those facilities with the highest priority are upgraded first.

To establish the required numbers of facilities in the COMMZ, FASTALS is programed to generate workload requirements which include: troop populations, number of fixed hospital beds, miles of LOC roads, ammunition storage, POL storage, refrigerated storage, general supply storage, personnel replacements, and PWs. Quantities for each workload are developed on a time-phased basis, normally by 30-day time periods. These data are then converted to engineer tasks using factors to identify specific numbers of required facilities. The engineer functional module requirements are then aggregated for these facilities within each sector and time period. After the module requirements are established, the engineer unit requirements are developed using the optimizing routine mentioned earlier.

The following discussion will address the objective stocks analysis included within GENERATOR. This analysis was developed to identify objective Class IV materiel requirements which would support the objective force designed by FOREWON.

Figure 4 is a typical organizational schematic of a DGMTO. Within each MTO, there is one major and one minor contingency.

Time-phased facility requirements for each single theater operation are developed as discussed earlier. These lists of time-phased facilities will be the base data from which more detailed analyses will be conducted, namely the examination of materiel requirements by FSN.

A breakdown of these time-phased requirements is postulated, based on deployment time considerations for the theaters under analysis. The first increment of materiel, shown as hatched areas on the schematic, is made up of requirements which must be pre-positioned in theater or airlifted with troops. The limits are established for each theater based on sealift delivery dates.

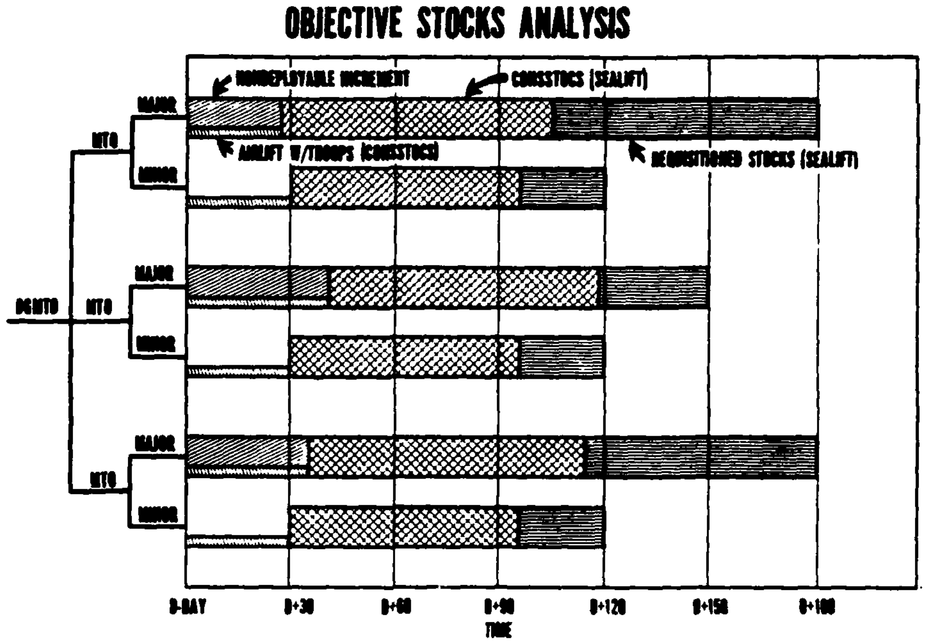


Figure 4

The next increment of materiel, shown as crosshatched areas, is made up of requirements which could be satisfied from on-hand stocks located in CONUS and deployed to the theaters as required using sealift. These are contingency support stocks (CONSSTOCS).

The last increment of materiel, shown as lined areas, is made up of requirements which could be filled by requisitioning from materiel suppliers and still meet the theater requirement dates.

To establish the objective stocks which will be consistent with the objective force developed by FOREWON, the following analysis can be conducted. Since the nondeployable increment of materiel will usually be pre-positioned in theater, the most demanding case analyzed by time period for each unique theater will govern the makeup of this requirement. Therefore, a single list of facilities for each major theater will represent pre-positioning requirements.

The next increment of materiel to be analyzed is the contingency support stocks located within CONUS which stand ready to satisfy requirements on a multiregional basis. All CONSSTOCS identified within each MTO are added together by time period. This is consistent with the DGMTO organization, since all requirements within each MTO are considered to be simultaneous requirements. Following this summation process within each

MTO, the resultant lists of facilities for each time period and MTO are screened to identify maximum requirements by type facilities. The time-phased facility lists identified will constitute the makeup of required CONSSTOCS. Requirements for requisitioned stocks are developed in the same manner as described for CONSSTOCS. This method for developing objective stocks is entirely consistent with the FOREWON process for determining objective forces.

All facility requirements identified within the objective stock increments can be manipulated using several routines. Net materiel costs can be developed in conjunction with DCSLOG and AMC so that these costs may be considered simultaneously with the FOREWON-computed costs that reflect force requirements. The net materiel weight and cube requirements will also be established on a time-phased basis and will be used with the strategic lift system analysis included within FOREWON. These requirements will serve to improve the current planning factors included in the lift analysis. Since the deployment weight and cube of Class IV materiel will be defined by time period, a more realistic lift system analysis can be developed.

Requirements identified in the early time periods will be of particular concern since surge requirements would severely impact on the lift system. Significant surge requirements are expected to result from this type analysis. Facility requirements can also be analyzed from the individual materiel item standpoint, using the bills of material available in the AFCS. This will be done for such major items as lumber, steel, cement, piling, and other items of concern.

A full test of the GENERATOR system has been completed. The real-time parallel runs to the FOREWON models were a success, and the unit requirements developed for the cases analyzed resulted in answers remarkably similar to those developed internal to the FOREWON system. GENERATOR results have also been used to modify Class IV supply factors.

Future uses of this system will include periodic runs to verify the unit allocation rules and supply factors used in FOREWON. An extensive analysis of the objective stocks will be conducted in an effort to identify critical shortfalls in asset positions of Class IV materiel; this analysis will be accomplished in concert with ODCSLOG and AMC.

In summary, the following project highlights are offered. GENERATOR will be a valuable tool for the Chief of Engineers in that it will provide a far more timely and complete view of engineer requirements as part and parcel of the Army force development planning process. GENERATOR will also help in directing OCE attention and effort towards improving the military engineering system. This assistance will be provided by the insights gained into eccentricities in the design for certain engineer TOEs, and by the demand data provided to the AFCS office. Finally, GENERATOR will provide a credible basis for concurrently stating requirements for engineer troops and materiel because it derives its authority from accepted force development planning techniques.

AD P000629

DECISION ANALYSIS FOR XM578 APFSDS CARTRIDGE DEVELOPMENT PROGRAM

Stephan R. Pearcy, ARMCOM

A decision analysis was performed on the XM578 APFSDS projectile development program. The decision analysis differed from a "Risk Analysis" in that, along with assessing program risks, the decision analysis proposed alternative program approaches and compared the expected outcomes of the proposed alternatives with the basic program. Prime consideration was given to the quantification of uncertainties, examination of allocation of resources between test and design phases of the development program and to quantify the value of information obtained in a test program.

DEVELOPMENT OF ALTERNATIVES

The first task in the analysis was to bound the problem which included identifying decision choices and assumptions, defining outcomes, etc. The following is a list of the critical definitions and assumptions initially made when formulating the decision problem.

1. A successful project outcome was defined as successful completion of ET-EST within the established schedule.

2. An unsuccessful project outcome was defined as any outcome which required a higher level decision (addition of resources, waiver of requirements, etc.) to enable program success. If the program had an unsuccessful outcome, it was assumed that the higher level decision would be "megative" (no addition of resources, no waiver of requirements, etc) and the program would be terminated.

3. The above implied that design modifications would not be permitted after completion of design activities.

The above considerations, development program structure, and initial analysis led to the generation of nine possible alternatives consisting of the possible combinations of three different engineering design efforts (ED1, ED2, and ED3) and three different confirmatory testing efforts (CT1, CT2, and CT3) and ET/EST. A tenth alternative (terminate program) was included for completeness. A listing of the alternatives appears in Table 1.

TABLE 1
ALTERNATIVE PROGRAMS

1.	ED1,	CT1,	ET/EST
2.	ED1,	CT2,	ET/EST
3.	ED1,	CT3,	ET/EST
4.	ED2,	CT1,	ET/EST
5.	ED2,	CT2,	ET/EST
6.	ED2,	CT3,	ET/EST
7.	ED3,	CT1,	ET/EST

Table 1 (Con't)

8. ED3, CT2, ET/EST
9. ED3, CT3, ET/EST
10. Terminate Program

These alternatives are also illustrated in the decision tree of Figure 1 where it is seen that the decisions are:

1. Select design effort alternative
2. Select a test alternative

The evaluation of these decision choices was based on the following characteristics:

1. Cost of the activity if it is successful
2. Cost of the activity if it fails (depends on type of failure)
3. Probability of success (risk) of the activity
4. Value (or information) gained if the activity is performed

Activity time was not considered since each of the alternatives was expected to meet program shcedule requirements.

GENERATION OF COST ESTIMATES

Expected costs of successful programs were well defines, however, failure costs were less certain and were expected to be dependent on the type of failure. Functions were generated relating failure costs to the type and expected frequency of failure. Typical of this relation was the one generated for determining expected cost if failure occurs in ET/EST. A list of failure types and estimated probability of occurrence was first obtained:

Type of Failure	Estimated Probability of Occurrence Given a Failure Occurs in ET/EST
In-bore security	.37
Accuracy requirements not met	.12
Penetration requirement not met	.13
Case/projectile interface problems	.26
Others (e. g., meeting drop test)	.12
	$\Sigma = 1.0$

It was next determined that certain types of failure would have more severe impact than others so each failure type was categorized into whether it would have severe or non-severe impact. It was estimated that a severe failure type would result in a loss of 60 percent of ET/EST

DECISION TREE

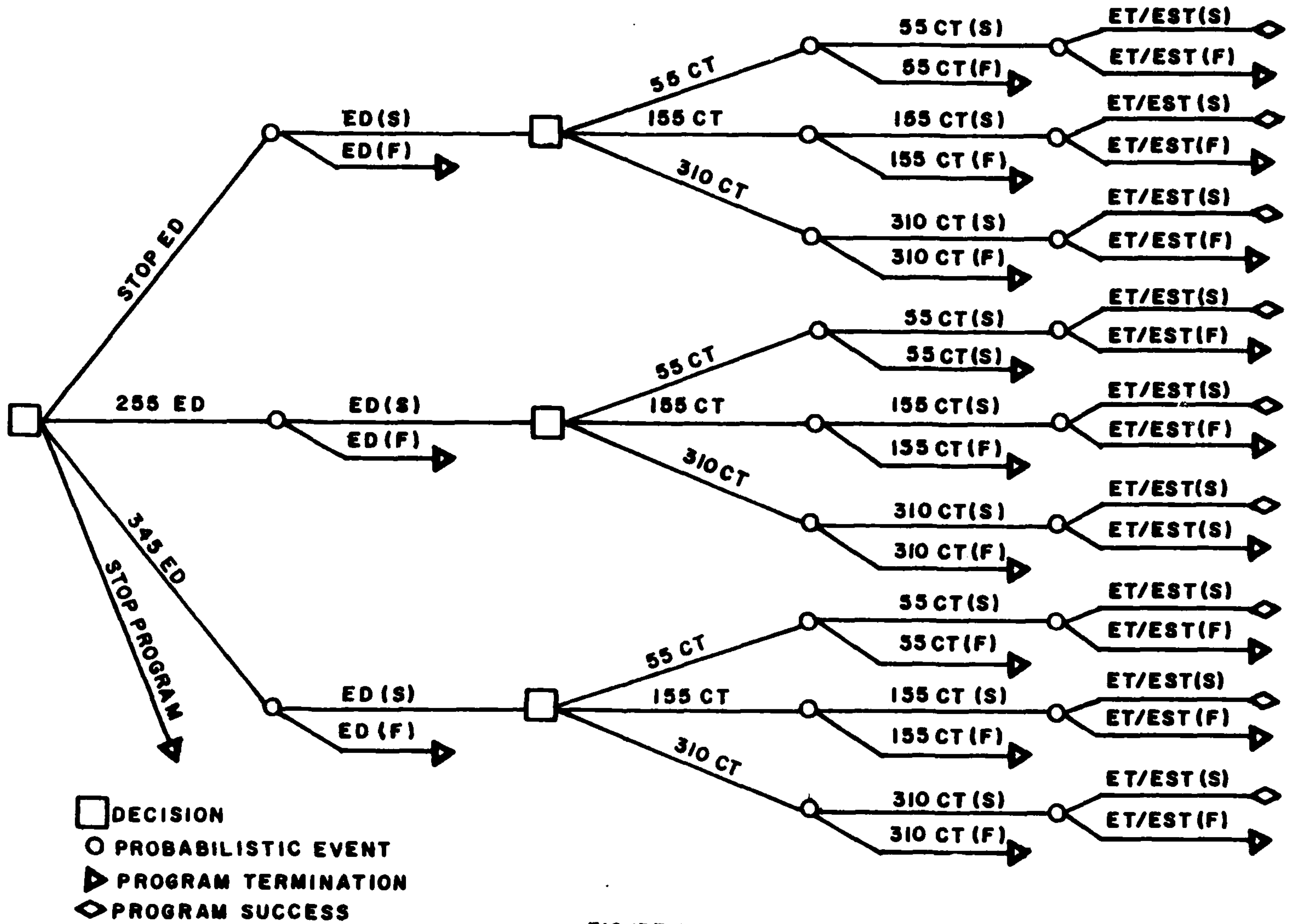


FIGURE 1

manufacturing costs; a non-severe type would result in a 10 percent loss. This resulted in the following table:

Failure Type	Failure Degree	Estimated Probability of Occurrence Given that a Failure Occurs in ET/EST	"Loss"
Security	Severe	.37	60%
Accuracy	Severe	.12	60%
Penetration	Severe	.13	60%
Case	Non-Severe	.26	10%
Others	Non-Severe	.09	10%
Others	Severe	.03	60%

This data, along with estimates of manufacturing and testing costs for ET/EST provided a distribution of expected loss if failure occurs in ET/EST as shown in Figure 2. In a similar manner, other cost estimates were obtained.

TABLE 2
MEAN COST ESTIMATES OF ACTIVITIES

Activity	Cost ($M) Success	Cost ($M) Fail
ED1	0.0	0.0
ED2	.91	.91
ED3	1.16	1.16
CT1	.19	.15
CT2	.5	.41
CT3	.98	.8
ET/EST	4.6	1.97

SUBJECTIVE PROBABILITY ESTIMATES

After the necessary cost data had been obtained, probability of success estimates for the elements of each of the alternatives were obtained. It was necessary to make some initial definitions and observations in order to remove ambiguity from the estimates. It should be noted that these definitions/observations will not necessarily apply to other test development programs, however, they were sufficient for both the characteristics of this development program and the needs of the analysis.

1. The probability of success of the design effort is actually the probability that subsequent confirmatory test will be initiated. The level of success of ED is reflected in the probabilities of success of the subsequent final test and ET/EST.

2. Whereas a design fault may occur as a random failure, its frequency of failure will be high enough to be detected by a proper set of tests; i.e., if a true design fault exists, it will be uncovered in ET/EST.

PROBABILITY (P) THAT COST OF FAILURE IN ET/EST IS LESS THAN X

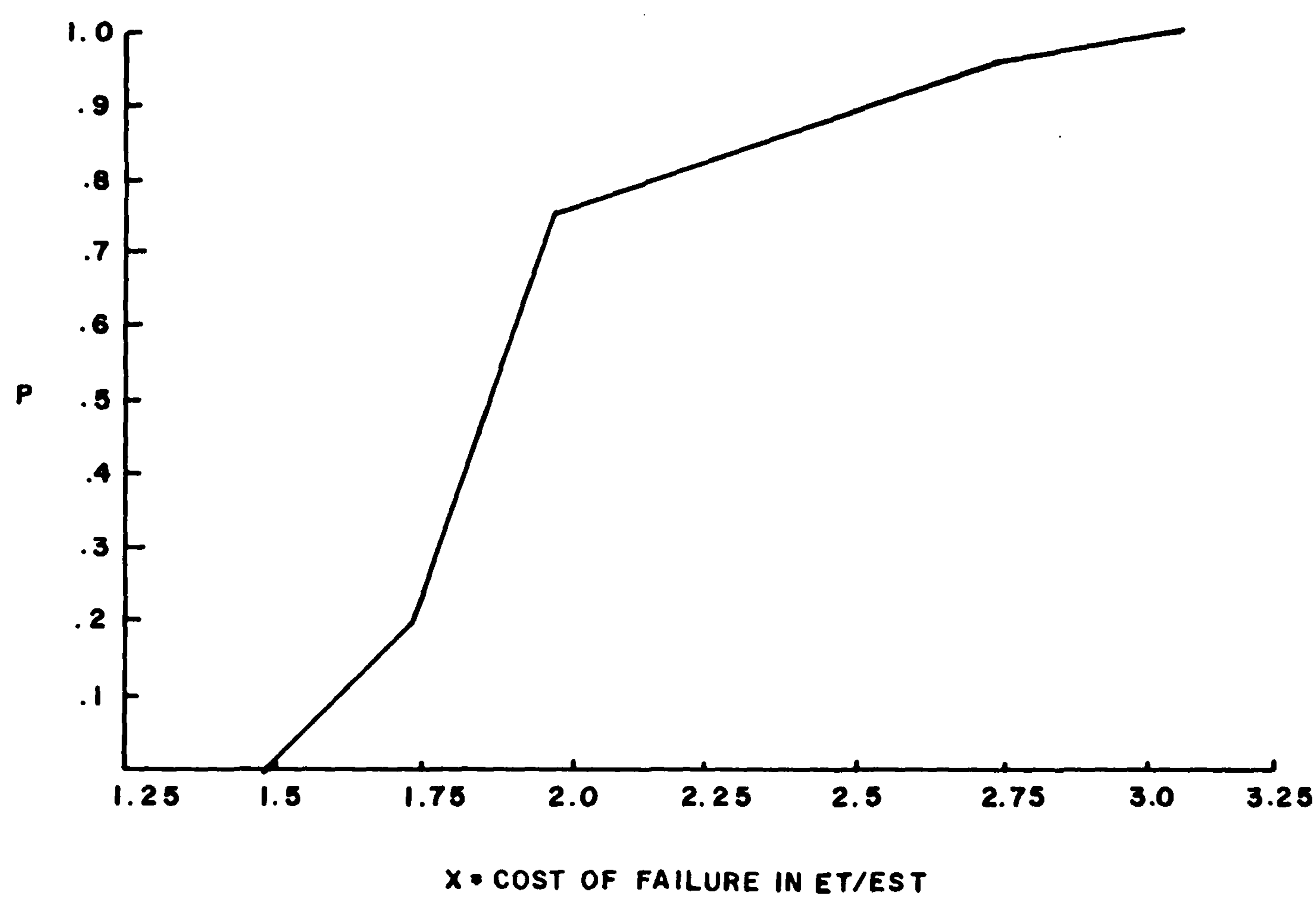


FIGURE 2

3. Any random failures (not design faults) which may occur at low frequency are considered to be of such low frequency that the addition of CT rounds to ET/EST rounds as on increased sample space results in "no" (insignificant) greater chance of uncovering such a failure.

4. Two and three above imply that ET/EST is considered to be a "perfect" (no statistical error) test.

5. Final test and ET/EST are assumed to be testing phases only (failures cannot be corrected), and the probability that a round passes a combination of final tests and ET/EST is a constant for a given level of ED. Since design changes were assumed to be not permitted after the completion of the design phase, the design resulting from ED efforts has a fixed probability of passing a set of tests. The value of the probability is dependent on the set of tests.

It should also be noted that, although it would be possible to perform a formal statistical analysis on each of the proposed test programs and ET/EST, it was considered proper to utilize subjective estimates. This was done because the size and composition of the test programs had not been firmly established and the errors introduced by these uncertainties would negate any efforts in a formal statistical analysis.

Estimates were first obtained for the probability that the round would pass ET/EST given that the round had successful completed ED:

Engineering Design Effort	P_S of ET/EST
E1	.1
E2	.85
E3	.9

Note that this probability is actually the joint probability of passing ET/EST and CT.

The probability of success estimates for CT was next acquired indirectly by finding the probability of the following event: Will the CT detect a fault (failure) given that there exists at least one fault in the design. (P(D/F)). The above question was asked for each combination of CT and ED type. ED type was a factor since it was considered that the probability of detecting a fault was dependent on the level of effect of ED. The following estimates were obtained:

Level of Effort in ED	Level of Effort in CT	P(D/F)
ED1	CT1	.49
	CT2	.83
	CT3	.99
ED2	CT1	.09
	CT2	.87
	CT3	.93
ED3	CT1	.12
	CT2	.8
	CT3	.9

This information and the previously noted assumptions enabled calculations of the probability of success estimates for CT and ET/EST. Also, estimates were acquired for the probability of success of ED. The results are presented in Table 3.

The decision problem was now represented by a state-of-nature chart where Θ_1 is state-of-nautre: Projectile is good; and Θ_2: Projectile is bad. The selection of ED affects the probability of Θ_1, Θ_2 and the consequences of CT selection are shown in the boxes.

	CT1	CT2	CT3
Θ_1	Best because it is the least expensive and the round is good.	Not as desirable as CT1: unnecessary money spent for CT.	Not as desirable as CT2; more unnecessary money spent for CT.
Θ_2	Low probability of discovery fault in CT; expensive ET/EST failure is most likely.	Better chance of discovery fault in CT; less chance of expensive ET/EST Failure.	Best chance of discovery fault in CT; minimizes probability of expensive ET/EST failure.

<u>ED1</u>	<u>ED2</u>	<u>ED3</u>
$P_{\Theta_1} = .1$	$P_{\Theta_1} = .85$	$P_{\Theta_1} = .9$
$P_{\Theta_2} = .9$	$P_{\Theta_2} = .15$	$P_{\Theta_2} = .1$

The selection of CT was evaluated by examining the expected value of perfect information (EVPI). Perfect information is a prediction with certainty of the outcome of a future event and the expected value of perfect information is the maximum amount that should be paid for this prediction. The following two events were compared (note that the information must be paid for before it is received).

1. No confirmatory test

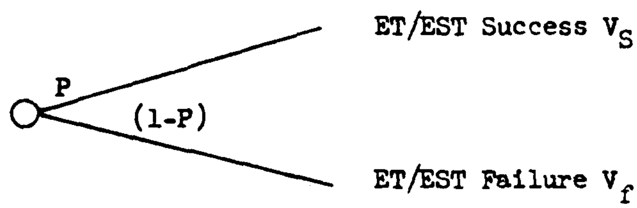
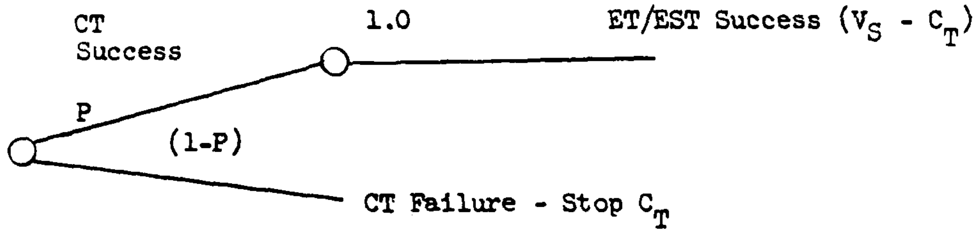


TABLE 3

SUCCESS PROBABILITIES OF ACTIVITIES AND PROGRAM ALTERNATIVES

Group	Alternative	Activities (P(S))	Overall P(S)
A	1	ED1 (1.0), CT1 (.56), ET/EST (.179)	.1
	2	ED1 (1.0), CT2 (.25), ET/EST (.9)	.1
	3	ED1 (1.0), CT3 (.102), ET/EST (.988)	.1
B	4	ED2 (.85), CT1 (.986), ET/EST (.86)	.72
	5	ED2 (.85), CT2 (.87), ET/EST (.978)	.72
	6	ED2 (.85), CT3 (.86), ET/EST (.986)	.72
C	7	ED3 (.95), CT1 (.988), ET/EST (.91)	.86
	8	ED3 (.95), CT2 (.92), ET/EST (.98)	.86
	9	ED3 (.95), CT3 (.91), ET/EST (.988)	.86
	10	STOP PROGRAM	0.0

2. Confirmatory test that provides perfect information



where

V_S = value of success

V_f = value (cost) of ET/EST failure

C_T = cost of perfect test

P = prior probability of ET/EST success

Comparison of the event sequences show that the maximum test cost is dependent only on the risk and value of failure

$$(1-P)\ V_f = C_T$$

The EVPI for each of the alternative groups was calculated:

Group*	P_S of ET-EST	EVPI
A	.1	1.8M
B	.85	.3M
C	.95	.2M

*See Table 3

When compared to the expected costs of the various CT programs (Table 2) it is seen that only for Group A alternatives could a CT have any possible benefit. Each of the CT's for Group A alternatives were evaluated to determine which provided relative maximum value:

RELATIVE VALUE OF CT PROGRAM
FOR GROUP A ALTERNATIVES

CT Type	Relative Value
CT1	-.04
CT2	+.3
CT3	+.19

For Group A alternatives, CT2 provided maximum worth as a test activity.

The CT's had value in that they provided a forecast of expected results of ET/EST. However, off-setting this value were the incurred costs and lack of certainty in the CT forecast. As the forecast becomes more certain the costs rose correspondingly and for some CT types the value gained was not worth the cost of the CT.

After the effectiveness of the CT's had been evaluated, the worth of each of the alternative programs were evaluated by the use of a value function. This function was a mathematical representative of the decision tree rollback which included probability of success, costs of success and failure, and value of program success:

$$W_P = (1 - P_{ED}) \times F_{ED} + P_{ED} \times (S_{ED} + (1 - P_{CT}) \times F_{CT}$$
$$+ P_{CT} \times (S_{CT} + (1 - P_{ET/EST}) \times F_{ET/EST} \times (S_{ET/EST} + V_S)$$

where

W_p = program worth

$P_{(ED)}$ (CT) (ET/EST) = probability of success of (ED) (CT) (ET/EST)

$S_{(ED)}$ (CT) (ET/EST) = success costs of (ED) (CT) (ET/EST)

$F_{(ED)}$ (CT) (ET/EST) = failure costs of (ED) (CT) (ET/EST)

V_S = value of success

The value of success is a measure of the net positive return of having a desirable outcome. This value of success was viewed as the amount that would be spent to obtain a certain successful outcome. By assigning values to desirable outcomes, it was possible to compare alternatives with different resources expenditures. The above value function was written in a more compact form:

$$W_P = - E + P(S) \times V_S$$

where

W_p = program worth

E = expected program resource expenditures

P(S) = overall probability of success of the program alternative

V_S = value of success

Expected resource expenditures could be readily calculated and P(S) was known, however, the value of success was not specifically known. In order to evaluate each of the alternatives, the dominant altermatives were identified for the range of values of success:

Value of Success	Program Alternative with Highest Worth
0.0M to 6.05M	Stop program (alternative 10)
$6.05M and above	(ED3, CT1, ET/EST) (alternative 7)

Final alternative selection was based on an estimate of the value of success. Prior program expenditure and consideration of the military worth of the final item led to estimate of the value of success well above the $6.05M point and alternative 7 was recommended.

CONCLUSIONS

For this particular development program situation it was determined that extended design (with associated design testing) activities provided a significant net return. Confirmatory testing activities in general did not provide a net return due primarily to the situation that if a fault was detected, nothing could be done to correct the fault. It was recommended that the rounds allocated for the confirmatory test included in alternative 7 be used as backup rounds for the ED phase or used for a comprehensive test of selected critical design characteristics.

PERFORMANCE RISK ANALYSIS FOR A SURFACE ATTACK GUIDED MISSILE SYSTEM (SAGUMS)

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SUMMARY

This paper examines the data obtained from gunner qualification tests (using a trainer) and the live firings of the SAGUMS missile during Expanded Service Test (EST) and draws conclusions based on that data. It is concluded that the SAGUM Trainer (SAT) qualification scores can be utilized to predict the gunners' performance with the live round. It is further concluded that multiple firings of live rounds are not necessary in the training program. Results are presented which indicate the value of selectivity picking gunners based on SAT qualification scores. Finally, the influence of gunner selectivity and target postures on SAGUMS performance are indicated.

BACKGROUND

Prior to the EST the SAGUMS Project Office had been projecting high probability of hit values under the "arms room" concept and the Qualitative Materiel Requirement (QMR) was expected to be met. It was anticipated that a large percentage of gunners could be trained and qualified with the SAT. Moreover, it was believed that a gunner's SAT score would be indicative of his performance with the live round. No plans had been made to fire live rounds as a portion of the training program. The SAGUMS Project Manager was at a major decision point and was preparing for the Army Systems Aquisition Review Council/Defense Systems Acquisition Review Council (ASARC/DSARC). It was at this point that preliminary EST results were being evaluated by various groups and presented to the Project Manager was receiving.

Figure 1 shows the probability of hit (given a reliable round) as a function of the number of shots fired by each gunner. This information, as presented, indicated that a learning process was involved and that after approximately five shots the probability of hit changed very little. This implied that live rounds could be required in the training program.

Figure 2 presents the qualification scores on the SAT versus the score achieved in live firings. Figure 3 shows the same general information in a different format. Each of these figures separates the gunners according to SAT scores above and below a specified level. These figures indicate that the SAT scores cannot be used to predict "good" gunners. All three figures taken together indicated that the QMR value for P_h could not be achieved using the "arms room" concept.

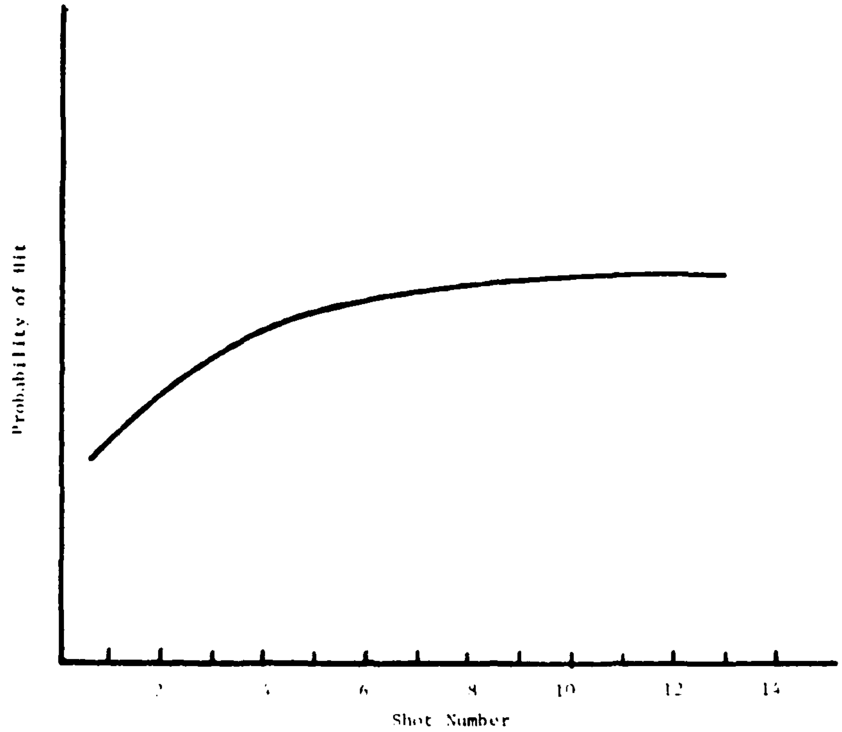

Figure 1. Probability of Hit Versus Number of Shots

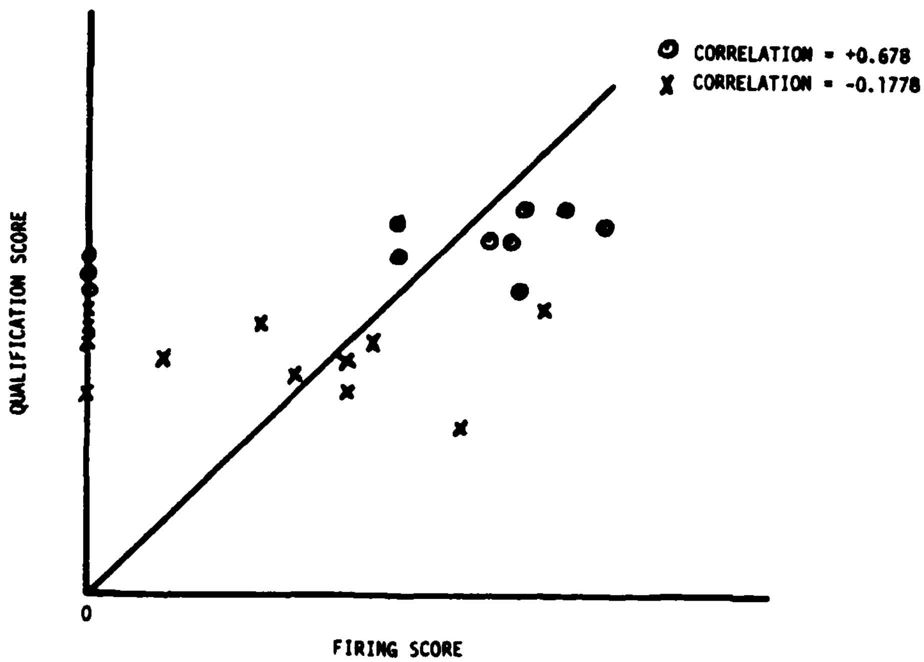

Figure 2. Qualification Scores as a Function of Demonstrated Scores and Compared to a Perfect Correlation Line

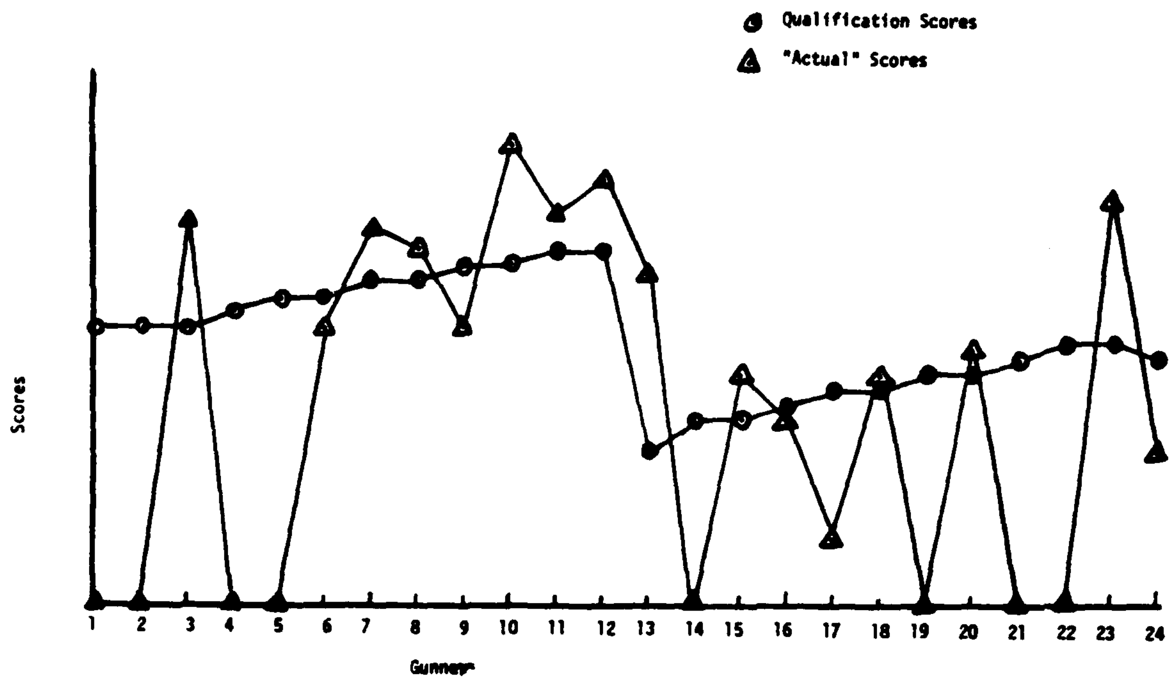

Figure 3. Qualification Scores as Compared to Actual Scores for 24 Group A Gunners

This indicated that a "dedicated" gunner or "designated" gunner concept would have to be adopted in order to achieve a satisfactory hit probability. However, since the SAT scores did not point out the "good" gunners, it was not possible to select those gunners. The SAGUMS Project Manager then requested this independent analysis to determine the implications of these results on the performance of the trainer and the system.

DISCUSSION

It was decided at the outset that the independent evaluation would utilize only the basic test data rather than any intermediate results or conclusions. One of the first areas to be examined related to the question of a learning process associated with firing the live round.

Examination of the data showed that some of the gunners that received training were not utilized in the live firing phase of the test. Some of the gunners were allowed to fire only one round while others fired in excess of ten rounds each. In general, as the number of rounds fired per gunner increased the total number of gunners decreased. It appeared evident at this point that some gunners were more accurate than others. This possibility indicated that an examination of learning should incorporate a consistent set of gunners. We began by examining those gunners that fired the greatest number of shots. Eight gunners fired at least nine rounds. The percentage of targets hit by these gunners was determined and is shown by curve X in Figure 4.

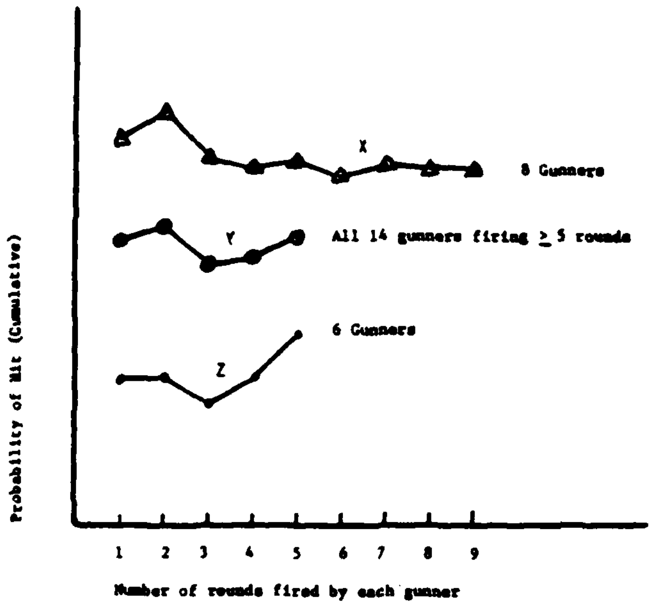

Figure 4. Demonstrated Probability of Hit on Subsequent Rounds

If a learning process were involved we should observe an increase in the probability of hit as the number of rounds fired per gunner increases. This does not occur. Curve Y in Figure 4 is the same type of data for the 14 gunners that fired at least five rounds. This curve contains results from the gunners in curves X and Z. The results have not been included for those gunners that fired only one round since nothing can be said about their learning.

The important thing to notice here is that if we grouped all these gunners results together (to plot probability of hit as a function of the number of rounds fired per gunner) it would appear that learning occurs after the fifth round. In fact what happens is that on the average we are eliminating some poor gunners. Examination of these data on a noncumulative basis or by consideration of variation in target posture leads to the same general result.

Consideration was next given to the problem of identifying "good" gunners by using only the SAT qualification scores. It was decided at the outset to eliminate, in this comparison, those gunners that fired only a few shots since it was not possible to obtain a good value for the actual score (several gunners had fired only one shot). It was noticed that the ratio of stationary to moving targets was approximately 3 to 1 during the live firings but was approximately 1 to 2 during qualification with the SAT. A significant difference (at the .05 level) existed between the probability of hit for stationary and moving target. This indicated that in order to predict the performance with the live round consideration must be given to the target condition (which should not be an unexpected requirement). The procedure used then was to develop a qualification score for stationary targets and one for moving targets for each gunner. These scores were then "weighted" according to the percentage of stationary and moving targets each gunner was to engage in the live firings. This weighted score became the predicted score for each gunner. The result of this procedure is shown in Figure 5. The regression line for this data has a slope of 0.94 and its intercept is 0.0024. The correlation coefficent is 0.76.

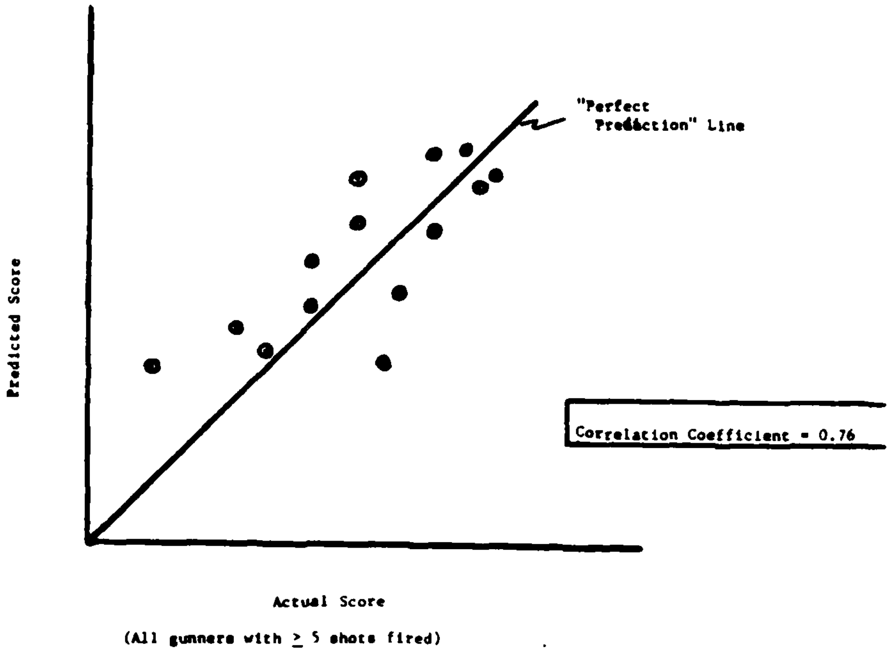

Figure 5. Predicted Scores as a Function of Demonstrated Scores and Compared to a Perfect Correlation Line

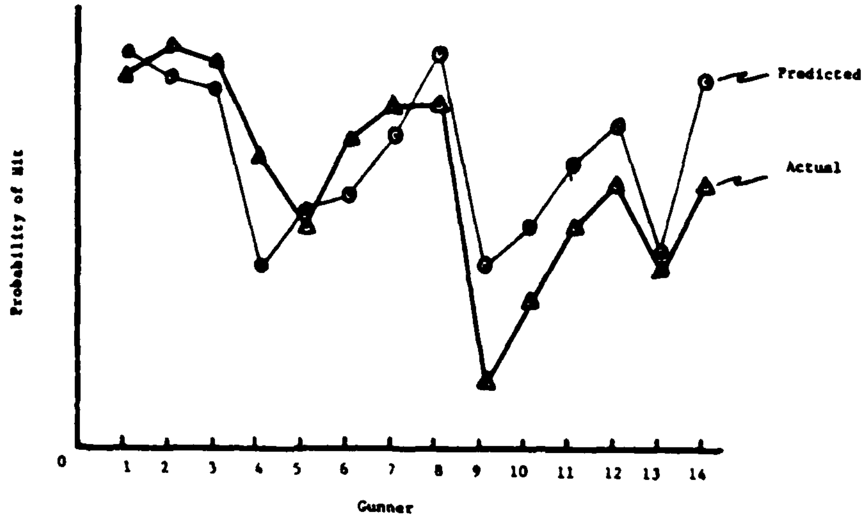

Figure 6. Probability of Hit for Each Gunner Using Prediction Methodology and Actual Values

These same results are shown in Figure 6 in a manner which gives a better visual image of the comparison. For all the firings by these gunners (as a group) the difference between the predicted and actual was 3 percent.

As previously indicated, some of the "better-than-average" gunners had fired a large portion of the rounds. When an overall probability of hit (using all rounds fired in the test) was determined the resulting value was biased toward the higher values. To attempt to overcome this bias the information shown in Figure 7 was developed. A predicted score was determined for each gunner using a proportion of stationary to moving targets equal to that used in the actual test (approximately 3 to 1). A cumulative average score for the 100 percentile indicates the overall score that should have been accomplished if each gunner had fired the same ratio of stationary to moving targets and were equally weighted. The triangle point in Figure 7 indicates the results obtained if the scores demonstrated by the gunners are equally weighted. The gunners are in the same order as above which accounts for the increase in the cumulative average score at some point of greater percentile (meaning that the ordering according to demonstrated scores was slightly different from the predicted score ordering).

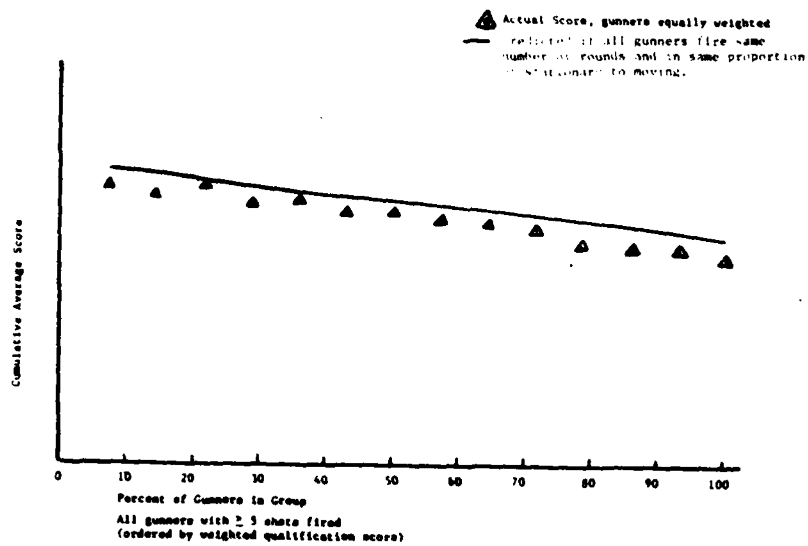

Figure 7. Predicted Scores of Various Percentiles of Gunners Selected According to Predicted Performance

The previous figures indicate the performance predicted and demonstrated by those gunners that fired at least five live rounds each. Since the prediction methodology appeared valid for those gunners that had established a score it seemed worthwhile to predict the performance of all the gunners. There were 30 gunners for which SAT scores had been obtained in the same manner as the gunners in the previous figures. This provides a larger base and also indicates how those gunners used in the test compared to the projected performance of the other gunners that had been trained.

Figure 8 presents the cumulative predicted scores as a function of the percent of gunners included (beginning with the best gunners). This figure includes all 30 gunners in the group and is calculated using the prediction methodology presented earlier in this paper. To obtain this figure, two assumptions were made. First, it was assumed that each gunner would fire the same number of rounds (that is, they were equally weighted). Second, it is assumed that they would engage the same ratio of stationary to moving targets as that utilized in the test (approximately 3 to 1).

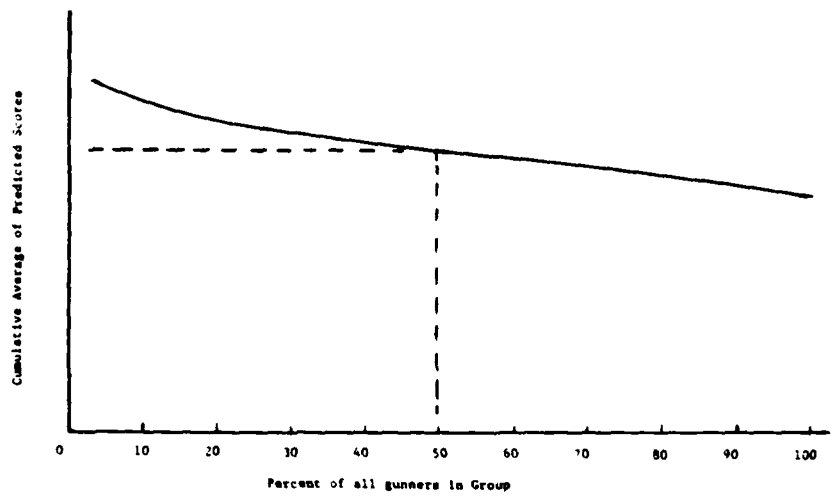

Figure 8. Predicted Scores of Percentiles Chosen from a Representative Group of Gunners

The dashed line indicates the cumulative probability of hit (Ph_{50}) predicted for the top 50 percent of all the gunners in the group. Note that this does not say that each of the gunners in the top 50 percent will have a probability of hit equal to Ph_{50} but rather as a group these gunners are predicted to probability of hit equal to Ph_{50}.

All of the previous projections were determined from a specific ratio of stationary to moving targets, namely that ratio as used in the test. If that ratio changes, then the projected probability of hit curve also changes. Figure 9 presents five different projected curves. The top curve is the cumulative probability of hit that would be projected as a function of the percent of gunners selected (starting with the best) if all targets are stationary. The bottom curve is the corresponding result for moving targets. The intermediate curves are for varying ratios of stationary to moving targets as indicated.

In order to relate these results to the QMR (which specified kill probabilities rather than hit probabilities) some single shot kill probabilities (SSKP) values were calculated for specific percentile values. Probabilities of kill given a hit for both stationary and moving targets were obtained from the test impact points. Also obtained was the demonstrated reliability. These values were applied to the probability of hit curves at specific points to determine the SSKP at the points indicated. This same procedure was utilized to determine the percentile point associated with accomplishing the QMR values for SSKP.

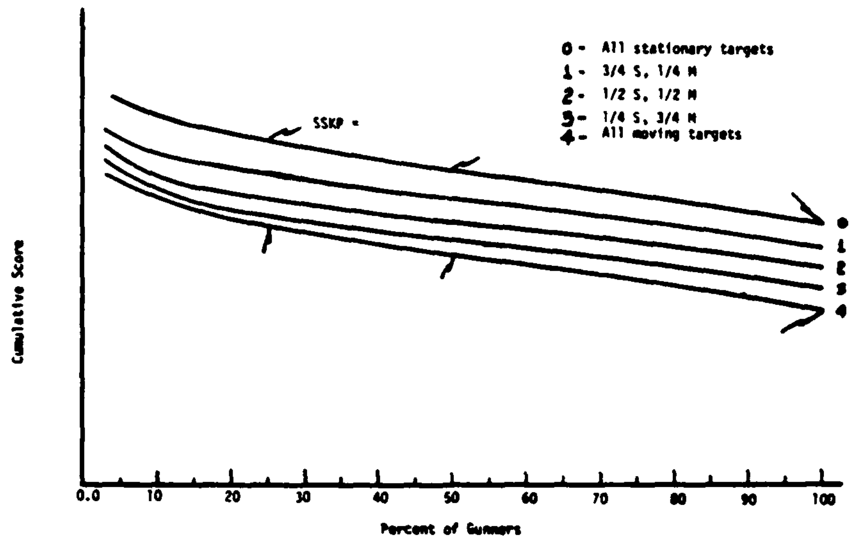

Figure 9. Predicted Scores for Different Ratios of Stationary to Moving Targets

CONCLUSIONS

1. The test data did not indicate the presence of a learning trend during the live firing phase of the test.

2. Hit probability is greater for stationary targets than for moving targets.

3. SAGUM Trainer (SAT) qualification scores can be utilized to predict the performance that can be achieved by individual gunners or a group of gunners.

4. The mean value of probability of hit demonstrated in the test does not result in an SSKP equal to the QMR value. Some of the gunners exceeded the requirement and some fell below the requirement.

5. In order to meet the QMR value of SSKP it would be necessary to select a specified percentage of the gunners based on the SAT scores.

DECISION RISK ANALYSIS
for
XM204, 105MM Howitzer, Towed
Reliability/Durability Requirements

Mr. Thomas N. Mazza
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INTRODUCTION

There is a continuous discussion between the user and the designer as to what the reliability and durability requirements for a weapon system should be. This is particularly true for weapon systems which are primarily mechanical such as howitzers. The user documents a need (through the MN or ROC process) for a system possessing reliability and durability significantly higher than previous systems. The designer on the other hand feels the user should accept any system which is at least as good as the existing weapons reliability and durability, since the new design will undoubtedly possess other characteristics such as increased range, reduced weight, etc. which the designer feels are the primary reasons for the new system and are, in themselves, inversely related to reliability/durability. (He has never been asked to design a totally new system strictly to increase reliability or durability:) When the discussions are over and a compromise is reached, the true benefit of the agreed-to requirement to the Army is questionable. Each side attempts to provide enough documentation to support its position.

This analysis develops a rationale for the reliability and durability requirements for the XM204, 105MM Towed, Howitzer while simultaneously defining a plan to test for those requirements. The system reliability requirement, subsystem durability requirements, reliability and durability uncertainties of the proposed design, and the number of prototypes and test lengths to establish reliability and durability parameters, are related to expected costs.

Certain of these factors are identified as variables. This lends to consideration and evaluation of alternative courses of action with the objective of reducing expected life cycle costs. The expected loss (life cycle cost for this analysis)of an alternative is identified as the risk of that alternative in accordance with standard statistical terminology[1].

REQUIREMENTS

As a result of DT/OT-II decisions will be made as to the acceptability of the entire system from a reliability viewpoint and on each of the four major subsystems from a durability viewpoint. Therefore reliability requirements must be specified for the total system and durability requirements must be specified for each major subsystem. It was assumed that a truncated test would be preferred to a fire to failure test for planning purposes. Therefore, a maximum number of rounds to fired or each system truncation point must be specified. As a total system configuration is

[1]Ferguson, T.S., Mathematical Statistics, A Decision Theoretic Approach, Academic Press, 1967.

required to conduct the test, the number of systems to be put on test must be specified along with the number of spare or replacement components. Also since statistical techniques produce not one but a family of alternative statements from the same test, the confidence level associated with the test must be specified. Additionally, each reliability and durability requirement must be specified. Rejection, fix and acceptance region were specified by the pairs (R_1,R_2) for reliability and (D_1,D_2) for durability (defined in the section "Loss Function"). Combining the above, the following set of requirements must be specified to define the requirements and statistical test environment for DT/OT-II.

System:

- Number of systems on test
- Reliability acceptance MTBF - R_1
- Reliability rejection MTBF - R_2
- Truncation Point - T_p
- Confidence Level

Subsystem:

- Number of spare subsystems - N
- Durability acceptance MTBF - D_1
- Durability rejection MTBF - D_2

The subsystem requirements must be specified for each major subsystem which are: the carriage, the recoil, the tube and the breech.

QUANTIFICATION

Research scientists and design engineers were interviewed to quantify their expectations regarding durability of the subsystems under their cognizance. Reliability expectations were developed by the WECOM Product Assurance Directorate based upon failure and stress data from the M102, 105MM Towed, Howitzer and expected stress levels and failure modes of the XM204.

The primary technique used to quantify the durability of the subsystem was presented by Stanford Research Institute at the 1972 US Army Operations Research Symposium. In essence, the design engineer is required to choose between two lotteries. Lottery No. 1 concerns the durability of the subsystem. The design engineer will win, say, one million dollars if the durability of the subsystem will be demonstrated less than X rounds (X is specified by the interviewer). Lottery No. 2 concerns the spin of a pointer on a wheel. The design engineer will win one million dollars if the pointer falls within the red sector. After a choice has been made by the interviewee, the red sector is increased or decreased with the object of making the interviewee indifferent between the lotteries. When the indifference has been obtained, the percentage of the exposed red sector is recorded as the belief of the interviewee in the occurrance of the event - subsystem durability is less than X rounds.

$$P[\text{durability} < X] = \%\ \text{red sector}$$

The process is repeated for various values of X until a probability distribution can be drawn. Two experts were interviewed for most of the major subsystems for which a durability requirement exists. The experts were either engineers working on the design of the subject subsystem or physical scientists with knowledge of the subsystem.

These data were input to the computer simulation in the form of a discrete distribution. The probability content of an interval was obtained (by subtraction of probability values at endpoints of the interval (and assigned to the midpoint of the interval. These distributions are presented in Table 1 for the distribution fit to the data.

TABLE 1
PRIOR DISTRIBUTION ON MEAN-ROUNDS-TO-FAILURE PARAMETER
SUBSYSTEM

	CARRIAGE		RECOIL		TUBE		BREECH		RELIABILITY	
	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB	MID-PT	PROB
1	2500	.05	2500	.24	4250	.32	48750	.03	1050	.10
2	7500	.05	7500	.14	4750	.16	56250	.07	1150	.15
3	12500	.05	12500	.13	5250	.12	63750	.40	1325	.15
4	17500	.04	17500	.15	5750	.10	71250	.30	1450	.10
5	22500	.04	22500	.15	6250	.10	78750	.13	1725	.15
6	27500	.04	27500	.16	6750	.08	86250	.07	2000	.10
7	32500	.08	32500	.03	7250	.06			2350	.10
8	37500	.15			7750	.06			2625	.05
9	47500	.25							3000	.05
10	52500	.25							3500	.05

The distribution quantify the uncertainty associated with the expected number of rounds to failure. The breech safe life and tube fatigue safe life were estimated to be one-third of this value. The expert opinion on the minimum safe life was higher than the optimistic estimates on tube wear life; this led to consideration of only tube wear in regard to estimating tube durability.

THE LOSS FUNCTION

The purpose of the loss function is to estimate the expected losses (expenditures which will occur when action is taken in accordance with the belief that the state of the system is S' when, in fact, it is S.

The contractually specified performance parameters, reliability ($\underline{R}$) and durability (D), are considered to be bounded by military necessity or cost-effectiveness. From the military necessity standpoint, reliability can be translated into the requirement that a battery, fire on the average, a specified number of rounds during a mission. A system with a lower reliability will, on the average, fire fewer rounds. Increasing the number of systems per battery will achieve this goal of a minimum-expected-number-of-rounds/battery/mission. If the resulting design of the systems does not meet the specified limits, this alternative can be used as an upper bound on the cost of the second alternative, that being to "fix-up" a marginal system. In all cases an additional alternative is to cancel the program and live with the existing system. The term "fix-up" as used here means that a reliability growth program will be entered. A sequence of design-test cycles will be conducted until the reliability is grown to the required level.

Similarly, durability is a requirement on the life of a system. Durability can be translated into the requirement that a system, on the average, survives a specified number of rounds before requiring an overhaul, or replacement when overhaul isn't applicable (i.e., tubes). A system with a lower durability will, on the average, survive fewer rounds before an overhaul is required. The cost of this lower than desired system durability can be estimated by the expected increase in overhaul/maintenance actions, over a suitable time frame.

Reliability Loss Function, $L(R,R')$

Definitions:

R - true value of system reliability

$\hat{R}$ - statistical estimate of R based on test data

R' - $= R_2$ if $\hat{R}$ not significantly less than R_2 (based on statistical test of hypothesis)

$= \hat{R}$ if $\hat{R}$ is significantly less than R_2

R_1 - a value of R' which is less than or equal to R_1 is cause for system rejection

R_2 - a value of R' which is greater than or equal to R_2 is cause for system acceptance with regard to reliability. This value is viewed as a requirement designed to insure that the expected number of rounds fired by a battery in a particular mission will not be below a specified level.

$L(R,R')$ - is the costs incurred in taking a course of action when R is the true reliability and R' its estimate.

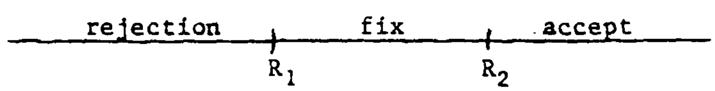
Consider a pair (R_1,R_2) to be defined such that if the true system reliability R were known, the following actions would occur (depending on R):

1. $R \leq R_1 \Rightarrow$ Action: Reject entire system

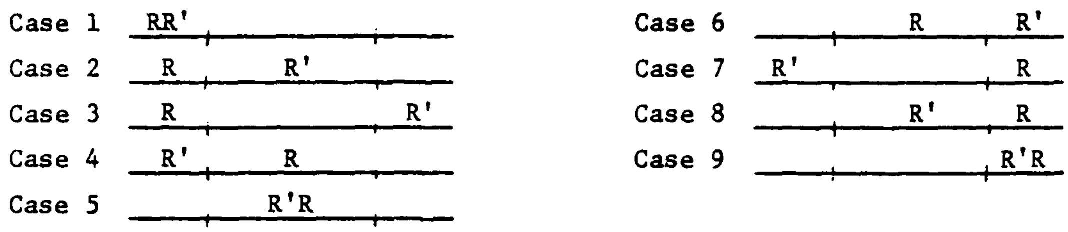
2. $R_1 < R < R_2 \Rightarrow$ Action: Fix - the system will be made acceptable, by entering a reliability growth program or fielding more systems per battery to insure the expected number of rounds criterion.

3. $R_2 < R \Rightarrow$ Action: Accept the system with respect to reliability. Unfortunately, the value of R is not known. Statistical techniques will provide an estimate, $\hat{R}$, from test data. This value will be compared to R_2 to determine if $\hat{R}$ is significantly less than R_2 on a statistical basis. If the test does not show a significant difference then action will be taken as though $R' \geq R_2$, otherwise we will take action as though $R' = \hat{R}$.

Consider the reliability decision space divided into three regions as shown below.



The actual or true reliability, R, could fall into anyone of the three regions. In addition, when we test the system the estimate R' could also fall into anyone of the three regions. As we increase the sample size of our test R' should asymptotically approach R, however, the cost of the test will also increase. As we lower the test cost or reduce the sample size then the expected difference between R and R' will increase. Therefore, there are nine possible states that could occur. They are:



The following discussion outlines a method for estimating the expected losses incurred for each of the three possible decisions when, in fact, R is the true system reliability. The nine cases as outlined above are grouped according to the decision that is made. Contained within the discussion of each case are several cost figures which are referred to as C_1, C_2, C_3, etc. The definition of each are as follows:

C_1 - The cost of extending the life of the present (M102/M101A1) system during a new development program (6 years)

C_2 - The cost of a new development program

C_3 - Cost of procuring and operating a second generation design during the remaining planned life (14 years)

C_4 - Cost of the planned first years procurement

C_6 - Cost of a redesign effort to correct a R failure mode

C_7 - Cost to procure one XM204

C_9 - Cost to operate and maintain one XM204 over 20 years

Decision:

Accept: RR' - Case 9

Under this case the true system R is acceptable and as a result of the test the system is accepted. The correct decision is made and the only cost incurred are the cost to procure and the cost to operate the weapon over the 20-year life cycle. The cost of R failures over the 20-years is based on the actual MRBF of the system.

$$L_9(R,R') = (C_7+C_9)(\text{No of Systems}) + (947.65)(\text{Total Rnds})/(\text{MRBF})$$

Accept: R R' - Case 6

Under this case the true system R lies within the fixup region and as a result of the test the system is accepted. An incorrect decision was made and the cost associated with this decision are as follows. Since it is thought that the system is good we go ahead with the first years production. However, after the first years production it is assumed that it will now be discovered that the true R is not as good as thought. A product improvement program is initiated and the system R is grown via a redesign-test cycle until the true system R is acceptable. Now since one years production has already been made a retrofit program will be needed. To cost this out it was assumed that it would cost a factor of two times the cost of an ordinary R growth program had it been determined (i.e., the right decision made) before the first years production was made, that the true R was not acceptable.

$$L_6(R,R') = (C_7+C_9)(\text{No of Systems}) + (2)(\underline{R}\text{ growth cost})$$

Accept: R ——+————+—— R' - Case 3

Under this case the true system R is definitely not acceptable, but as a result of the test the system is accepted. An incorrect decision was made and the cost associated with it are as follows. Since it is thought that the system is good we go ahead with the first years production. It is assumed that it will now be discovered that the true system R is definitely unacceptable, and the total system will be rejected. The cost of the first years production will be lost and a new development program will be initiated. The present system will have to be maintained and operated during the new development program which is assumed to last six years, per AR 1000-1.

$$L_3(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + C_4$$

Note: It is assumed that as a result of the new development program the new system will meet the specified MN requirements - This applies to all cases where a new development program is entered.

Reject: RR' ——+————+—— - Case 1

Under this case the true system R is unacceptable and as a result of the test the system is rejected. The correct decision was made. A new development program will be entered and the life of the present system will be extended. In addition, the cost of the prototypes and test cost for the first design will be lost.

$$L_1(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

Reject: R' ——+—— R ——+—— - Case 4

Under this case the true system R lies in the fixup region. As a result of the test the system is rejected. Therefore the cost described for Case 1 are incurred.

$$L_4(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

Reject: R' ——+————+—— R - Case 7

Under this case the true system R is acceptable. As a result of the test the system is rejected. Therefore the cost described for Case 1 are incurred.

$$L_7(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

Fixup: ——+—— R' ——+—— R - Case 8

Under this case the true system R is acceptable. As a result of the test a R growth program is initiated. Funds will be allocated based on R'.

It should soon be learned that the true R is acceptable, but since the funds have been allocated the growth program will continue. This will increase the true R which will lower the total life cycle R cost.

$$L_8 = (C_7+C_9)(\text{No of Systems}) + \text{Cost of } \underline{R} \text{ Growth Program}$$

Fixup: R R' - Case 2

Under this case the true R is unacceptable. As a result of the test a R growth program is initiated. The funds for the growth program will have been sunk and soon it will be realized that the system should be rejected. Consequently, a new development program will be started, and the cost of Case 1 will also be incurred.

$$L_2(R,R') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of } \underline{R} \text{ Growth Program}$$

Durability Loss Function, L(D,D')

There are two basic differences between the reliability loss function and the durability loss function. The first is that there are durability requirements at the subsystem level while reliability requriements are only at the system level. The second is in the concept of fixing a marginal system for reliability vs. accepting an increased maintenance burden for durability.

Definitions:

- D - true value of subsystem durability
- $\hat{D}$ - estimate of subsystem D based on test
- D_1 - a value of D' which is less than or equal to D_1 is cause for subsystem rejection
- D_2 - a value of D' which is greater than or equal to D_2 is cause for subsystem acceptance with regard to durability

$D' = D_2$ if $\hat{D}$ not significantly less than D_2

$= \hat{D}$ if $\hat{D}$ is significantly less than D_2

For each subsystem a pair (D_1,D_2) will be defined such that if the true subsystem durability D were known the following actions would occur, (depending on the value of D).

1. $D \leq D_1 \Rightarrow$ Action: Reject subsystem

2. $D_1 \leq D \leq D_2 \Rightarrow$ Action: Fixup - The cost incurred to maintain the subsystem at D vs. D_2 will be used as an upperbound for the cost of this action.

3. $D_2 \leq D \Rightarrow$ Action: Accept subsystem, plan to maintain subsystem based on D_2 being the true durability.

However, the value of D is not known. Statistical techniques will provide an estimate $\hat{D}$ from test data. This value will be compared to D_2 to determine if $\hat{D}$ is significantly less than D_2 on a statistical basis. If the test does not show a significant difference then action will be taken as though $D' \geq D_2$, otherwise we will take action as though $D' = \hat{D}$.

Similar to the reliability decision space, the durability decision space is divided into three regions as shown below:

Reject	Accept/Marginal	Accept
D_1		D_2

As with the reliability the true durability D could fall into anyone of the three regions as could the estimate D'. Therefore, there are nine possible states that could occur. There are:

	Reject	Accept/Marginal	Accept
Case 1	DD'		
Case 2	D	D'	
Case 3	D		D'
Case 4	D'	D	
Case 5		DD'	
Case 6		D	D'
Case 7	D'		D
Case 8		D'	D
Case 9			DD'

There are only three instances where the decision would be to reject the subsystem, namely Cases 1, 4 & 7. If any subsystem is rejected then the cost incurred are the same as those that would occur for a reliability rejection. A new development program will be entered and the life of the present system will be extended. In addition, the cost of the prototypes and the test cost for the first design will be lost.

$$L_{1,4,7}(D,D') = C_1 + C_2 + (C_3)(\text{No of Systems}) + \text{Cost of Prototypes} + \text{Test Cost}$$

In all other cases the subsystem will be accepted, however, the expected number of renewals E[N] (overhauls) will differ depending on the decision space. For Cases 2,3,6 & 9 the expected number of renewals will be calculated based on the true mean time between durability failure D. For Case 8 the estimate D' will be used to calculate the expected number of failures. And for Case 5 the minimum of D and D' will be used.

$$L_{2,3,5,6,8,9}(D,D') = (E[N])(\text{Cost/overhaul})(\text{No of Systems})$$

For Cases 2,3,6 & 9 the test estimate D' is the mean time between overhaul the subsystem is thought to have. Once the end item is fielded, the true durability D is the actual maintenance burden that will be exhibited, therefore, the expected number of renewal based on D is the true cost. It would have to be overhauled at D.

For Case 8 the planned overhaul time would be based on D' and since D > D' it will not be possible to take advantage of the full designed durability. Therefore, the E[N] is based on D'.

For Case 5 the calculation of E[N] is based on the Min(D,D'). If D > D' then D' will be used as for Case 8. If D' > D then D will be used as for Cases 2,3,6 & 9.

Total Loss

The total expected cost if the system is accepted, is the sum of the reliability and durability losses. However, if any subsystem is rejected for durability or if the system is rejected for reliability then a total redesign stage is entered. It is assumed that no matter what magnitude of improvement is required during the redesign stage, when the "new" system is tested it will meet all MN requirements regardless of what level the requirements are set at. The expected number of durability and reliability failures for the "new" design are calculated on the basis of the MN requirements over the remaining 14 (20-6) years.

PARAMETER SPACE

The procedure adopted for pursuing the objective of the study was to search over the relevant variables and choose that combination which yields the lowest expected loss.

The system reliability requirement for the XM204, states a minimum acceptable average number of rounds between failure (MRBF). This requirement assumes MRBF to be constant during the operating life of the system. A constant MRBF will be assumed for this study with respect to reliability. Subsystem durability requirements are expressed in terms of a subsystem operating no less than a specific number of rounds with a specified probability; e.g.,

$$\text{Prob [Subsystem Life} > 500 \text{ rounds]} \geq .5$$

A direct search with acceleration was adopted for searching the parameter space for parameter vectors yielding lower expected losses. This routine makes steps on either side of the baseline to establish a direction for each of the parameters (variables in this context) and takes larger or smaller steps in the established direction (constrained by a specified number of step cuts), until not further improvement can be made in the objective function, which in this case is expected loss.

The initial baseline reliability/durability validation test plan and requirements are presented in Table 3. The test of hypothesis confidence level (Table 2, A6) pertains to the test conducted on the statistic under consideration. (i.e., test data is used to generate a statistic which estimates durability, say $\hat{D}$. Is D significantly different than the desired durability D_2?

TABLE 2

BASE LINE PARAMETERS

A. Test Parameters

1. No. Carriage Subsystems - 3
2. No. Recoil Subsystems - 3
3. No. Tubes - 12
4. No. Breech Subsystems - 3
5. Truncation Point - 22,500
6. Test-of-Hypothesis Confidence (Assumed) - 90%

B. Reliability/Durability Parameters

1. Reliability Rejection, R_1 = 1500
2. Reliability Acceptance, $\hat{R}_2 = R_1$
3. Durability Rejection, (0,D)

   a. D_1 (Carriage) = 22,500

TABLE 2 CONTINUED

b. D_1 (Recoil) = 22,500
c. D_1 (Tube) = 7,500
d. D_1 (Breech) = 22,500

4. Durability Acceptance, (D_2,∞)

a. D_2 (Carriage) = D_1 (Carriage)
b. D_2 (Recoil) = D_1 (Recoil)
c. D_2 (Tube) = D_1 (Tube)
d. D_2 (Breech) = D_1 (Breech)

TEST PLAN

During DT/OT a certain number (N_1) of howitzers will be placed on test. For testing purposes the howitzer is composed of one critical subsystem (the carriage) and several major non-critical subsystems (recoils, tubes & breeches). Each howitzer will be fired until one of two events occur:

(1) a carriage durability failure occurs,
(2) a specified number of rounds, t_p, have been fired.

A maintenance support test package will accompany each weapon and among its contents will be N_k spare prototypes for each of the major non-critical subsystems (N_2 - Recoil, N_3 - Tube, N_4 - Breech).

A total system configuration is required to conduct the test, however with respect to probability of failure, each subsystem is assumed independent. During the course of the test as each non-critical subsystem durability failure occurs, the failure time is noted, and the failed subsystem is replaced until either:

(a) all of the spare prototypes of type k have suffered a durability failure,
(b) the carriage has suffered a durability failure or has fired t_p rounds.

If all of the spares of a particular type subsystem have failed before (1) or (2) above occur, then that subsystem will be "patched-up" to allow the test to continue until either (1) or (2) does occur. However, no additional information will be collected on that weapon for that subsystem.

When a reliability failure occurs for any subsystem the failure time is noted and the failure is repaired to allow the test to continue. The repair will be assumed as-good-as-new and each reliability failure is assumed independent.

A hypothetical design and observation of this type of test is shown in the following example:

Example 1:

Number of Carriages, N_1	3
Number of Recoils/carriage, N_2	4 (original + 3 spares)
Number of Tubes/carriage, N_3	7 (original + 6 spares)
Number of Breeches/carriage, N_4	2 (original + 1 spare)

t_p = 22,500 rounds

The above test design depicts a test where three howitzers will be fired for a maximum of 22,500 rounds each. Each carriage has three spare recoils, six spare tubes, and one spare breech in its maintenance support test package.

Test Observations

	Reliability Failures	Durability Failures
Carriage #1	3085, 5667, 15594	15597
Recoil #1.1	8766, 10729	No observed failure
Tube #1.1		6648
Tube #1.2		8823
Tube #1.3		14402
Tube #1.4		No observed failure
Breech #1.1		No observed failure
Carriage #2	8020, 16672	No observed failure
Recoil #2.1		9166
Recoil #2.2	13587, 18178	20293
Recoil #2.3		No observed failure
Tube #2.1		6822
Tube #2.2		13339
Tube #2.3		20122
Tube #2.4		No observed failure
Breech #2.1	22498	
Carriage #3	5552, 9229, 18178	No observed failure
Recoil #3.1	11443	11666
Recoil #3.2		16674
Recoil #3.3	22498	No observed failure
Tube #3.1		7270
Tube #3.2		17924
Tube #3.3		No observed failure
Breech #3.1		No observed failure

The above failure times are the number of rounds on the carriage at the time the failure occurred. Carriage #1 has a durability failure at 15597 rounds at which time all testing was stopped on that weapon. Testing on Carriage #2 and #3 were stopped at the predetermined truncation point of 22,500 rounds.

Associated with weapon #1 were five reliability failures which occurred at the times shown. Three of the reliability failures occurred on the carriage and two occurred on the recoil. The original recoil did not have a durability failure and lasted until the carriage failed or 15597 rounds. The original tube was replaced at 6648 rounds, the first spare was replaced 8823 rounds, and the second spare was replaced at 14402 rounds. The last tube did not fail in the remaining 1195 rounds. The original breech survived the 15597 rounds.

Test Statistics

The observations as outlined in Example 1 were generated from the two parameter Weibull distributions as shown below. Along with the true values are shown the estimates which are based on the observations.

	True	Estimate
Carriage		
	Shape parameter = 2.48642	$\hat{\alpha}$ = 3.15846
	Scale parameter = $.449008 \times 10^{-11}$	$\hat{\lambda}$ = $.775047 \times 10^{-14}$
	with MTBF = 31,613 rounds	$\hat{\mu}$ = 26,152 rounds
Recoil		
	Shape parameter = 1.21277	$\hat{\alpha}$ = 2.05138
	Scale parameter = $.487712 \times 10^{-5}$	$\hat{\lambda}$ = $.379892 \times 10^{-8}$
	with MTBF = 17,728 rounds	$\hat{\mu}$ = 10,644 rounds
Tube		
	Shape parameter = 1.995004	$\hat{\alpha}$ = 2.833641
	Scale parameter = $.2712387 \times 10^{-7}$	$\hat{\lambda}$ = $.1150474 \times 10^{-10}$
	with MTBF = 5,164 rounds	$\hat{\mu}$ = 6,371 rounds
Breech		
	Shape parameter = 1.911326	-
	Scale parameter = $.7511622 \times 10^{-9}$	-
	with MTBF = 5,328 rounds	-
Reliability		
	Shape parameter = 1	α = 1
	Scale parameter = $.26666 \times 10^{-3}$	$\hat{\lambda}$ = $.28058 \times 10^{-3}$
	with MTBF = 3,750 rounds	$\hat{\mu}$ = 3,564 rounds

Consider the following as the requirements for the test

	Carriage	Recoil	Tube	Breech	Reliability
D_1	11,000	8,000	5,000	15,000	
D_2	22,500	22,500	7,500	22,500	
R_1					1,790
R_2					3,795

then based on the test results the following decision would be made.

Durability

Carriage - Accept - Case 9
Recoil - Accept - Case 5
Tube - Accept - Case 5
Breech - Accept - Case 3
Reliability - Fixup - Case 6

RECOMMENDATIONS

In accordance with the definitions prescribed within this report, the following table outlines the "optimized" results of the simulation.

TABLE 3

Test Description

N_1 - Number of Prototypes to be put on Test - 3
N_2 - Number of Spare Recoils/Prototypes - 5
N_3 - Number of Spare Tubes/Prototypes - 13
N_4 - Number of Spare Breeches/Prototypes - 3
Max Number of Rounds to be Fired/Prototypes - 20,000
Confidence Level for Test of Hypothesis - 90%

Requirements

Carriage	D_1 - 13,500		Breech	D_1 - 7,500	
	D_2 - 21,000			D_2 - 16,000	
Recoil	D_1 - 6,000		Reliability	R_1 - 400	
	D_2 - 10,500			R_2 - 1,500	
Tube	D_1 - *				
	D_2 - *				

*No Recommendation, See Section "Sensitivity and Conclusions

With the above test description and requirements, the expected total test cost is $6,423,010.80 which can be broken down into $3,751,500 for prototype cost and $2,671,510.80 for ammunition. Other expected values associated with the simulated test are shown below in Table 4.

TABLE 4

Sample Size = 500

E[N] Carriage Failures During the Test = .948
E[N] Recoil Failures/Carriage = 5.68
E[N] Tube Replacements/Carriage = 8.494
E[N] Breech Failures/Carriage = .144

Number of Occurrences for Each Case*

Case No.	1	2	3	4	5	6	7	8	9
Carriage Durability	50	2	15	1	0	27	0	2	403
Recoil Durability	149	0	10	11	1	55	2	4	268
Tube Durability	-	-	-	-	-	-	-	-	-
Breech Durability	0	0	0	6	1	127	1	0	365
System Reliability	0	0	0	0	0	136	0	2	250

*See Section "Loss Function" for definition and explanation of each case.

Probability of Not Rejecting System at DT/OT-II

Carriage Durability	-	87.6%
Recoil Durability	-	71.4%
Tube Durability	-	-
Breech Durability	-	99.0%
System Reliability	-	100.0%
TOTAL SYSTEM		61%

Expected Total 20 year life cycle cost = $6,223,908,800.00

SENSITIVITY AND CONCLUSIONS

A sensitivity analysis was conducted by varying the input probability distribution for each subsystem and system reliability as outlined in the section "Quantification of Performance Uncertainties." The difference in the total 20 year life cycle cost as compared to the "optimized case" are shown below.

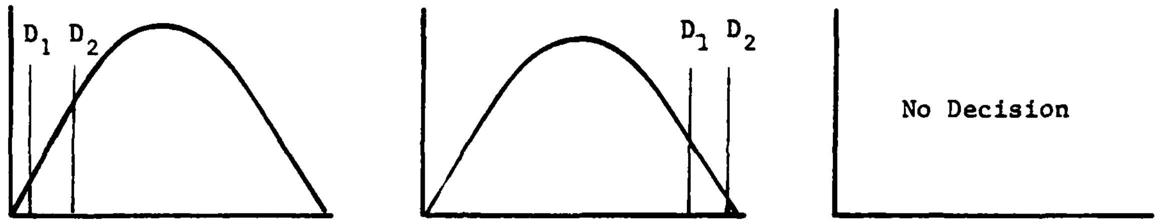
Subsystem	Direction	Difference ($ x 10^6)
Carriage	Pessimistic	+ .991
	Optimistic	- 2.789
Recoil	Pessimistic	+ 2.6414
	Optimistic	- 2.7834
Tube	Pessimistic	+ 31.9099
	Optimistic	- 6.5098
Breech	Pessimistic	+ 5.1265
	Optimistic	- 2.3168
Reliability	Pessimistic	+ .6303
	Optimistic	- 7.2014

The estimate of the standard deviation σ for the total life cycle cost, due to random occurrence is ~ $1.3846 x 10^6, therefore $2\sigma = 2.7692$ and $3\sigma = 4.1538 \times 10^6$.

Since the tube showed the highest variability and was considerably outside the 3σ range it was decided to further study the tube durability requirements. Holding all other parameters at the "optimize" values, the parameters D_1 and D_2 for the tube were varied with the following results.

	Life Cycle Cost	Probability of Acceptance/ Without Redesign
$D_1 = D_2 = 1,000$	6.647478×10^9	100%
$D_1 = D_2 = 3,000$	6.313495×10^9	99.9%
$D_1 = D_2 = 5,000$	6.254015×10^9	95.6%
$D_1 = D_2 = 7,500$	6.243281×10^9	59.2%
$D_1 = D_2 = 10,000$	6.238615×10^9	27.6%

In each of the above outcomes, the life cycle cost was based on replacing the tube at D_2 rounds. Since there was almost no risk associated with building a tube that would last 1,000 or 3,000 rounds and the difference in total life cycle cost is above $300 million there is no reasons not to demand the 3,000 round tube. Similarly, a $59 million savings can be expected with only a 4% probability of rejection increase by requiring a 5,000 round tube. As the durability requirement is increased to 7,500 and 10,000 the percentage of savings vs. the increased probability of rejection makes one question the advisability of demanding these higher requirements. Since the simulation considers a $1 savings just as important as a $1 billion dollar savings in its effort to optimize and in addition it was assumed that the state-of-the-art was no barrier; the simulation forced the recommended durability values for the tube to the upper boundary set in the simulation. Realizing that the state-of-the-art would be a barrier at these high levels one additional sensitivity run was made. The program test logic was changed to ignore any tube requirements and the life cycle cost was calculated based on replacing the tube at whatever wearout life could be designed for each iteration. (This would be similar to using pull-over guages.) This resulted in a total life cycle cost of 6.2239×10^9 which was even less when $D_2 = 10{,}000$ rounds. In an effort to explain this outcome consider the following three cases.



Case 1 Case 2 Case 3

The curve represents the prior probability density of the expected tube durability parameter. D_1 and D_2 define the acceptance, fix rejection region defined earlier (See Loss Function). Assume the probability density curve is the same for all three cases.

In Case 1 the rejection region is inconsequential in contribution to the expected loss. The acceptance region is large, but the longer durability life is not considered as tube replacements are based on the acceptance requirement D_2 (See Loss Function Case 9). In Case 2, the acceptance region is inconsequential. The rejection region is high in probability causing frequent rejection of the system with resulting expenditures in development of a system that meets the specified requirements, D_2, for all subsystems; and additional testing funds to validate these requirements.

Case 2 was preferred to Case 1 as the additional expenditures produce high durability while much of the predicted durability would not be utilized under Case 1.

Case 3 was preferred to Case 2: Again $D > D_2$ occurs with small probability. $D_1 < D < D_2$ results in expenditures which are approximately the same for Cases 2 and 3. If $D < D_1$ then Case 3 replaces tubes based on test estimates of durability avoiding the waste incurred by Case 1 and the expense of a new development program recommended in Case 2.

These recommendations are sensitive to the predicted estimates on tube durability. A pessimistic prediction of tube wear leads to a recommendation of Case 2 over Case 3.

The conclusions of this analysis are:

1) Expected loss is highly dependent on tube durability.
2) Sufficient tube testing should be performed to establish tube durability rather than base replacements on requirements.
3) Attainment of higher tube life is a basis of rejecting the program according to the logic of the simulation. A more realistic action would be initiation of a program to achieve a state-of-the-art tube.

4) A study should be initiated after test to evaluate the durability of the tube compared to the state-of-the-art. A study similar to this should be performed to determine benefits to be derived from accepting the tested tube design or, alternatively proceeding with a tube development program.

5) No decision regarding a tube durability requirement should be made at this time in view of the sensitivity of this parameter.

For the carriage, recoil and breech durability the "D" values as shown in the "RECOMMENDATIONS" section represent the recommended design goals or acceptance for each subsystem. The sensitivity analysis conducted by varying the prior probability distribution for each subsystem show that if the designers risk profile were in error up to 25% in either direction, the difference in the total expected loss is still close to the variability of the simulation and therefore the results are not overly sensitive to these inputs within the ±25% bands. The analysis of the simulation indicates that the reduced maintenance/replacement cost that would result by raising the D_2 values does not offset the expected increase in loss due to the increased probability of system rejection and the associated redesign-retest and related cost.

The D_1 values represent the minimum acceptable durability values. Any subsystem design which falls below these values should be rejected. Below these points the combination of redesign cost, retest cost, probability of rejection, and cost of continuing the present system are favorable as compared to the increased maintenance/replacement cost that would be incurred by fielding a weapon system with these low values.

For system reliability the R_2 value represents the design goals and the reliability value at which the system should be fielded. The R_1 value represents the lowest value for which it would be advantageous to enter into a reliability growth program and grow the system reliability to R_2. (This is based on a "Duane" growth model with a slope of .523.) An analysis of the simulation indicates that this growth slope is extremely optimistic and that a more realistic growth model needs to be developed before any recommendation can be made on the value for R_1. If the system reliability falls below R_1 then the system should be rejected and a complete redesign effort should be initiated. Until a more realistic growth model can be incorporated into the simulation, it is recommended that reliability level presently exhibited by the M102, 105MM Howitzer system be used for R_1, i.e., 400 rounds.

Use of Computer-Assisted Wargaming in Force Development Testing

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Wargames have historically been used to assess the capabilities and limitations of a force concept without fielding such a force. The advantages of wargames are obvious; no real casualties, the game can be played, adjusted, analyzed and discussed, documented and reanalyzed as required. There are limitations, however, in that game results are vulnerable to challenge because of real or imagined discrepancies in game rules, routines, forces, or unrealistic game play. Because of these limitations, concepts are usually subjected to field evaluation by a "user" or tester in the environment applicable to the particular concepts under examination. MASSTER (Modern Army Selected Systems Test Evaluation and Review), located on Fort Hood, Texas, fields and tests dozens of concepts yearly. Some of these evaluations are simple man/machine relationships, other examinations deal with large size forces requiring detailed planning, a long lead time for preparation, and large land areas for execution.

Wargaming was suggested as a means to assist Project MASSTER, the forerunner to MASSTER, in speeding up the evaluation process and enhancing the product of force development testing. The first attempt was to develop wargames for analysis of the concepts to be tested; i.e., use the game to answer questions posed by the evaluation. An exhaustive survey was made of computerized and computer-assisted games in order to take advantage of capabilities already in being. What started out with great promise ended with the realization that wargames could not be used in the conventional way in an effective manner.

The force development testing that is amenable to wargames are those tests of company or larger size units. The units may be armor, infantry, airmobile infantry, mechanized or aviation, or composite units.

A complicating feature to the use of wargames in testing is the lack of commonality among tests. Although there may be common features, a given test will vary markedly from other tests not only in size and complexity, but also in the type questions to be answered and the environment in which the test is to be conducted. Therefore, a new game would need to be developed for each evaluation to preclude erroneous stereotyping.

With the foregoing as background, an effort was made to identify and define those common factors of tests that might be responsive to gaming techniques. In gross outline, they were determined to be as shown in figure 1.

A brief description of the game and how it functions is presented in order to facilitate an understanding of how it is used.

The MASSTER wargame is computer-assisted. It is operated on line from differing sites as the need arises. The computer is an IBM 370/145, located at Central Texas College, approximately four miles from Headquarters, MASSTER. The input/output devices are a Hazeltine 2000 CRT, keyboard and printer. They are linked to the computer by means of a telephone line.

The game requires that a unit involved in an evaluation be described to the detail that permits analysis. For example--it may be desirable to look at platoon operations as part of the evaluation of a company.

TEST PLANNING

Scenario Evaluation
Data Collection Planning
Training

TEST CONDUCT

Event Recorder
Casualty Assessment Assistance
Resupply
Combat Ratio

POST TEST ANALYSIS

Event Reconstruction
Force Interaction and Results

Figure 1. Common Factors of Tests

In this case, look-up files are constructed--files describing the company and its organization to include platoons and the sections or squads of the platoons. The other files contain the equipment of interest. In a tank company this would be the organizational structure (the company headquarters, numbers and types of platoons), number of tanks in the sections of the platoon, and associated firepower scores for each tank. Described organizations, weapons, and items of equipment have unique codes that are used in any action in which they may be involved.

Rules and firepower scores for each game are determined beforehand based upon FM 105-5 Maneuver Control, supplemented by rules from other games, studies, combat and test experience. Some rules may be used repeatedly

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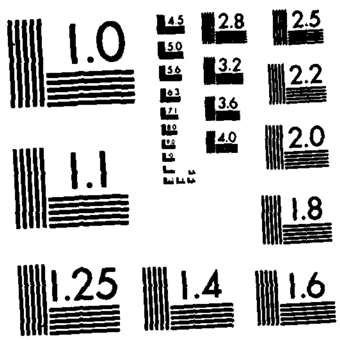

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

for different evaluations; others, however, must be the logical consequence of analysis of the concepts to be tested. For example, pilots flying nap-of-the-earth on an anti-tank mission behave differently than those not so engaged.

The discussion that follows is based upon a typical use of the game in a two-sided analysis.

As indicated in figure 2, unit files are set up on IBM cards that contain information on structure, personnel, equipment, weapons and firepower scores. The equipment file contains items of interest such as trucks and tanks. The weapons file contains weapons and associated firepower scores. Once the files are complete, a printout of pertinent data is furnished the appropriate force for review, information, and use. Each team then issues an operation order. Depending upon the purpose of the game, the play may be either one-sided or two-sided; open or closed. The blue and red commanders issue operation orders based upon their mission and the situation confronting their forces. Control uses these operation orders to move the forces according to predetermined rules until forces interact. The interaction is evaluated and casualties assessed by control. This assessment is placed on the automated file by means of the terminal keyboard. Losses of both men and equipment are identified by unit, location in eight digit coordinates, and date at time of the assessment. Resupply is accomplished by inputting replacement items based upon the loss data and time. The results of each interaction or action is displayed on the CRT. If desired, a printout of the displayed information can be furnished the players and control. This process is continued until the last situation is completed at which time the game is ended.

In the testing cycle, planning-conducting-reporting, the first opportunity to use the capabilities of the game is in test planning shown in figure 3.

Scenario Evaluation.

Scenario writers use the game to review the scenario, event by event, to determine whether the required number and types of events are included in the test. The tendency in test planning is to include more in a scenario than can actually be accomplished in the field in the time allotted. Also, events may be so disparate that the unit may not be able to reconfigure in a logical fashion in the time allotted. Exposing the scenario to critical review by test planners acting as adversaries helps to identify these and other problems.

Data Collection Planning.

A review of the essential elements of analysis, those specific bits of required information, against a played event will suggest ways to collect the data or it will indicate that there is a high probability that the

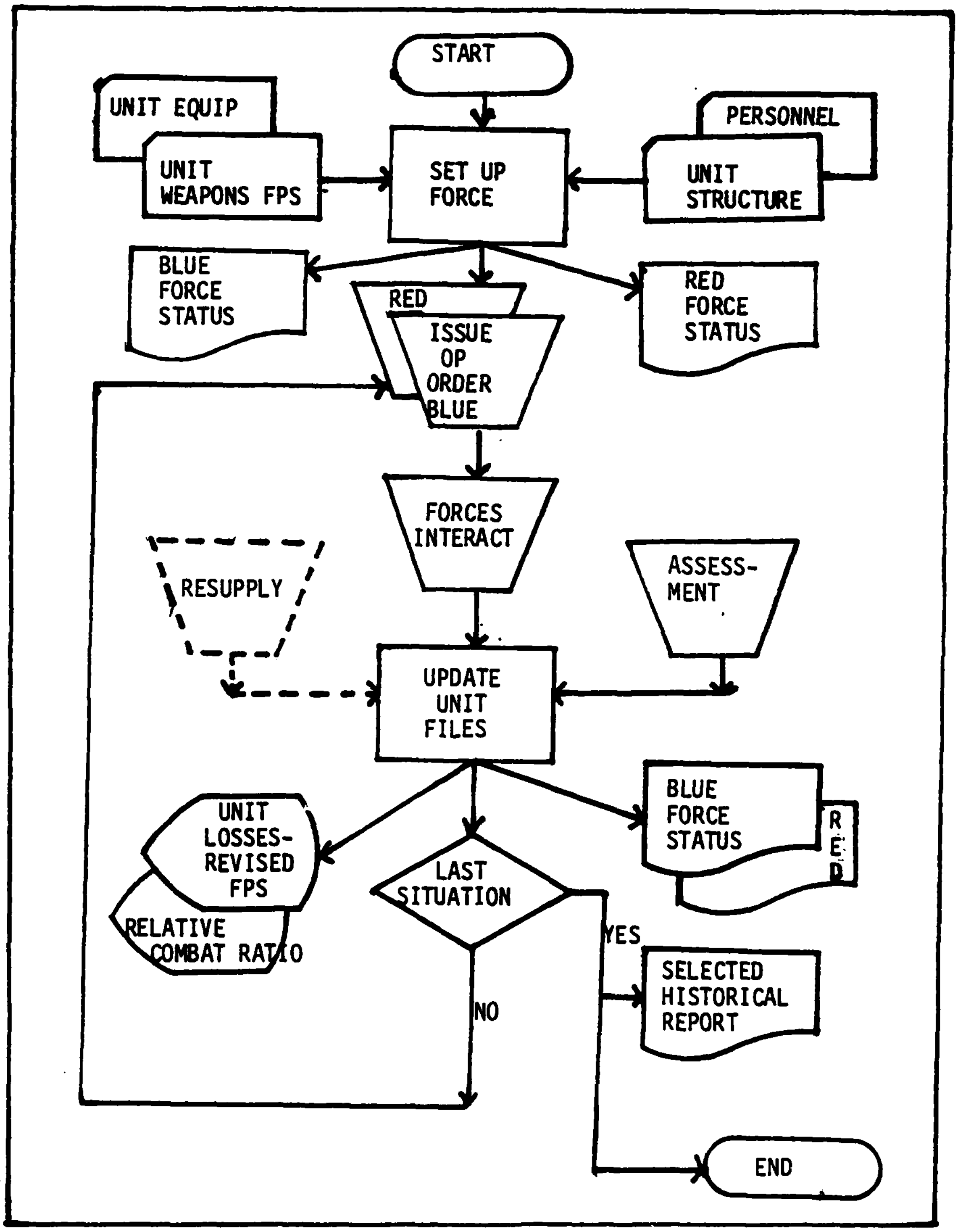

Figure 2. Game Flow Chart

Scenario Evaluation
Data Collection Planning
Training

Figure 3. Test Planning

data will not be collected because of a number of things such as lack of time to have collectors at the time and place required; events will probably not occur as envisioned in the draft scenario; or inadequate numbers and types of collectors are planned for the test. The review may also indicate where savings in personnel and equipment may be made.

Training.

The game provides valuable training for the test controller since he has to visualize the events as if they were occurring in the field in order to provide realistic continuity to the game play. This visualization will assist him in determining crunch points that will stress the planned control organization, particularly if the test is relatively free play in nature. Different commanders may react differently in a given situation; however, they have limited choices that are reasonable. In combat, one of the penalties for a poor choice is a higher casualty list. The controller can simulate this condition by casualty assessments to the extent he deems appropriate. As long as the assessments are reasonable, considering all factors, the attrition assessed against a force can influence the commanders thinking and action. In order to safeguard the security of the actual test scenario, a training scenario is used. The training scenario uses a different map area than that of the test scenario and a different sequence of events. Only representative events that will highlight major test objectives are played by the commanders and selected staffs of the test units and the aggressor. The benefits derived from the play are a higher probability that individuals will be better informed as to the doctrine, tactics and techniques that are under investigation and a more cooperative relationship between players and test control. The training scenario may be used for the pilot test which further enhances the training of all concerned.

The conduct of the test provides the opportunity to assist in providing realism to the opposing forces in the field. This is done by providing the services as described below.

Casualty Assessments Resupply Combat Ratio

Figure 4. Test Conduct

Event Recorder.

Controllers at the scene of significant happenings determine what would have occurred had the events occurred in actual combat. Naturally, this is a product of the individual's background and motivation.

Casualty Assessment.

The losses by type, numbers, time, location, and unit or sub-unit are transmitted by radio to control headquarters by the controller making the assessment. The transmissions are monitored by the support team that operates the input/output devices located in the test control center. These losses are entered into the system which performs a bookkeeping function and displays the results. A new status report for each unit of interest can be made available at this time, as required. Care is required to provide the information in a realistic manner rather than automatically furnishing it as it becomes available. The results are provided the units and controllers in the test within a matter of minutes when such action is appropriate. The chief controller at any time can obtain the current and past status of any unit or sub-unit in the test.

Resupply.

If logistics are being played, a resupply action must be performed by the tested unit using the resupply procedures specified for the test. The test control structure or an actual support organization determines when the replacement item is or would have been available to the unit. The information is entered into the system which updates and displays the results. The resupply action is keyed to a prior loss action giving date time and place of loss. The time from loss to receipt of an item is the resupply time. Any loss is carried until positive action is taken to resupply the needed men or items involved in the loss.

Attrition of weapons results in a lower total firepower score for a unit and eventually a shift in combat ratio when confronting an enemy. This combat ratio is a key indicator as to what a unit may or may not accomplish. Other factors considered by the controller making an assessment are variables such as the type of forces and engagement, deployment of forces, terrain, weather and time of day.

Event Reconstruction Force Interaction and Results

Figure 5. Post Test Analysis

The data in the game file is useful in reconstructing what occurred during the test.

Event Reconstruction.

At the completion of the test, disgorging of all the file in the sequence that items were entered is possible. This may be useful for reconstructing what happened during the entire test, particularly when used with the test control log or annotated test scenario. The planned test scenario will usually be of little value for a detailed transcript of what happened in the test since deviations will usually have occurred during the test. The system can provide valuable data in filling gaps and indicating the action taken to amplify portions of the scenario as it was executed.

Force Interaction and Results.

The test analyst can cut the data in practically endless ways. For example, he may want to review losses by type of weapon by time of day, or he may desire to determine total and mean time for resupply of a certain item. He may want to review incidents when certain types of losses were greater than a specified number. The wargame data does not eliminate the need for other data, rather it enhances and clarifies that collected by other means.

The game has been successfully used in a large scale test involving both ground and air elements. It was used to review the scenario and control measures prior to the test resulting in significant changes to both. Results of engagements during the test were especially well received by test controllers and test unit commanders. The data collected were used to a limited extent to assist in report writing.

Plans call for the game to be used in appropriate tests. Minor modification is currently being accomplished on the input/output interface to speed up and simplify the display of information for both controller and players.

AD P000633

Simulating Indirect Fire Effects in Field Experimentation

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Experimentation Command

As the Army's only field experimentation laboratory, the Combat Developments Experimentation Command (CDEC) experiments with developing concepts and material using sophisticated instrumentation to produce objective data on these developmental options. Throughout its seventeen year existence, CDEC has constantly strived to improve its product through improvements in methodology, instrumentation, data analysis and reporting.

One of the basic experimentation techniques has long been the mock tactical engagement between two opposing forces. In such two-sided experimental trials, CDEC seeks to objectively simulate the realities of the battlefield so as to produce the best possible analysis for consideration by the decision makers. Objectivity is achieved by eliminating, wherever possible, subjective human judgements of engagement interactions and replacing them with near-real time computer analysis based upon generally accepted decision rules. Sophisticated instrumentation provides the input data necessary for such rapid decisions.

Within the past three years, CDEC has developed the capability to simulate, in near-real time, direct fire casualty assessment in two-sided field experiments. The next logical step in improving the capability of the command to more completely treat the dynamics of the battlefield is the addition of indirect fire effects.

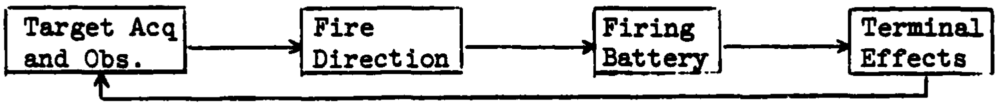
The purpose of the Indirect Fire Casualty Assessment/Suppression (IFCAS) Study, which this paper describes, is to design and guide the development of an IFCAS system for use in field experimentation.

The program has been divided into four phases in order to focus on goals established by Major General E. R. Ochs, the former CDEC Commander who initiated the IFCAS Study in December 1972. These four phases, and the milestones associated with the second and third phases are defined as follows:

- Conceptualization.
- Concept Testing, during Phase III, Experiment 11.8 (TETAM) in November 1973.
- First record use during Phase IV, Experiment 43.8, Attack Helicopter-Daylight Offense in the summer of 1974.
- Refinement and Documentation.

Each of these phases will be discussed in turn. Since the Concept Test will not be conducted until next month, this discussion will focus on the initial concept, planning for the Concept Test, and the preparations to date for the first record use of IFCAS next spring. Some tentative long range ideas now under consideration will also be presented.

An indirect fire system may be considered as a series of four functions with a feedback loop:



The first three functions interact to produce the terminal effects, which in turn provide the feedback information to the observation function. Each functional module is composed of many parameters, and within modules those parameters will vary with type of fire mission, caliber of weapon system, and nationality of the system being simulated or experimented with.

The ultimate goal of the IFCAS Study is to produce a modular system with flexible interfaces which will allow any of the first three functions either to be simulated or to be played by participating individuals or units. For example, the fire direction function could be simulated in the software or performed by an actual FDC section. With this flexibility, the IFCAS system could be used either to add the effects of indirect fire to maneuver unit experiments or to directly experiment with indirect fire systems and concepts. The latter, long term goal is two to five years away, at the current level of effort.

The immediate goals of the Study are to integrate indirect fire effects into ongoing maneuver unit experimentation. The Concept Test will involve the simulation of preplanned, single caliber and fuze action artillery fires against a defending infantry platoon reinforced with antitank guided missiles. The fires will support an attacking medium tank company. The mid-intensity scenario is set in Central Europe in the 1975-80 time frame. By next summer, during Experiment 43.8, it is planned to have simulated artillery fire available to both the offensive and defensive forces and to be able to simulate target of opportunity engagements.

Before proceeding with the details of the IFCAS concept, the approach to suppression needs to be discussed. Suppression is a temporal, psychological phenomena about which there exists much subjective opinion but little useful objective data. It is generally agreed that individuals or units are suppressed if their ability to observe, fire or move has been reduced without their having suffered physical injury. To suppress, then, is to cause those human reactions in the target force that result in such reduced fighting efficiency. Objective data on efficiency losses and time durations are practically nonexistent. Therefore, it was decided that our initial approach to suppression would rely on the desire of experimentation players to continue participating in the competition of the mock battle. The initial IFCAS concept is an attempt to create an environment that stimulates suppressive reactions approaching those that occur under live fire. The system is being designed to cue the players of the threat presented by indirect fire, to cause credible casualty assessment based upon personnel postures, and to permit the players to react to this threat in the context of their mission, their competitive spirit, and their risk function. This personal risk function is meant to describe the sum of many factors, including experience, relationships with superiors, subordinates and peers, perception of the threat cues, and judgement of the significance of the threat relative to the total tactical situation perceived by the player at the time of an indirect fire attack.

The Phase I IFCAS Concept will be tested using the Phase III, Experiment 11.8 (TETAM) scenario as an environment. Phase III of Experiment 11.8 is a two-sided, near-real-time casualty assessment experiment to obtain data on antitank missile systems, aggressor tank/armored personnel carrier elements and ATGM launch vehicles in simulated combat. Three ATGM systems (TOW, DRAGON, and SHILLELAGH) when employed on a reinforced mechanized infantry platoon front will defend against an armored threat (reinforced company) in operations representative of a mid-intensity European environment. Artillery fires will only be employed in support of the attacking company against the defending platoon.

Indirect fire produces three major effects: attrition, suppression, and obscuration. Of these, IFCAS addresses the first two. Through near-real time computer simulation in conjunction with the Range Measuring System (RMS), IFCAS will simulate the casualty production of indirect fire and communicate these effects to experimentation players. By informing players of the presence of indirect fire and providing some knowledge of its threat to their survivability, IFCAS will motivate players to take protective measures to improve their probability of survival. Since the players' posture will be input to the IFCAS software routines by controllers and the latest reported posture used to calculate kill probabilities (Pk), the players will be able to reduce their Pk by changing their posture. In this way, it is expected that suppressive reactions approaching those encountered under live fire may be achieved.

Figure 1 presents a schematic diagram of the Phase I concept. During the preparation, the computer will initiate fire events against thirteen preplanned target areas according to a programmed schedule of fires. The FDC controller will cause the appropriate effects simulator to be detonated according to the schedule of fires in synchronization with the computer casualty assessments. After the preparation is completed, the FDC controller may begin to initiate preplanned supporting fires and/or receive fire requests from the threat force commander via radio. During these subsequent supporting fire missions, the FDC controller will insert appropriate time delays for mission processing and times of flight.

Upon receipt of the concentration number, the computer will perform the following tasks which are discussed in more detail below:

- Determine individual round impact points.
- Notify the controller of the impact event to permit the synchronization of the effects simulators during preparatory fire.
- Assess casualties based on target type, posture, range and position from impacting rounds.
- Notify players of assessment results via a light display panel.

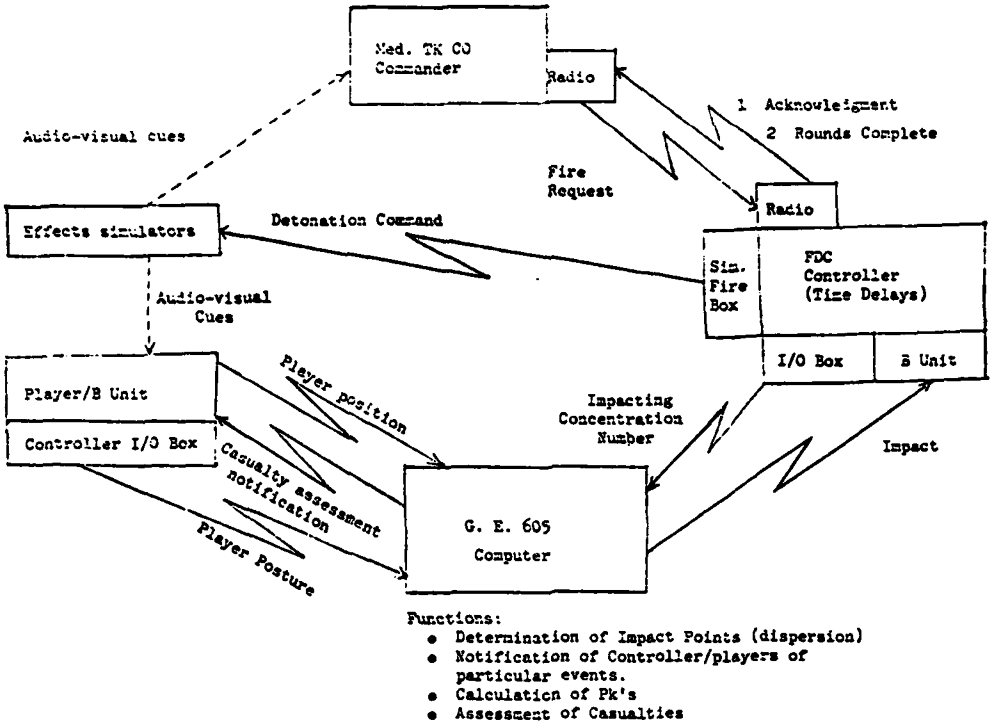


Figure 1, Phase I Concept

Controllers with each defensive system will supply the computer with current posture of the crewmen via the I/O box. The Range Measurement System (B units) will supply the computer with the location of each weapon system. With this data, the computer can then determine kill probabilities and assess casualties.

Simulated artillery fire may cause personnel kills, firepower kills and total system kills. Defensive system controllers will assess specific personnel kills singularly, based upon computer notification and player posture. Individual personnel kills will be accumulated by the computer until a total kill is achieved. Firepower and total kill messages will not require controller interpretation or judgement.

The target players will receive cues of impacting artillery from the computer via a light display panel and the detonation of effects simulators. Based on these cues, the surviving players may choose to increase their probability of survival by taking protective measures. The tank commander will be cued that artillery has impacted by observing the detonation of the effects simulators and from receipt of the "rounds complete" message from the FDC controller.

In the concept test a maximum of thirteen different preplanned concentrations may be engaged with a single caliber using point detonating fuzing. The selection of these areas will be made based on the availability and quality of intelligence of the attacking force.

The IFCAS program is being prepared to permit up to five batteries to be used during preparation. One battery will provide subsequent supporting fires after preparation.

The location of the impacting rounds in a volley is a function of the aim point of each round and the dispersion about that aim point. Therefore, the first step in the determination of the impact points of each round in a volley is to determine the aim points.

In the concept test the aim points will be predetermined and stored in the computer for each of the thirteen predesignated areas. When the FDC controller enters predefined area through his I/O box, the appropriate individual aim points will be called up from memory and dispersion randomly added to each point in order to determine the impact int of each round.

Dispersion will be accomplished by multiplying range and ..ection probable errors (PE) times a random number drawn from a norma stribution of zero mean and unit standard deviation, i.e., a N (0 'stribution. These two PE will be constant for the concept test.

The simulation of casualty effects will be discussed in two parts. First the Carleton function (Reference 1) which will be utilized to generate Pk values will be presented, followed by a discussion of target parameters to be considered, including target posture and component kills.

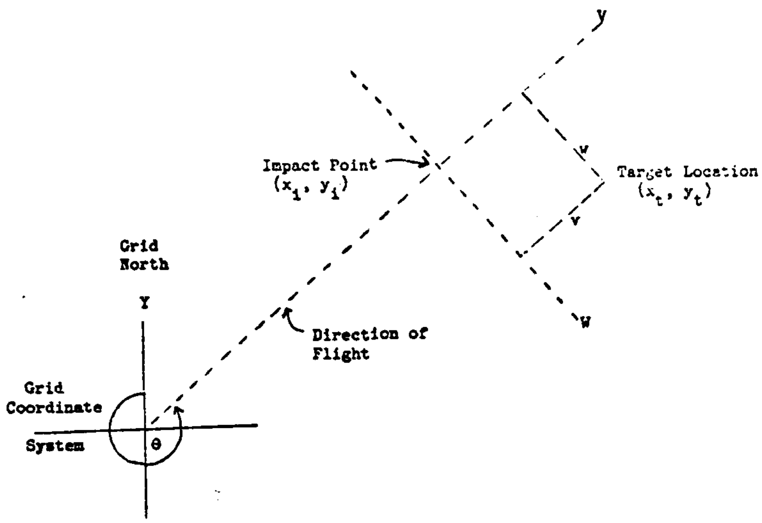
The casualty effects of each round will be assessed individually using an elliptical damage function. The function approximates the probability of a target, located at (w,v) with respect to the point of impact, being killed (or damaged to a specified degree). The values w and v are orientated with respect to the gun-target line (see Figure 2). This will require a transformation from the map grid coordinate system used for target/impact location (x,y). The equation is in the form:

$$P_k\,(w,v) = D_o \operatorname{Exp}\left\{ - D_o \left(\frac{w^2}{R^2(1)} + \frac{v^2}{R^2(2)} \right) \right\}$$

The parameters Do, R(1) and R(2) may be adjusted to reflect any combination of the following conditions:

- Target Type
- Target Posture
- Round type/caliber (a single caliber will be used in the concept test)
- Angle of Fall (this will be considered constant in the concept test)
- Burst Height (point detonating fuze will be used in the concept test)
- Terrain/Vegetation (typical terrain/vegetation conditions will be used to generate the above constants)

Target posture is extremely important and will be treated during the casualty assessment for the following reasons:



(x, y) = grid coordinate locations of impact point and targets.

(w, v) = required input (transformed coordinates) for Carleton Function.

θ = 360° - (Grid Azimuth of Direction of Flight).

$w = |(x_i - x_t)| \cos\theta + |(y_i - y_t)| \sin\theta$

$v = |(y_i - y_t)| \cos\theta - |(x_i - x_t)| \sin\theta$

Figure 2, Damage Function Coordinate System

- Casualty effects are extremely sensitive to personnel postures.
- Target posture and suppression are closely related. Unless the Pk reflects the posture of the target, there is little incentive for the target to respond realistically with protective reactions -a higher immediate probability of survival being the incentive.

Each target system will have a controller who will monitor crew posture and enter posture changes through an input/output box as they occur. Personnel casualty assessment would then be based on the last posture category entered prior to the impact of the rounds in question. The posture of the most exposed (least protected) crewman will be the posture reported. Upon receipt of a personnel kill, the posture reported will be changed to that of the second most exposed crewman, the most exposed crewman being declared a casualty by the controller.

Each of the defensive systems are unique and therefore require a slightly different treatment of the casualty effects (see Figure 3). The TOW and DRAGON systems will each be treated as separate man and materiel subsystems, each being assessed individually. A firepower kill assessment will be made against the materiel system and a personnel kill assessment will be made against the most exposed individual. The software will accumulate three personnel kills before a total kill is assessed against the TOW system and two personnel kills for the DRAGON systems.

The probability of a firepower kill against the M551/SHILLELAGH

WEAPON	Pk/POSTURE	Pk GROUP*
Dragon	personnel/erect and exposed	1
	personnel/partially erect in firing position	2
	personnel/prone or protected	3
	firepower/ ---	4
TOW	personnel/erect and exposed	1
	personnel/partially erect in firing position	5
	personnel/prone or protected inside APC	6
	firepower/ ---	7
M551	personnel/erect and exposed	1
	personnel/standing in open hatch	8
	personnel/completely inside vehicle	6

* Pk group refers to the set of constants (Do, R(1), R(2)) to be used in The Carleton function.

Figure 3, Posture Categories and Kill Probability Groupings

being quite small, only personnel kills will be assessed against this system. A total kill message will be transmitted on the third personnel kill.

There will be two systems used to cue the players of impacting artillery in the concept test, a set of lights and the detonations of simulators.

Four lights will be located on each of the defensive systems for IFCAS messages, three of which will be shared with the direct fire system.

- A survive light will indicate that an assessment has been made for either direct or indirect fire but that the target system has survived.
- A personnel kill light will permit the gradual attrition of the crew. This message is unique to indirect fire and provides an additional stimulus for suppressive reactions.
- A firepower kill light will indicate a firepower kill resulting from either direct or indirect fire.
- A total kill light will signify a total kill by direct fire or the assessment of a total kill by indirect fire due to the attrition of crew members.

To assist the defensive players to discriminate between the two survivability messages (i.e., direct and indirect fire) and to assist in stimulating suppression reactions, noise/smoke simulators will be emplaced on the defensive position and their detonation initiated by the FDC controller in synchronization with the impacting rounds and casualty assessment.

The IFCAS Concept Test will consist of four record trials which will duplicate one cell (rapid advance tactic on site A) of the baseline matrix of Phase III, Experiment 11.8. Much of the evaluation of the Phase I concept will be based on the comparison of measures between baseline and IFCAS trials.

The following measures of effectiveness (MOE) have been developed in order to assess the effects of IFCAS artillery on all systems involved. The MOE have been catagorized under the two primary effects of artillery:

- The infliction of casualties.
- The suppression of certain weapon systems (This in turn, may indirectly increase the number of casualties by increasing the effectiveness of the threat ground force).

Casualty effects may be determined through the following measures:

- The average number of kills by system and type (total, firepower, and personnel) inflicted by the artillery.
- The average number of firepower and total kills inflicted by the threat force (ground and artillery) with and without artillery.
- The change in effectiveness of the threat medium tank company due to artillery (Firepower (total) kills with artillery)-(Firepower (total) kills without artillery)-(Firepower (total) kills by artillery).
- Loss Exchange Ratio with and without artillery for the total forces and each weapon/target combination.

Suppression effects may be determined through the following measures:

- The percent of the total live time each player is in any given posture.
- The average number of engagements per system type per unit time from the beginning of a trial until the system is killed or the trial is terminated as a function of range by both forces with and without artillery.
- The number of engagements by range for each system type with and without artillery.
- The number of target hand-offs with and without artillery.
- Posture of each player as a function of time with times and ranges (from closest impact point) of each volley.
- Players will also complete debriefing forms for subjective evaluation.

Due to the limited number of IFCAS trials to be executed, much of the data may be only accurate enough to provide subjective estimates of the performance of the Phase I concept. However, this should be sufficient to guide future IFCAS development.

For the first use of IFCAS in record trials in Experiment 43.8 next summer, several significant improvements are required. The software and cueing technology to conduct target of opportunity engagements are being developed and the expansion required to provide artillery support for both of the opposing forces is being planned. At the present time, the instrumentation computer, a modified GE 605, is quite heavily taxed by the data processing requirements of large scale, two-sided experimental trials. It is questionable that added IFCAS sophistication can be achieved to the degree desired on the current system. Added computation capability is being acquired and hopefully will be operational in time for Experiment 43.8.

To conduct target of opportunity engagements and to provide more cueing information to target systems, an expanded light display panel is being designed. Thirteen lights will be arranged in a cross, with three lights on each arm of the cross and one in the center. These may then be used to provide the artillery forward observer (FO) with sensing information from which to make subsequent adjustments and also used to give more specific cues of simulated impacts to target systems. Each FO and target system will have one light panel. Through software and telemetry, each panel will be identified with its assigned player and the type and content of the light messages may be programmed according to the functions and requirements of the using player.

At present, it is planned for the FO to input his fire request directly to the GE 605 computer through the RMS. This is directly analogous to the TACFIRE communications procedure, but not identical. It is desired ultimately to be able to integrate TACFIRE and FADAC with IFCAS and that possibility is being investigated as a long range goal.

In order to allow an actual firing battery to participate in experiments without actually firing, a Weapons Orientation Measuring System is being considered. Such a system would measure the orientation of each individual piece and provide those actual directions of fire to the computer to allow calculation of individual aim points for each simulated round fired. In this way, artillery and mortar crew proficiencies would be directly incorporated into experimental results as are those of direct fire weapon systems today. Again, this is a long range goal of the IFCAS program.

To summarize, IFCAS is a program at CDEC to, in the near term, add the effects of suppression and attrition from indirect fire to maneuver unit experimentation and, in the long term, to improve our ability to experiment with indirect fire systems. The approach is to simulate casualty effects as accurately as possible and to induce suppressive reactions among the participants by providing them the information necessary to evaluate their risk of being assessed a casualty.

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AD P000634

OPERATIONAL TESTING

Control vs Realism - Lessons Learned from the OSD Reserve Component Study

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HQ FORSCOM

INTRODUCTION

In the developmental cycle of hardware and deployment concepts, testing in a operational or tactical situation must typically precede acceptance. When a high degree of tactical realism must be incorporated into testing plans, the rigor and controls associated with the data collection methodologies of other testing stages in a developmental life cycle are occasionally sacrificed in favor of increasingly subjective judgments in troop test paradigms. This paper describes one solution to the problem of enhancing the reproducibility and objectivity of data collected under such a situation.

THE OSD RESERVE COMPONENT STUDY

For the past two years, first CONARC and now FORSCOM have been involved in the supervision of a number of field tests and evaluations conducted at various military installations around the United States. The purpose of these tests, known collectively as the OSD Reserve Component Study, has been to identify the effect of various training and organizational innovations on the combat readiness of selected Army Reserve and Army National Guard units. In all the field tests, standard experimental designs such as test/control group models or test/retest plans, as appropriate, were used. The principal methodological problem was the development of a data collection methodology. The developmental work included both the definition of a philosophy of data collection and an evaluation instrument. To meet requirements imposed by the conditions surrounding these tests, that methodology had to ensure objectivity of data in an environment where instrumented data collection was not feasible and had to offer reproductibility where tactical realism was essential. Three particular conditions of the testing program constrained the nature of the data collection methodology.

BASIC TEST CONDITIONS

First, the tests all concerned training or organizational changes to improve combat readiness and thus to decrease requirements for postmobilization training. Therefore, our evaluation system had to assess unit combat proficiency. As a part of unit combat proficiency, staff planning and staff decision making capabilities were to be assessed as well as the unit's ability to deploy tactically. Field settings and tactical realism

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were essential to accomplish this. Second, sample sizes were small and opportunities for replications limited. For example, in a typical test, three battalions constituted the test group and three the control group, and data was collected twice - once to establish a baseline and once to establish relative changes in proficiency. Third, although the OSD Study addressed seven different concepts which were to be tested in field environments by six different test directorates, data had to be comparable across tests so an evaluation of the relative effectiveness of different concepts could be made. Thus, data was to be collected in such a manner that the conclusions drawn depended to a minimal degree on judgment or subjectivity. The principle test of adequacy of all collected data was to be reproducibility, and objectivity was to be the test of all conclusions.

Two of these three conditions, the need for reproducibility and the limited sample base, required an evaluation scheme that stressed rigorous controls. However, the third aspect, the need to test in a field setting and make statements about combat proficiency and readiness, required an evaluation procedure that stressed freedom of operation for the commander and his staff so that the ability of units to actually plan and carry out tactical maneuvers might be assessed. Our method of assessing unit proficiency had to retain rigor and objectivity and ensure reproducibility; on the other hand, it had to allow unit commanders a reasonably free hand similar to that which they would expect in combat.

The major step in the development of a methodology was to be the definition of a basic philosophy to underlie the testing scheme. It was decided that the dominant requirement was the need for combat realism, which implied the need for a field exercise in which a variety of tactical operations were carried out. Because of the requirements to test in a field setting and assess combat readiness and proficiency, the standard Army Training Test (ATT) was selected as an acceptable model around which to structure all evaluations. During the course of such an exercise, a unit is required to deploy and operate against an aggressor under simulated combat conditions and perform certain common tactical operations. A scenario controlled by the testing group builds up a combat situation complete with preplanned messages and intelligence data and forces responses without unrealistically restricting the range of responses.

The use of an ATT type exercise then would provide the desired realism and would also allow control. The prior sequencing of major events would mean that control could be exercised over the environment in which a unit operated without restricting the commander's relative freedom of action in directing responses to aggressor threats and reacting to orders from simulated higher headquarters. The fact that the overall sequencing is known in advance by the data collector also afforded the opportunity to introduce a second controlling feature, standardization of the data collection. Since preplanned stimuli existed in the form of directives and known aggressor threats, the most probable time and location for a particular response by the unit commander or some unit element could be predicted and a data collector could be prepositioned. Since the nature of the stimuli were known, the range of typical responses could also be anticipated and the data collector provided with a definite checklist covering a relatively narrow range of probable responses. Finally, since the significance of the stimuli was known in advance, published doctrine or military judgment could supply acceptable a priori standards against which the adequacy or acceptability of actual overt responses could be measured.

Such a procedure offered us objectivity and reproducibility to the extent that the responses to be observed and their associated standards could be prestated in behavioral or quantitative terms. Our principal developmental efforts, therefore, concentrated on developing the items on which units and individuals were to be scored.

Eight separate ATTs were eventually developed as a part of the OSD Reserve Component Study. These included a company-level test for mechanized infantry units, six battalion-level tests for infantry, mechanized infantry, armor, 155 and 105 field artillery, and construction engineer units, and a division-level test. The division-level test was a five-day exercise, and all the others were three-day exercises. All the tests were structured into four phases - forward movement, defense, withdrawal, and attack; all the tests required a controlled aggressor force; and all tests utilized the principle of scenario control by having preplanned and standardized messages from a simulated next higher headquarters and intelligence data interjected into the problem.

To ensure that the broadest possible range of unit functions was assessed, areas to be observed were selected from each of the five functions of land combat. The process of defining critical behavioral elements consisted of an analysis of the tasks involved in each area until a level of detail was reached that permitted the statement of: (1) a specific behavior that must be exhibited, (2) specific products that must be developed, and/or (3) specific results that must be accomplished in order to perform each function adequately. The basis for this analysis was the five functions of land combat.

The analysis proceeded as follows:

Within each of the five land combat functions, two or more broad objectives were identified. Then within each objective one or more subobjectives were identified, and parameters were identified within each subobjective. These parameters specified actual measures of performance, usually stated in quantitative terms.

At the lowest level of analysis, data form questions were developed. These were simply specifications of the observations or measures required to derive the measure of performance asked for in the parameter. For example, if a parameter asks for the proportion of critical control measures included in an operations order, a dataform question is needed to identify each critical measure and ask if it was included. The number of critical control measures included can then be counted and the proportion can be computed by data reduction personnel.

An example of this analytical process is shown in Figures 1-4.

Function 4. Intelligence

Objectives:

4.1 Determine if the unit can effectively collect and report intelligence information.

4.2 Determine if the unit can effectively employ counterintelligence measures.

4.3 Determine if the unit can effectively plan, process, and disseminate intelligence information.

Figure 1. The Analytical Process, Step 1.

Objective 4.3 Determine if the unit can effectively plan, process, and disseminate intelligence information.

Subobjectives:

4.3.1 Planning intelligence requirements.

4.3.2 Processing and dissemination of intelligence.

Figure 2. The Analytical Process, Step 2.

Subobjective 4.3.1 Planning for intelligence requirements.

Parameters:

4.3.1.1 Effectiveness of S2 planning for map requirements.

4.3.1.2 Effectiveness of S2 ground surveillance planning.

4.3.1.3 Effectiveness of the S2 intelligence collection plan.

Figure 3. The Analytical Process, Step 3.

Parameter 4.3.1.1 Effectiveness of S2 planning for map requirements.

Criterion: A total of 75% of the platoon leaders must have at least one map of the area in their possession.

Dataform Questions:

4.3.1.1.A How many platoon leaders had maps covering the company area of operations? ________

4.3.1.1.B How many platoon leaders were checked? ________

Figure 4. The Analytical Process, Completed.

This hierarchical structure for the development of test items or areas of evaluation constituted the first feature of the ATT that led to a rigorous data collection effort. By using this process, operational definitions of unit performance were generated which resulted in the elimination of ambiguity concerning the aspects of unit performance to be considered in assessing proficiency in such broad areas as intelligence or mobility.

Once these operational definitions of unit performance were identified, we were able to introduce the second element of our data collection methodology which ensured objectivity, pre-stated standards of those levels of performance which constituted acceptable proficiency on each level of the hierarchy. When possible, these criteria were drawn from published military doctrine; when no doctrine existed, a consensus of experienced military judgment was the basis for the criteria. In order to verify their suitability, these latter criteria were later checked against observed behavior of a unit judged to be combat ready. Criteria were generally quantifiable expressions of unit performance such as times required to complete a maneuver, number of communication checks completed, or the presence of a critical element in an order. They constituted an explicit pre-stated logic for computing pass or fail on each parameter and provided one of the basic comparative measures of unit proficiency, the percentage of parameters passed.

The diagnostic value of the proficiency information was also recognized, and a related comparative measure, training time required to correct observed deficiencies (where a deficiency was defined as failure to meet a pre-stated standard), was developed. These two measures yielded slightly different data because of the acknowledged unequal importance of the individual parameters, but both were based on observed data and objective statements of unit proficiency.

Having developed the operationally defined measures and pre-stated quantifiable standards, it was possible to fully exploit the advantages of using the ATT-type test by developing closely controlled test scenarios that channeled the flow of action and permitted the pre-positioning of data collectors who had been instructed in the exact type of individual and unit behavior which they were to observe.

That then is the methodology for introducing control and reproductibility into a field exercise without sacrificing the commander's freedom to command and control. We have good reason to believe we were successful in devising a test instrument that was objective and measured unit proficiency. This statement is based on an analysis of the data collected during Annual Training (AT) 72 by testing thirty Active Army and Reserve Component (RC) mechanized infantry, armor, and field artillery battalions. Although collected by a number of different Test Directorates to answer specific test questions, when grouped across Directorates these data reveal the presence of some common factors, the existence of which would have been difficult to detect had standardized data collection procedures not been employed.

ANALYSIS OF TEST RESULTS

Table 1 is a summary of test performance by various groupings of battalions. These figures show that, as expected, Active Army units performed better than RC units. Within RC units, the armor battalions did better than the mechanized infantry battalions. As the mechanized infantry and armor tests are virtually identical, we can only speculate that the difference between the two is due primarily to the type of training conducted. Armor being traditionally employed in more independent operations than infantry, the fact that their training is decentralized and that there was a lack of opportunities for battalion-level training during IDT probably had less effect when they were tested as a battalion than for an infantry battalion.

In addition to unit type, another factor which impacted on the test results for specific units was the amount of training time available to the units prior to undergoing the ATT. Table 2 compares the average results for the eight maneuver battalions receiving the test during the first week of AT and the nine battalions receiving the test in the second week. As expected, units receiving an extra week of training did better than units tested during their first week of AT, regardless of the Test Directorate administering the test. The effects of this additional week of training may be attributed to the opportunity, unique for some units, to train as a battalion or for filler personnel from the Individual Ready Reserve (IRR) pool to "settle in" to the unit. The important fact for us, however, is not the cause but the observation that the predictable effect of a variable was not confounded with differences among Test Directorates, thus demonstrating the effectiveness of our techniques to eliminate the high variance associated with more subjective data collection procedures.

An additional fallout of the OSD test program was the assessment of weeks of remedial training required to attain a combat-ready status as a function of specific, observed deficiencies. Figure 5 shows a plot of the training time required versus the percentage of parameters passed. The approximating line was fitted by standard regression techniques. A goodness of fit test was applied and showed that the contribution from higher-order effects was negligible. This plot is important because again it shows that, in spite of the fact that data was derived by different Test Directorates at widely scattered locations, the grouped data shows a very consistent relationship.

Finally, two item analyses of the ATT were conducted - a parameter analysis and a subobjective analysis. The parameter analysis was done primarily to identify weaknesses in the test vehicle itself (e.g., overly stringent criteria, ambiguity, duplication, or irrelevant material). The subobjective analysis was done to identify general areas of training weaknesses and to detect any patterns of failure that might bear on the question of what was actually being measured. For purposes of this analysis, three failure patterns were considered significant - those having high failure rates for both RC and Active Army, those having high failure rates for only RC units, and those for which no uniform failure rate could be identified.

TABLE 1

Comparative Analysis of ATT Performance by Unit Type

Group	%Param Passed	%Subobj Passed	Avg Training Required
1. Active Army (4)	70.6	64.3	3.0
Reserve Component (17)			
Mech Inf (9)	43.4	28.5	6.9
Armor (8)	53.8	41.7	6.8
2. Reserve Component FA Battalions (9)	48.6	24.3	7.6

TABLE 2

Comparative Analysis of ATT Performance by Week of AT

Group	% Param Passed	% Subobj Passed	Avg Training Required
ATT 1st Wk of AT (8 battalions)	44.0%	30.5%	7.0 weeks
ATT 2nd Wk of AT (9 battalions)	53.8%	40.5%	6.3 weeks

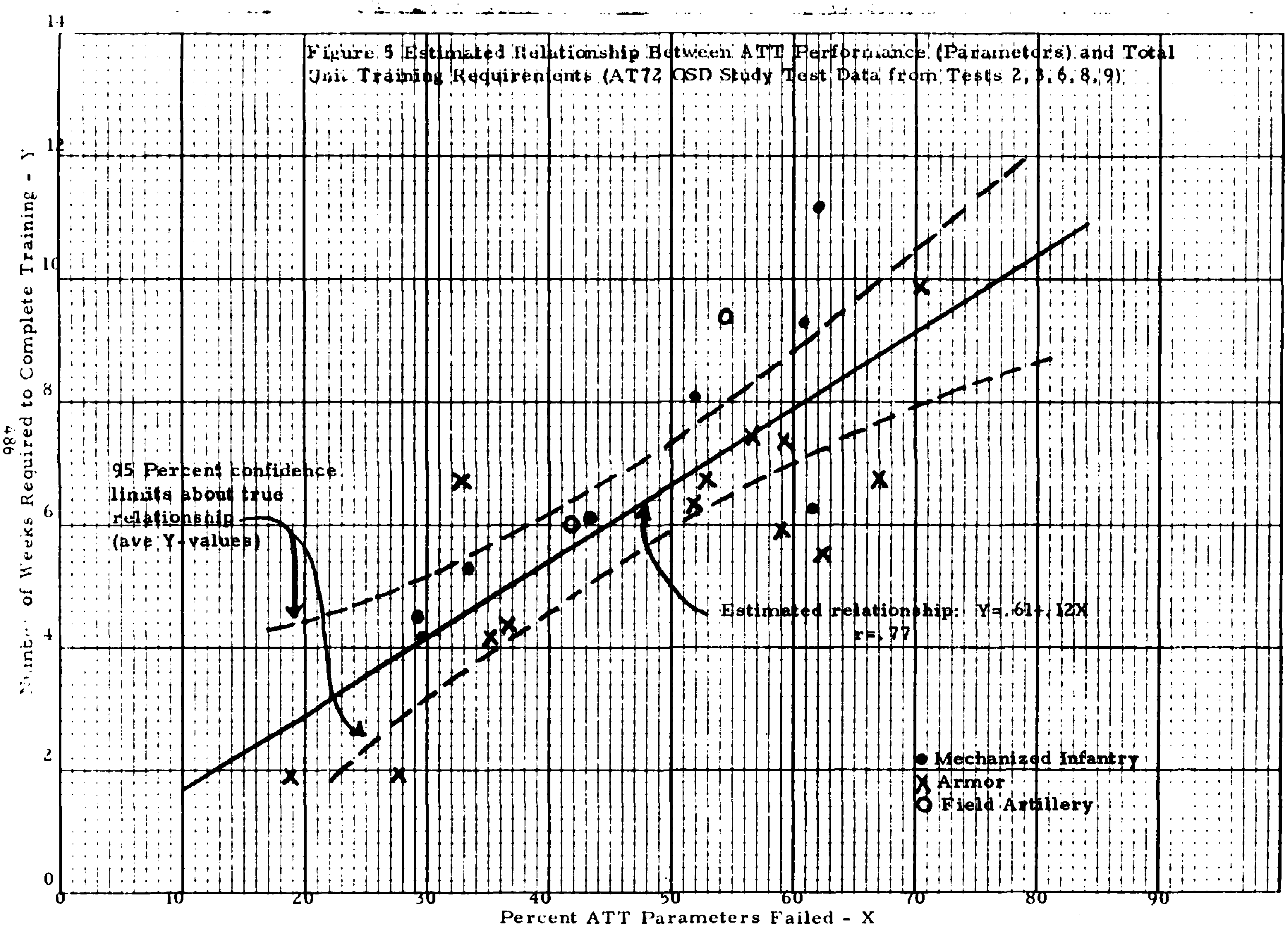

Figure 5 Estimated Relationship Between ATT Performance (Parameters) and Total Unit Training Requirements (AT72 OSD Study Test Data from Tests 2, 3, 6, 8, 9)

Only a small percentage of the subobjectives were failed by the majority of the test units. Accordingly, we concluded that most failures could be attributed to unit training deficiencies rather than to the test vehicle or the nature of the subject matter addressed by the subobjective.

Those subobjectives failed by all units may represent cases in which the criteria were too stringent or may be areas dealing with such specialized material that few units train for them.

Most of the subobjectives having high failure rates for only RC units could be attributed to lack of battalion-level training. This shortcoming is typical of most RC training. Of particular note in this category are those subobjectives dealing with coordinated infantry/armor operations, coordinated battery operations, and battalion mobility.

CONCLUSIONS

From the data available, we have been able to draw two major conclusions. First, we produced a test of sufficient objectivity that we were able to collect data suitable for comparison across directorates. Second, our efforts to standardize and to increase objectivity did not impair the utility of the test as a measure of unit proficiency.

We believe that the OSD Reserve Component Study clearly demonstrated the feasibility of obtaining objective performance data from large-scale military field exercises. Further, it demonstrated that such data could be collected without placing undue constraints on realism and without limiting a commander's freedom of action in deploying his units.

FUTURE USES

There is currently a project under development that makes use of many of the lessons we have learned from the OSD tests. This project involves a multi-level concept for training high priority RC units and draws heavily on the ATTs we have just discussed. A key part of this multi-level concept is the administration of an evaluation similar to the OSD ATTs but with modifications made as a result of our detailed analysis. Specific deficiencies observed during this evaluation will be the basis for developing unit training programs for the evaluated unit.

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INTEGRATION OF FIELD EXPERIMENTATION AND COMPUTER SIMULATION

by
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Introduction

The purpose of this paper is to present an example of the integration of the results of field experimentation and predictive computer models. The example is drawn from an on-going United States Department of Defense (USDOD) effort to evaluate the tactical effectiveness of the existing US antitank missile systems, SHILLELAGH, TOW and DRAGON. The program is called Tactical Effectiveness Testing of Antitank Missiles or TETAM. The USDOD intent in promulgating the testing program was twofold. First, there was the requirement to collect information which would contribute directly to an evaluation of weapons effectiveness. Second, the same information was to be used to verify the outcomes from predictive computer models and thus contribute indirectly, through the use of the verified models, to future evaluations of the weapons themselves or of the generic class of guided anti-armor systems.

In the context of the overall TETAM program, field experimentation is only one source of information. In the context of verification of the particular computer models being treated, CARMONETTE, Individual Unit Action (IUA) and DYNTACS, field experimentation is the primary source of empirical data to be used in the verification effort. It is important to keep in mind that in this example both predictive computer models and field experiments are simulations or models of battles. As such, both have inherent strengths and limitations.

Computer Simulation

One definition of simulation is that it is a technique used to study or analyze the operation and behavior, by means of models, of systems conditioned by human decision and/or probabilistic natural influences. A model in this context is a representative of a real situation in which only those properties believed to be relevant to the problem being studied are represented.[1] A computer simulation is simply a simulation in which the component manipulation, decisions, and calculations are either wholly, or in part, done by a computer.

[1]Glossary of Terms used in Gaming and Simulation. Fourth meeting of the Quadripartite Ad Hoc Working Group on Gaming and Simulation held at the US Army Strategy and Tactics Analysis Group, Bethesda, Md.

In recent years, computer simulations have become an increasingly popular source of data provided to military managers for use as a basis for decisions. This popularity is largely attributable to distinct advantages demonstrated by these tools. Among the advantages are availability, cost, reaction time, and comprehensiveness.

Availability is an advantage due to the nature of the data required. Much of the desired information is related to battles, casualties, or weapon system performance in a combat environment. The only true data available for these situations comes from actual combat. Attempts to collect unbiased, comprehensive information from actual combat have suffered from obvious practical limitations. Computer simulation, on the other hand, can be used to provide unbiased estimates of combat data, in any degree of detail, without actual combat.

In addition to actual combat and computer simulations, other sources of empirical "combat type" data are available. Some of these sources include field exercises, field experiments, and manual map and sand table exercises. The first two of these alternate methods employ troops, equipment, and varying degrees of instrumentation and control. The costs associated with these methods are extremely high even when a small number of combinations of independent variables are considered. Manual map and sand table exercises, although less expensive than field methods, are considerably more expensive than computer simulations when a statistically valid number of replications is required and extensive independent variable combinations are considered.

Most military decisions are time critical in that the particular decision must be made by a certain deadline on the basis of all available information pertinent to the subject. The reaction time needed to produce comprehensive empirical data using computer simulation, even if some modifications in logic are required, is far shorter than the lead times required for the other methods.

Despite the widespread use and definite advantages of computer simulations, they have not been universally accepted as a reliable source of unbiased data - often for good reason.

The credibility of results generated by these models are frequently questioned due, primarily, to the lack of input data, a modeling of poorly understood processes, and a lack of validation.

The lack of input data is crucial since, even if the internal logic within the models is valid, the appropriate parameters required to operate this logic must be present if valid results are to be obtained. Even sources of data such as field exercises, field experiments, and combat may produce data so confounded by unknown or uncontrolled variables as to be almost worthless. Particularly weak areas include suppression and neutralization factors, effects of countermeasures, and acquisition.

In some cases the processes being modeled are not sufficiently understood to allow credible results. When a number of these processes are present in a single model, often in different subroutines, the cumulative effects and possible interactions become sizable problems. Particulary important areas which need better definition include the aggregation of weapons or units, target acquisition, night operations, information processes, suppression, neutralization, and command and control.

The process of producing credible results using computer simulations hinges on the validation process. Model validation, or verification, "remains today perhaps the most elusive of all the unresolved problems associated with computer simulation techniques."[2] None of the major combat simulation models commonly in use today have been comprehensively validated - nor is it possible to do so in the strict sense of the term. The myriad of interactions present, the number of variables, the interdependence of these variables and the difficulty in obtaining comparative data presents a problem of gigantic proportions. The CDEC approach to validation, or perhaps calibration is a better term, within a limited range of variables is described in more detail later in my paper.

Every author has a slightly different method of classifying computer simulation models. For the purpose of developing a useful tool for generating empirical data using combat models, CDEC has concentrated on an existing set of simulations which could roughly be classified as large scale, high resolution, stochastic, and noninteractive. These simulations are CARMONETTE, DYNTACS, and IUA.

They are large scale since they are each capable of treating numerous weapons systems and their interactions on a battlefield. They are high resolution since they each subdivide and individually quantify the important functions, capabilities, and decisions associated with each weapon system. They are stochastic in that probability distributions are widely used in the internal decision processes and one replication represents only one realization in a distribution of possible outcomes. Finally, all are noninteractive in that all data input to the simulations is in the form of setup data cards.

I will now provide a short overview of each of the three computer simulations.

The Individual Unit Action model (IUA) simulates a company/battalion size force in the offense, defense, or delay. The primary focus of IUA is on tank and antitank systems; other weapon systems effects are played with minimum detail compared to tank and antitank systems. The interaction of various weapon systems including tanks, antitank weapons, armored personnel carriers, artillery, mines, helicopter-borne weapons and tactical close support aircraft can be simulated. The model requires input for such things as the mobility and terrain preprocessors, acquisition parameters, weapons systems accuracy parameters, and weapons systems vulnerability parameters.

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[2]Naylor, Thomas H., J. L. Balintfy, D. S. Burdick, K. Chu, Computer Simulation Techniques. New York: John Wiley & Sons, Inc., 1966, P-310.

CARMONETTE simulates the intense phase of ground combat from line of departure up to, but not including, hand-to-hand combat. The systems simulated in CARMONETTE consist of ground vehicles, aircraft, and weapons. Any unit can be assigned characteristics with respect to mobility and vulnerability to enemy fire. Infantrymen are explicitly simulated and can be killed one by one. Vehicle operators and weapons crewmen are simulated by movement of vehicles and firing of weapons. When the number of men left in a unit drops below the number required to serve a given weapon, the weapon ceases firing. CARMONETTE requires that units have explicit orders for every action. However, these orders are flexible; for example, they may contain provisions for the unit to modify its behavior if it acquires a desired target or is itself taken under fire. The trafficability of the terrain will cause the unit to change its rate of advance to be consonant with the ground being traversed.

DYNTACS simulates combat engagements ranging in size from a single element to a reinforced armored battalion; attack, defense, delay, and meeting engagements are portrayed. The foremost characteristic of DYNTACS is its emphasis upon representing individual weapon firepower, mobility, protection, and detection capabilities and their interactions with the terrain. Fundamental concepts are emphasized such as cover, concealment, fields of fire, and terrain mobility characteristics for each weapon. Moreover, this representation is achieved in the context of a dynamic combat situation where both forces can be mobile at the same time. The simulation event-sequencing procedure has been designed to emphasize flexibility and avoid prescheduling a battle. If the battle situation merits a new tactic at any point of the battle, changes are generated to a unit's route, formation, or firing assignments.

The following table outlines comparative information for the three models.

Table 1. Comparison of Computer Battle Simulation Models

CHARACTERISTIC	MODEL		
	CARMONETTE	DYNTACS	IUA
Realism	Medium	High	Low
Execution Time	Real Time	3-5 Times other two	Real Time
Complexity	Medium	High	Low
Required Core	Medium	High	Low
Preparation Time	Low	Medium	High
Documentation	Medium	High	Low

Field Experimentation

In the US Army Combat Developments Testing System, field experimentation occupies a small but highly significant niche. Field experiments have as their aim the collection of data concerning the interaction of the soldier with his environment. The environment is seen as including the soldier's equipment, organization, training, doctrine and operational setting - the battlefield. The last part of the environment, the operational setting, is simulated in some degree in all field experiments. A particular experiment may have as its object the testing of any one of the other factors of environment or some interactions of two or more of those factors.

Field experimentation as described above is performed in the United States Army only by Combat Developments Experimentation Command (CDEC). CDEC Field Experiments are characterized by a high degree of instrumentation and maximum possible control of independent variables. There are three general field experimentation techniques used at CDEC:

- Real-time Casualty Assessment (RTCA) whereby the two opposing sides are permitted free maneuver and casualties are attrited in near real-time.

- Two-sided data extraction whereby selected performance data is simultaneously extracted from two opposing forces using free maneuver but casualty attrition is not played.

- One-sided data extraction whereby selected performance data is extracted on one side when executing specific tasks in a controlled environment.

Generally speaking, as the techniques are listed above, they are in descending order of realism and ascending order of control. The following description of CDEC Field Experiment 11.8, the field experimentation part of TETAM, will serve to complete the description of a field experiment and its instrumentation.

The object of Experiment 11.8 is to collect data concerning the interaction of the antitank guided missile (ATGM) systems, including the system crews and certain command elements, with the operational setting. The setting in Experiment 11.8 includes the ratio of opposing forces, the terrain type and the tactics of the attacking tank force.

Experiment 11.8 is a major test effort consisting of three phases. Phase I treats the dual objective of terrain description and antitank missile system capabilities. Phase II treats antitank missile system susceptibility and vulnerability. Phase III is a two-sided simulated battle between defending antitank missile weapons and attacking tanks. Throughout the three phases, the antitank missile systems are considered in the defensive.

Phase I examined first those characteristics of terrain which were expected to influence the employment or performance of antitank missiles. Those characteristics are visibility and trafficability. It is obvious that both characteristics bear directly on the time duration of exposure of targets for antitank weapons. The techniques of determining trafficability from measurements of such factors as slope, vegetation and soil are well known and generally accepted. We chose a variation of the Batelle Walker Technique to measure the existence and extent of visibility.

Sites were selected in Europe and at our field laboratory, Hunter Liggett Military Reservation in California. Each site was five kilometers long by two kilometers wide and contained at one end an area suitable for the location of a platoon defensive position. Thirty-six representative antitank missile sites were selected on the platoon defense and ten trails were laid out leading into the position. The intent was to have a large number of individual positions in the defensive location, not to establish a coordinated defense; and to use ten approach trials, any one of which a tank might use during an attack on the defensive position.

Determinations were made at 25 meter intervals on each of the trials of whether or not visibility existed to each of the 36 antitank missile sites. These measurements were, of course, a preliminary to an assessment of the operational capabilities of the antitank missile systems.

The major part of Phase I was devoted to measurements of antitank missile system capabilities on sites at Hunter Liggett Military Reservation on which measurement of terrain characteristics had already been made. The time required to detect a target after it became visible was measured as well as the frequency with which detections were made. Further, the times required to accomplish the various tasks involved in ergaging, with an antitank missile, a target which had been detected were measured. From these measurements, the distributions of the various time intervals were calculated. Other questions concerning the ability of tanks to interrupt visibility and problems of command and control were also addressed.

Phase II was, in a sense, a mirror image of Phase I. Information was gathered on the capability of tanks in various postures to acquire and engage antitank missile emplacements. The design of this phase is presented in the paper, <u>An Adaptive Design for the Testing of Antitank Missile Systems</u>.

In terms of the descriptions of experimentation techniques, both Phases I and II are one-sided experiments. Similar data collection means were used in both phases. The principal data collection systems used were the Range Measuring System (RMS) and the Photographic Instrumented Data Recording System (PIDRS). The two interfaced with the Central Processing System (CPS) and/or the Range Timing System (RTS).

The RMS is a telemetry and wire system which provides the dual capability of position location and event entry for each instrumented player unit. The beginning of an opportunity to acquire a target was recorded by means of an event entry on the input-output box of the Range Measuring System. The information is passed by telemetry to the Central Processor and recorded. In a similar manner, each of the other events associated with target acquisition and engagement is collected and recorded. This data collection procedure is an instrument-assisted method. The event entries are made by a data collector who is not a player. Each input-output box,

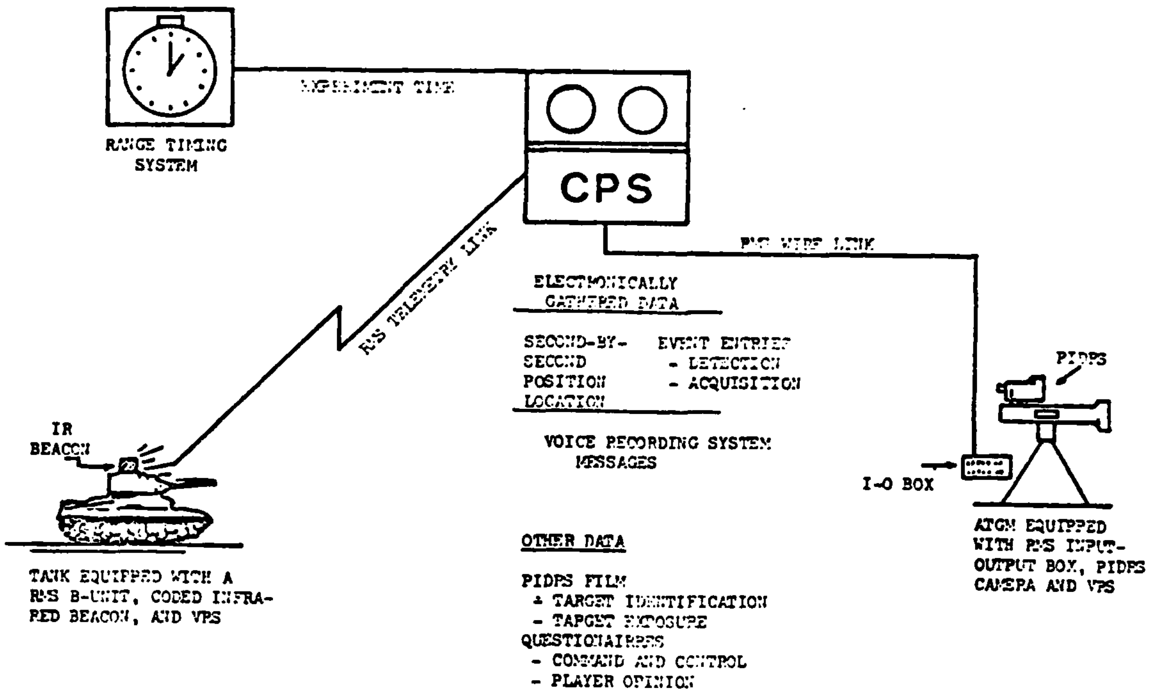

Figure 1. An Example of Instrumentation for One-Sided Experimentation.

or B-Unit, is queried by the CPS once each second for any events entered since the last query and for its identity and location. The time signal from the Range Timing System is simultaneously transmitted to the computer and recorded. Thus, from the combination of the Range Measuring and Range Timing Systems, we compile a second-by-second time-correlated history of the events and locations associated with each player.

The correct identification of the target which is acquired is assured by the use of another system - the Photographic Instrumented Data Recording System, or PIDRS. The PIDRS itself consists of a motion picture camera which interfaces with the Range Timing System. The timing signal from the Range Timing System activates a neon tube array displaying the experimental time which in turn is recorded on film. That film, in Experiment 11.8, was infrared sensitive. The targets had a coded infrared beacon to allow positive identification during post trial analysis. Other information available from the film includes accuracy of lay on the target, or tracking of the target, and target exposure data. The PIDRS cameras are connected to the weapons systems in such a way that they are activated automatically by a player or data collector in the course of his performance of other tasks. This system is representative of fully-instrumented data collection procedures.

As implied above, the RTS provies a common time base for all data collection systems. In the case of one-sided experiments, such as Phases I and II of Experiment 11.8, the functions of the CPS are just to query the RMS and so store data for later print-out and analysis. The CPS is a GE605 computer. As the description of Phase III data collection will show, it has capabilities not mentioned here.

The Voice Recording System (VRS) was used as a secondary system for event entry information in Phases I and II. This system also served as the primary collection means for information on command and control procedures and problems. The VRS is simply a tape recording system to monitor and record radio traffic. As with the other instrumentation systems mentioned, the Voice Recording System interfaces with the RTS so that the resulting tapes are time-correlated.

A common feature of all the data collection described so far is that it is used only for post-trial analysis. There is no real-time feedback to allow alteration of the events during a trial as a result of past events in that trial. This lack of real-time feedback is characteristic of one-sided experiments.

In contrast, the two-sided, casualty assessment experiment does employ feedback during a trial to use results of past events to influence the course of succeeding events. As compared to one-sided experiments, the two-sided, casualty assessment experiment offers the possibility of maximum realism and "free play" but, as noted, at the expense of some lessening of control of independent variables. To enhance realism, data collection means in two-sided experiments are almost exclusively fully-instrumented systems.

Phase III of Experiment 11.8 is such a two-sided experiment employing near real-time assessment of casualties. Each Phase III trial consists of a simulated tank-antitank battle. The friendly or defending force is a reinforced mechanized infantry platoon equipped with ATGM weapons. The threat or attacking force is a medium tank company reinforced with mechanized infantry and ATGM weapons. The battle begins at an initiation range beyond the maximum effective range of any of the simulated weapons involved and continues until one of two events occur:

- All threat tanks are destroyed
- All remaining threat tanks reach a trial termination line located approximately 200 meters forward of the defense position (this event includes the possibility that all defending ATGM were destroyed).

The players perform their tasks just as they would in a real battle and casualties are assessed as they occur.

In order to allow casualty assessment in near real-time, one instrumentation system in addition to those already described is required, The Direct Fire Simulator (DFS). Before I describe this system, let me say that it does not simulate the trajectory of a direct fire weapon. It merely indicates what weapon is attempting to engage what target. That firer-target pairing is passed to the Central Processor computer, which determines whether or not a casualty will be assessed.

The Direct Fire System consists of two primary components, a laser "gun" and laser sensors. Each player is equipped with a coded laser gun, coaxially aligned with the weapon to be simulated, and with one or more (up to three) groups of laser sensors. When one player, let us say a TOW missile system, decides to engage, for example, a tank, the TOW crew perform just as they would in a real situation. When the gunner "fires" his missile, he automatically does three things - he ignites a TOW launch signature simulator, turns on his coded laser gun and enters that event, a firing, into the CPS through his Range Measuring System input-output box. If he is properly tracking his target, the sensors on the target will be illuminated by the firer's coded laser beam and that event, receipt of fire, is automatically entered into the CPS through the target's input-output box. The CPS then receives the following information, the "firing", the "hit", and player identities to include type and location of both players involved. From that input, the computer calculates range and, for a missile, time of flight. Then, on the basis of stored information concerning probabilities of hit and kill for the specific combination of range, firer type and target type, a casualty may or may not be assessed. In the case of a missile, the assessment of a casualty is conditional on the target still being illuminated by the firer's laser at the end of time of flight of the missile. Results are relayed to the players involved via their RMS input-output boxes. The firer, if a missile is involved, receives a message telling him that his "missile" has reached the target. The target receives a message, if he is hit, informing him of that fact, whether or not he is a casualty and, if so, what type of kill has been assessed. If a firepower kill has been assessed, the target's laser gun is automatically deactivated.

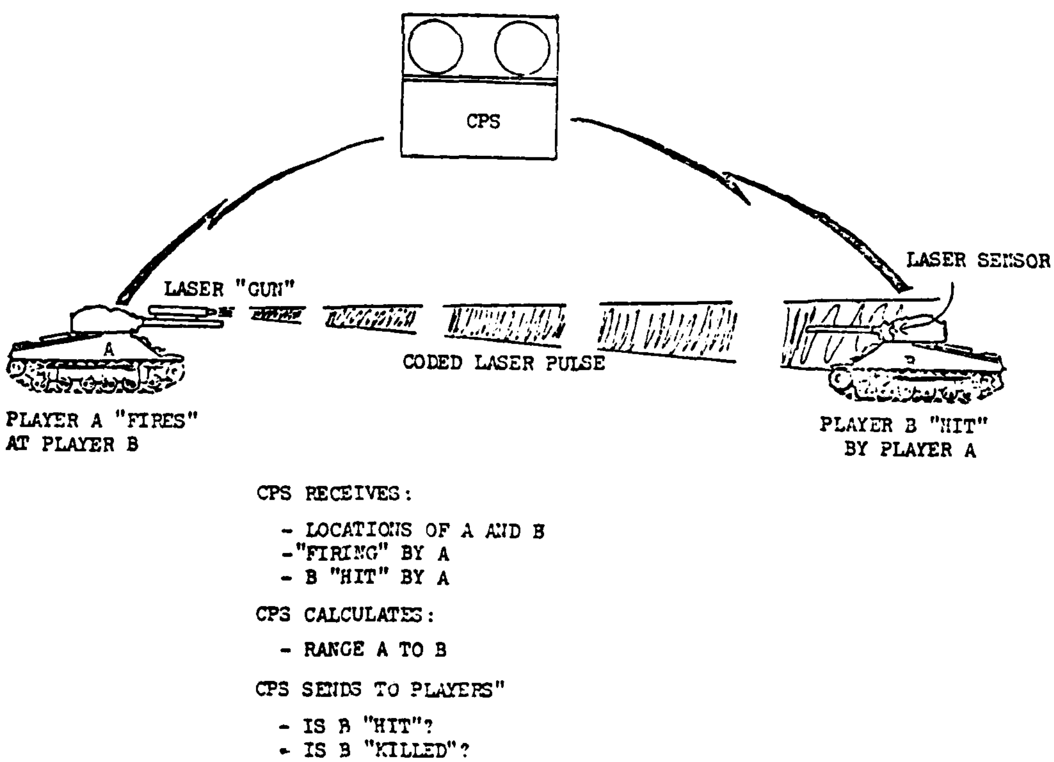

Figure 2. An Illustration of DFS/RMS Instrumentation.

In addition to the assessmnet of casualties in near real-time, the Central Processing System also records for post-trial analysis all of the information concerning the battle history for each player.

The DFS/RMS combination is not infallible. To salvage all possible information from those trials in which breakdowns occur, back-up instrumentation is provided where possible. The back-up systems do not provide for real-time feedback but they do allow an estimate to be made, through post-trial data analysis, of the effect on results of any instrumentation failures which may have occurred during a trial. An example of such back-up is the use of the PIDRS cameras to extract firer-target pairings which may not have been recorded by the DFS/RMS instrumentation.

Integration of Field Experiments and Computer Models

As previously indicated, both experimentation and computer simulation have strong and weak points. Basically, the field experiments provides the more accurate data but does so at a high cost. The computer simulation, on the other hand, is relatively inexpensive to use but frequently lacks credibility. The integration of field experiments and models provides a possibility of obtaining objective, quantitative information for effectiveness evaluations which overcomes the individual shortcomings of each.

The objective in interfacing field experimentation and computer models is to verify the computer representation of the field experiment results. The intention is to then expand the available data base by exercising the computer models. The expectation, of course, is that the results of the modelling work will enjoy the same credibility as do the results of field experiments, once the models have been verified.

The overall CDEC philosophy of integration can be briefly summarized by the following four steps:

a. One and two-sided field experiments provide objective information on specific variables which influence weapon system performance for use as input to models and validation of selected subroutines.

b. Models are exercised to provide information to assist in the design of two-sided real time casualty assessment experiments.

c. Two-sided, real time casualty assessment experiments provide objective information on the effectiveness of small units, equipped and organized with specific weapons, for use as input to models, and validation of the model battle outcome summaries and selected subroutines.

d. Within limited ranges of input variables, the models, once validated, become credible tools to provide quantitative information for different environmental, organizational and tactical conditions of interest.

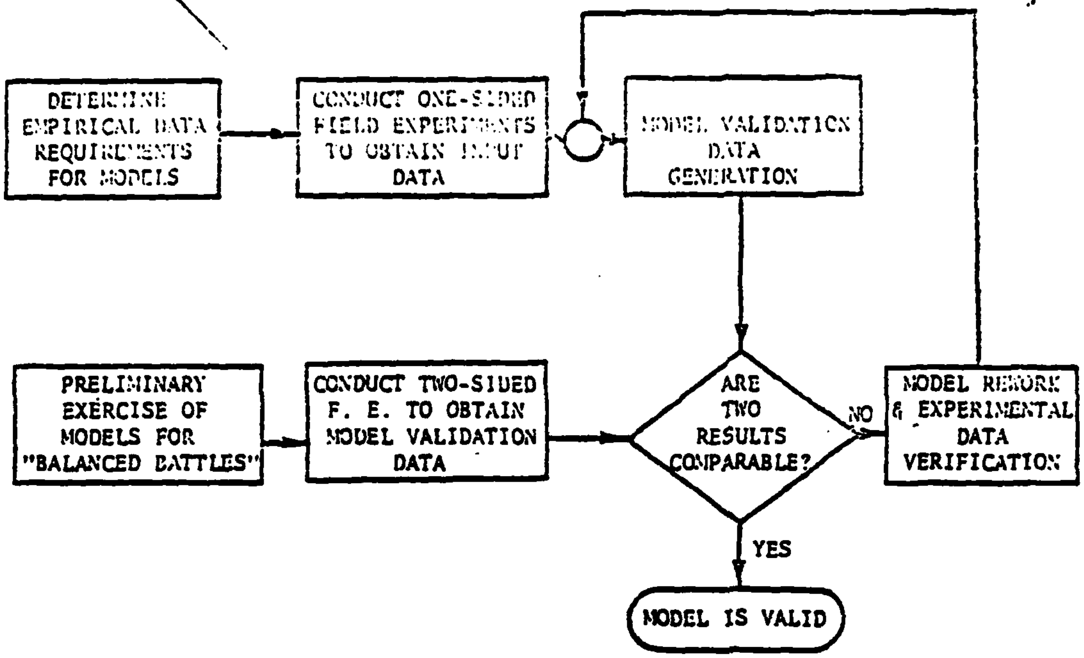

Figure 3. Field Experiment-Computer Model Integration

The key element of the first step is the ability to examine and quantify, using field experimental data, variables and algorithms associated with individual subroutines and decision rules. The validity of computer simulation results depends not only on a correlation in overall battle outcome for the two methods but also on a correlation of intermediate results. Only when this correlation exists can any confidence be placed in parametric excursions using a model validated for a small set of independent variables.

The second step exploits the relatively low cost of exercising computer simulations. Since field experiments, particularly two-sided casualty assessment ones, are expensive, it is desirable to optimize the levels of the independent variables treated in order to insure that the greatest amount of useful data is collected. Considerable insight into the form of the results expected during field experimentation can be gained by this exercising even before an extensive validation procedure for the models can be completed.

The third step utilizes the data collected during two-sided real time casualty assessment experiments to conduct an extensive validation procedure on both battle outcome statistics and intermediate processes. This verification is essentially an iterative procedure since any inconsistencies demonstrated between the two must be resolved by first insuring the validity of the experimental data, then modifying the appropriate simulation subroutine, and finally exercising the model again.

The result of successfully completing the preceeding steps is the development of a computer simulation which may be exhaustively exercised, within a limited range of input variables, and be expected to produce credible results.

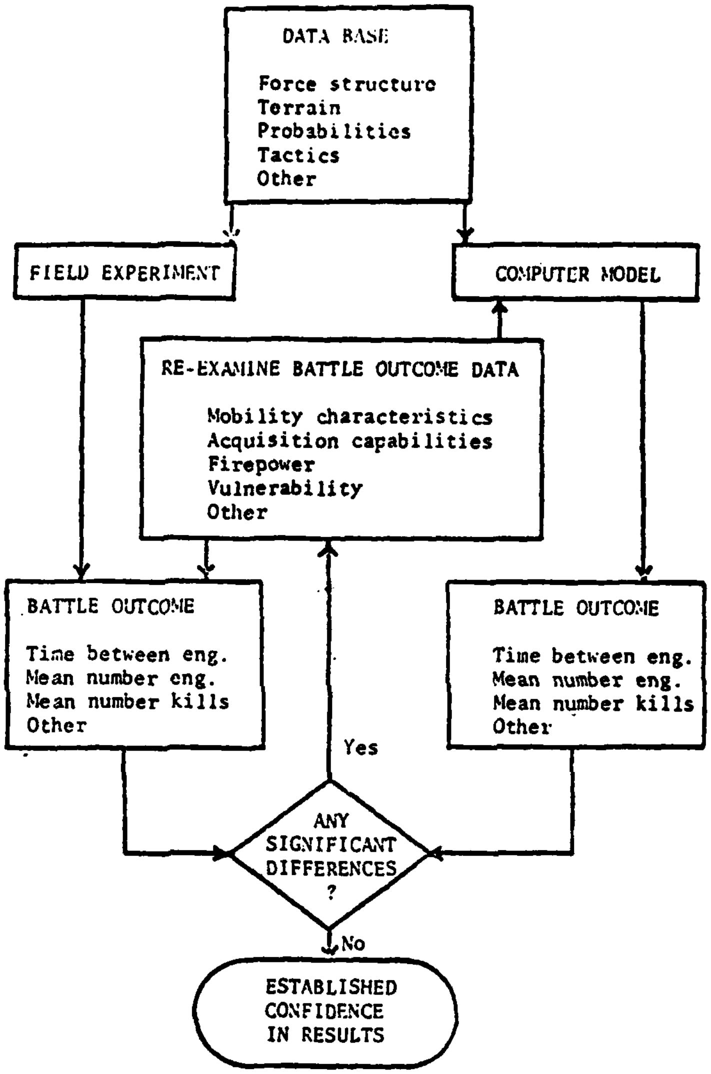

Figure 4. Model Validation Procedures.

TETAM Model Validation Procedure

The proposed validation procedure is to test the computer models thoroughly at one point and somewhat less thoroughly at a second point. The concept may be thought of as fitting a first order response by determining a point on the curve and the average slope between that primary point and some other point. The primary point must be very accurately located to fix the response curve. The second point must be as far from the primary as possible to minimize errors which occur in the estimate of slope due solely to the fact that the second point is not as accurately located as is the first.

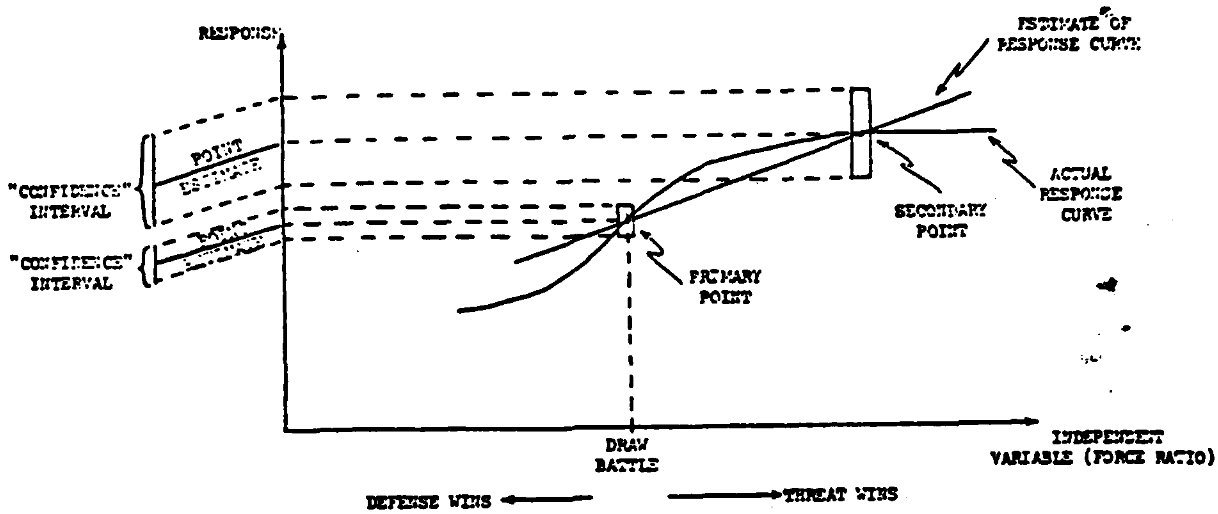

Figure 5. TETAM Model Validation Concept.

The practical problems with the approach I have just outlined are many. First is the selection of the location of the primary point, at which the models are to be thoroughly examined. One school of thought would set the experimental conditions of the primary point to be those in which there is the greatest practical interest. For example, the ratio of opposing forces should be representative of a ratio to be expected in a battle of especial interest. In the TETAM program, we have chosen a different course of action.

In the context of the interface between field experimentation and predictive computer models, the primary task is to verify that the models reproduce the results of the field experiment both in the general battle outcome and in the interactions which produced that outcome. In order to test the representation of the models most severely, we have chosen to use experimental conditions which locate our primary point of examination in the region where the model response is most sensitive to small changes in experimental conditions. We estimate that the region we are speaking of is a long battle, relatively speaking, which is, as nearly as possible, a stalemate.

Our position is based on two considerations. First, the command and control subroutines in the predictive models are expected to have the greatest influence on battle outcome when the force ratios are such that battle may go either way. Second, a long battle will provide more information concerning all of the pertinent interactions or experimental processes to which the computer models and their subroutines are to be compared. In particular, I am referring to command and control, visibility or line-of-sight, acquisition and engagement, and movement processes. So, we have elected to establish our point of primary interest at the draw battle from the standpoint of the starting forces ratios. Using this ratio of opposing forces, we examine the effects of different threat tactics and of differing terrain in order to refine our estimate of the response of both the experiment and the predictive models.

We obtain a bonus effect in terms of the conduct of the experiment by operating at this point. The players in a two-sided experiment become competitive. If one side or the other is always defeated, the players tend to become apathetic and to react in abnormal ways.

I should note here that, although I have been speaking only of Phase III of Experiment 11.8, interfacing with models, important information is also available from Phases I and II. Recall that, in comparing one and two-sided experiments, I remarked that the two-sided was more realistic but at the loss of some control over independent variables. The relatively more exact data on acquisition and engagement, as functions of range and correlated to terrain, available from these two phases can be used as a baseline against which results from Phase III of the field experiment as well as results from the computer models may be compared.

The selection of the point of primary interest for the TETAM program has been widely questioned. Most observers apparently would prefer a force ratio which they considered more realistic. The wide-spread concern about force ratios has led us to select the force ratio as the variable which we would treat in locating our second point, or set of experimentatl conditions. Recall that we intend to locate this second point as far away from the primary point as possible and that we do not intend to determine response here so accurately as we do at the primary point. In line with that concept, a ratio of forces for the second point has been selected which will insure defeat of the defending antitank weapons. Further, only one threat tactic and one terrain site are considered.

The specific techniques to be applied in the implementation of the procedure which I have just outlined are not completely finalized at this writing. A concept has been developed. The extent to which the concept can be carried out will depend on manpower and time available, among other things. Briefly, the plan consists of a two-step iterative procedure. The first step is to exercise the computer models using the same scenario and weapon performance data as was used in the experiment. The overall outcomes from the two techniques are then to be compared. The second step consists of "tuning" the subroutines of the computer models to fit the processes observed in the field experiment. For this step, a somewhat more detailed use of experimental information is envisioned in programming the battle into the computers. For example, in addition to the general scenario which includes the operations orders given to the player commanders, the attack order produced by the threat Tank Company Commander and the defensive fire plan overlay used by the defensive Rifle Platoon Leader might also be used in programming. After the model subroutines are "tuned" to the field experiment, the general scenario must be played again and the overall battle outcomes compared. The object is not only to reproduce the experimental results on the computers, but also to insure that the results are produced as the outcome of operating mechanisms, and interactions between mechanisms, which are the same in both cases.

The extent of this effort will of course be limited by the resources, primarily manpower and time, which can be devoted to it. The current program calls for completion of the Final Report of Experiment 11.8 by the end of February 1974. The comprehensive TETAM Evaluation and initial computer model verification have already begun. An interim report must be rendered by the end of June 1974. It is tentatively planned that the verification effort will continue beyond that date. Following the verification of the models, it is intended that they be exercised to expand the information available from the field experiment. At present, the areas of particular interest for this effort are a study of the effects of differing force ratios and of differing weapons mixes.

The TETAM Program is a sort of a pioneering effort for CDEC in the integration of field experiments and computer simulations. We think now that it will be the primary approach in future studies of this type. Therefore, we consider that one of the most important products of TETAM will be a methodology for effectively combining the strengths of field experiments and computer simulations.

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Directorate of Cost Analysis

DYNAMIC MODEL FOR ARMY RESOURCES (DYNAMORES)

(A concept for a fully integrated, automated system for use in development and management of the total Army structure.)

This paper describes a concept for a fully integrated, automated system capable of determining all resources required to establish, modify, maintain and operate the total organizational structure of the US Army. These resources, which are determined as a function of time, may be expressed in terms of forces, manpower, materiel, contracted services, real property and associated dollars.

The heart of the DYNAMORES system (shown in the center of Fig 1) consists of the "Resource Computation Model" and three data files. The "Computation Data File" provides the computation model with the data it requires in the form required. One set of such data would be generated for each unit identification code (UIC), base or installation for each time period in which no changes occur to affect its assets or resource requirements. The other two data files (i.e., the "EDATE" and "General Data" files), which provide data to the Computation Data File, obtain their information from, and are periodically updated by interaction with several of the Department of the Army (DA) staff's automated management information systems. The most important of these (shown in Fig 1) are as follows:

a. Force Accounting System (FAS)

b. The Army Authorization Document System (TAADS)

c. Table of Organization and Equipment (TOE)

d. Basis of Issue Plan (BIOP)

e. Structure and Composition System (SACS)

f. Force Cost Information System (FCIS)

g. Army Research and Development System (ARDIS)

h. Civilian Budgeting System (CBS)

i. Military Pay File

j. Bases and Installations File (probably non-existent in automated form as yet).

The Effective Date (EDATE) file contains the basic information pertaining to changes occurring to each UIC, base or installation over time. These resource effecting changes may be modification of authorized assets (manpower, materiel, real property, etc.), change of location or status of a unit/base or some other type of change. For each such change, the EDATE file provides the detailed information pertaining to the change (such as an updated TOE or TDA document) and the effective date of the change.

The DYNAMORES system will be designed to operate in two principal modes, corresponding to the two principal uses of the system as follows:

a. Determination of the resources required to establish and operate the official Army version of its forces for the current, budget and out years.

b. Determination of the resource requirements for any force different from the "official" Army force(s) referred to above.

In the first case (i.e., Mode 1 shown on Fig 1) the three principal data files and the computation model will be periodically updated and "batch processed" to produce an updated (official) Resource Data File. This file (shown in Fig 1) will contain the "official" resource requirements for each UIC/Base and Installation as a function of time and will be stored on disc file for rapid and remote access (by means of Cathode Ray Tubes) by DA staff analysts and other staff members concerned only with the official Army position in regard to its forces and bases.

The second mode of operation (i.e., Mode 2 shown in Fig 1) will provide staff analysts with the capability to modify, at will, any portion of the "official force" or to vary any of the system's factors, parameters or other data from their official/accepted values. This mode will then permit the analyst to determine the resource requirements/implication corresponding to, or resulting from, such changed conditions. Depending upon the problem confronting the analyst, he may use the batch process (i.e., communicating with the computer through cards and receiving printer outputs) or he may wish to communicate more directly with the computer through a remote Cathode Ray Tube (CRT), receiving his answers on the tube and/or in hard copy (i.e., computer printouts).

The distinguishing features of the DYNAMORES system, and in particular, the Resource Computation Model, are its great detail, accuracy, versatility flexibility and comprehensiveness in scope. This model will be unique among Army organizational cost/resource models in its treatment of the entire Army structure in the detail of individual units, bases and installations together with their assets and operations. Furthermore, DYNAMORES will simulate real-world conditions much more precisely than any existing Army resource model in the manner in which it determines the Army's total resource requirements over time. It does this by determining the resources required directly for and consumed directly by each individual unit, base and installation, with the progression of time, as each is activated, modified, operated and deactivated. Thus, the indirect support costs of field units, such as logistics and training, are determined as direct costs of support units.

The Resource Computation Model will be designed for maximum operational flexibility and maximum versatility in use. Figure 2 is a flow chart illustrating the stratification and categorization of all units, within the total Army structure, according to various organizational levels, theaters, commands and type organizations. Since each individual UIC may be so categorized, the incorporation of this organizational structure in the design of DYNAMORES will permit the system to determine (or isolate) the resource requirements for any portion of the total Army structure (i.e., for any individual unit, for the total Army structure or for any intermediate portion thereof).

Just as Figure 2 is intended to illustrate the systems flexibility in regard to the portion of the Army structure capable of being addressed, so is Figure 3 intended to illustrate the DYNAMORES system's flexibility in regard to addressable time periods. In this case, unlimited flexibility is offered in that any total time period may be addressed as well as any sub-division of that total period. The only restriction in this regard is the availability of data in the out years.

The versatility of the system is enhanced by the variety of methods and categorizations used to express Army resources. These may be expressed in terms of forces (i.e., divisions, separate brigades, combat support units, combat service support units and other units or aggregates of units), manpower, materiel, real property, contracted services or associated dollars. Dollars may be further categorized according to the Five Year Defense Program (FYDP) and program elements, the appropriation categories of the Army Fiscal Code, the Fiscal Guidance Categories (FGC), and the categories of the Land Force Classification System (LFCS). As a result of the system's characteristics and capabilities as described above, DYNAMORES will be applicable to the entire range of Army resource problems and will serve many important and basic functions and uses. Among the more important of these are the following:

The DYNAMORES system may:

(1) Serve as the focal point for the integration of Headquarters, Department of the Army resource models and Management Information Systems. In so doing, DYNAMORES may provide an automatic check on the consistency of the various official Army plans and information systems relative to the acquisition, distribution, use and disposal or liquidation of its assets/resources over time (i.e., the consistency of its plans for the acquisition of various assets with the ever changing composition, size and function of the total force over time).

(2) Aid the force development process by rapidly determining the resource implications of various alternative courses of action in the detailed planning and programming of Army forces.

(3) Aid in monotoring the expenditure of funds and use of other resources and detecting, in advance, problems relating to the proper rate of expenditure of these funds and resources.

(4) Serve as a tool in determining the resource implications of various alternative conceptual force designs in Conceptual Design for the Army in the Field (CONAF) type studies. This will require input data pertaining to the composition of any radically new conceptual units.

(5) Serve as a tool to answer, immediately, almost any question pertaining to the resources of any segment of the Army for any time period.

(6) Serve as a tool to gain a complete and comprehensive understanding of the dynamics of Army resource expenditures (i.e., to gain insights into the relation of the Army's composition and operation to the requirement for and utilization of its resources).

(7) Aid the DA staff in the recognition of the need for additional management information systems or management plans which may not be in existence nor even planned for the future.

The above is a rather brief and general description of a comprehensive and detailed automated system for use in the development and management of the total Army structure. The development of such a system is obviously a long term project involving the expenditure of considerable resources. Therefore, plans for the immediate future are to direct cost research efforts toward the development of a very basic skeleton framework of the system to permit demonstration of the more important capabilities described above. It is believed that the most important segments of this framework can be developed with a minimum expenditure of resources within a period of six to twelve months. During this period, emphasis would be placed upon the partial development of the Resource Computation Model and the three associated data files (i.e., the Computation, EDATE and General Data files). The degree to which the developed system may be demonstrated with Automated Data Processing (ADP) hardware and software, depends upon the ADP resources available for the project at the time required and the satisfactory solution to the more important non-ADP type problems involved in the design of DYNAMORES.

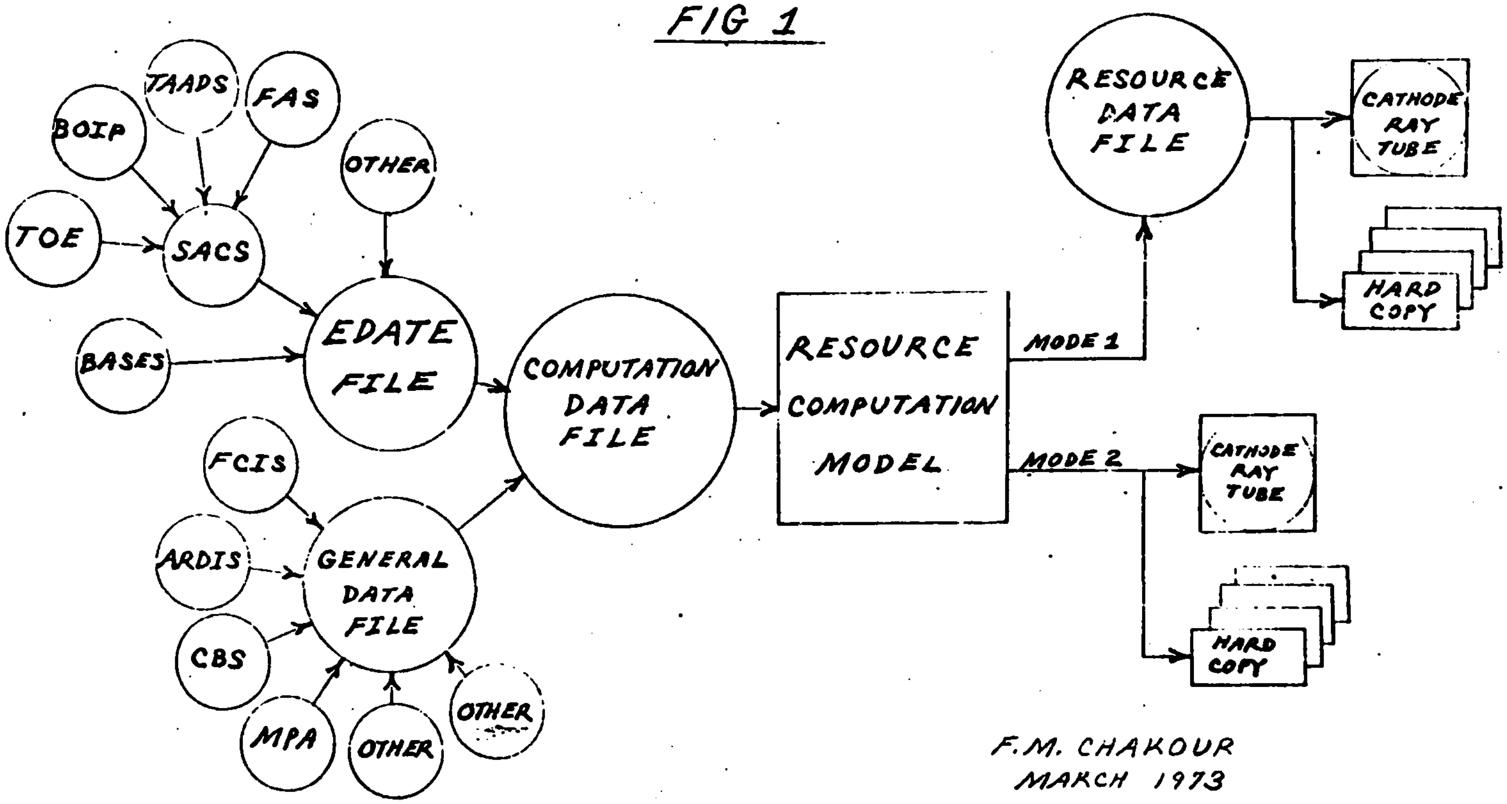
It may be stated that the DYNAMORES concept represents an idealistic (though attainable) comprehensive, fully automated and integrated Army resource system which is absolutely required if the Army of the '70's and beyond is to be managed with maximum effectiveness and efficiency. Without question, practically all the necessary technical ingredients for such a system are present (i.e., the data and state of the art). The degree to which the Army realizes this attainable management goal will depend solely upon its assessment of the need and, accordingly, its willingness to invest the resources required.

Therefore, it is believed that the development of this concept should be carried on, at first, in a relatively slow, deliberate and thorough manner, using a minimum of resources while solving the more basic and difficult problems. Continued and accelerated development of the system should be based solely upon the periodic successful demonstration of the system's actual and potential capabilities as its development progresses.

In this way the Army staff can eventually be in possession of an extremely powerful tool which will enable it to plan and manage the utilization of the Army's resources in the most efficient and effective manner possible.

DYNAMORES
(DYNAMIC MODEL FOR ARMY RESOURCES)

FIG 1



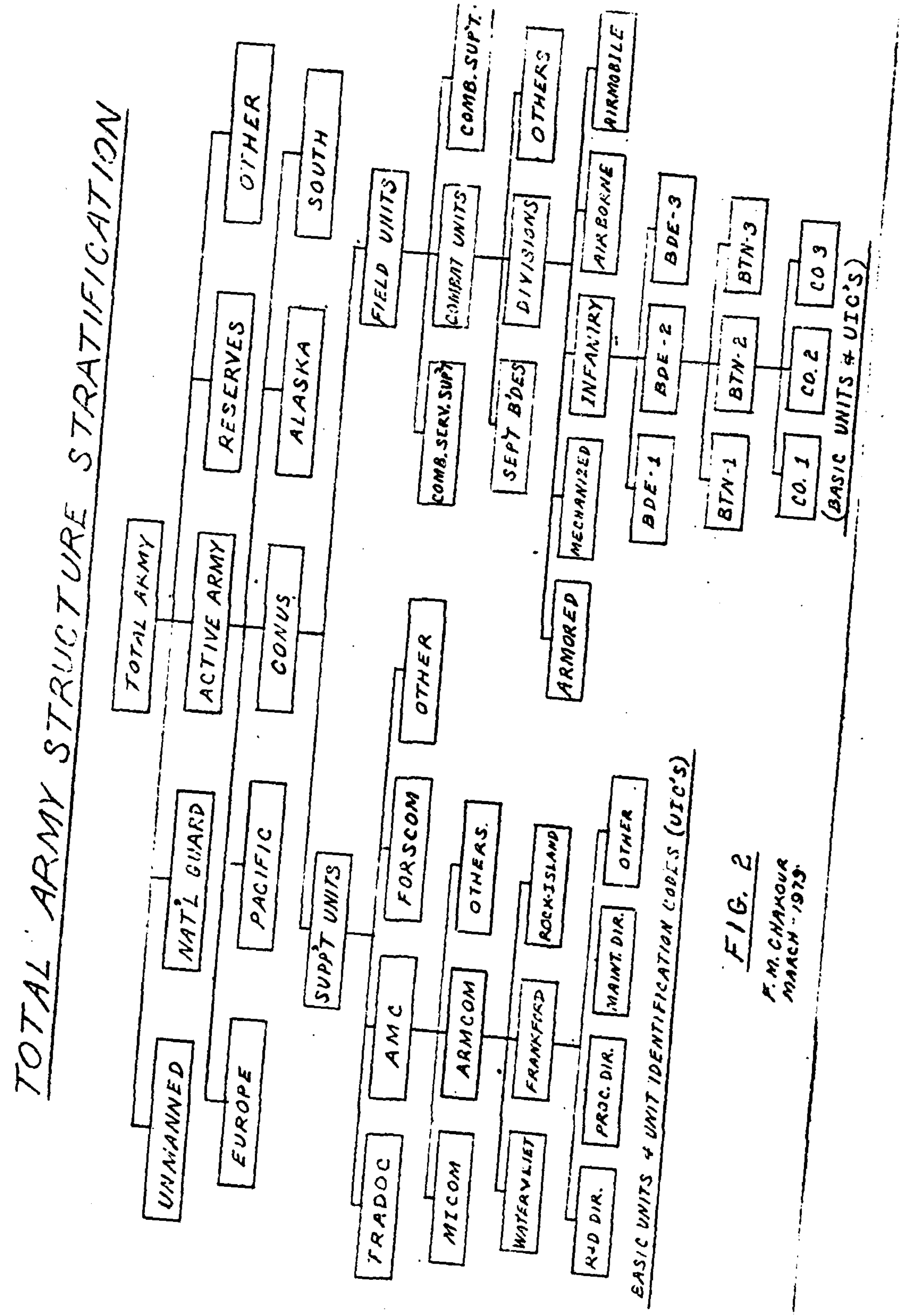

TOTAL ARMY STRUCTURE STRATIFICATION
TOTAL ARMY
UNMANNED
NAT'L GUARD
ACTIVE ARMY
RESERVES
OTHER
EUROPE
PACIFIC
CONUS
ALASKA
SOUTH
SUPP'T UNITS
FIELD UNITS
TRADOC
AMC
FORSCOM
OTHER
MICOM
ARMCOM
OTHERS.
WATERVLIET
FRANKFORD
ROCK-ISLAND
R+D DIR.
PROC. DIR.
MAINT. DIR.
OTHER
BASIC UNITS + UNIT IDENTIFICATION CODES (UIC'S)
COMB. SERV. SUP'T.
COMBAT UNITS
COMB. SUP'T.
SEP'T B'DES
DIVISIONS
OTHERS
ARMORED
MECHANIZED
INFANTRY
AIRBORNE
AIRMOBILE
BDE-1
BDE-2
BDE-3
BTN-1
BTN-2
BTN-3
CO. 1
CO. 2
CO 3
(BASIC UNITS + UIC'S)
F. M. CHAKOUR
MARCH 1979

FIG. 2

TIME SEQUENCE OF DYNAMORES COMPUTATIONS & TIME FLEXIBILITY

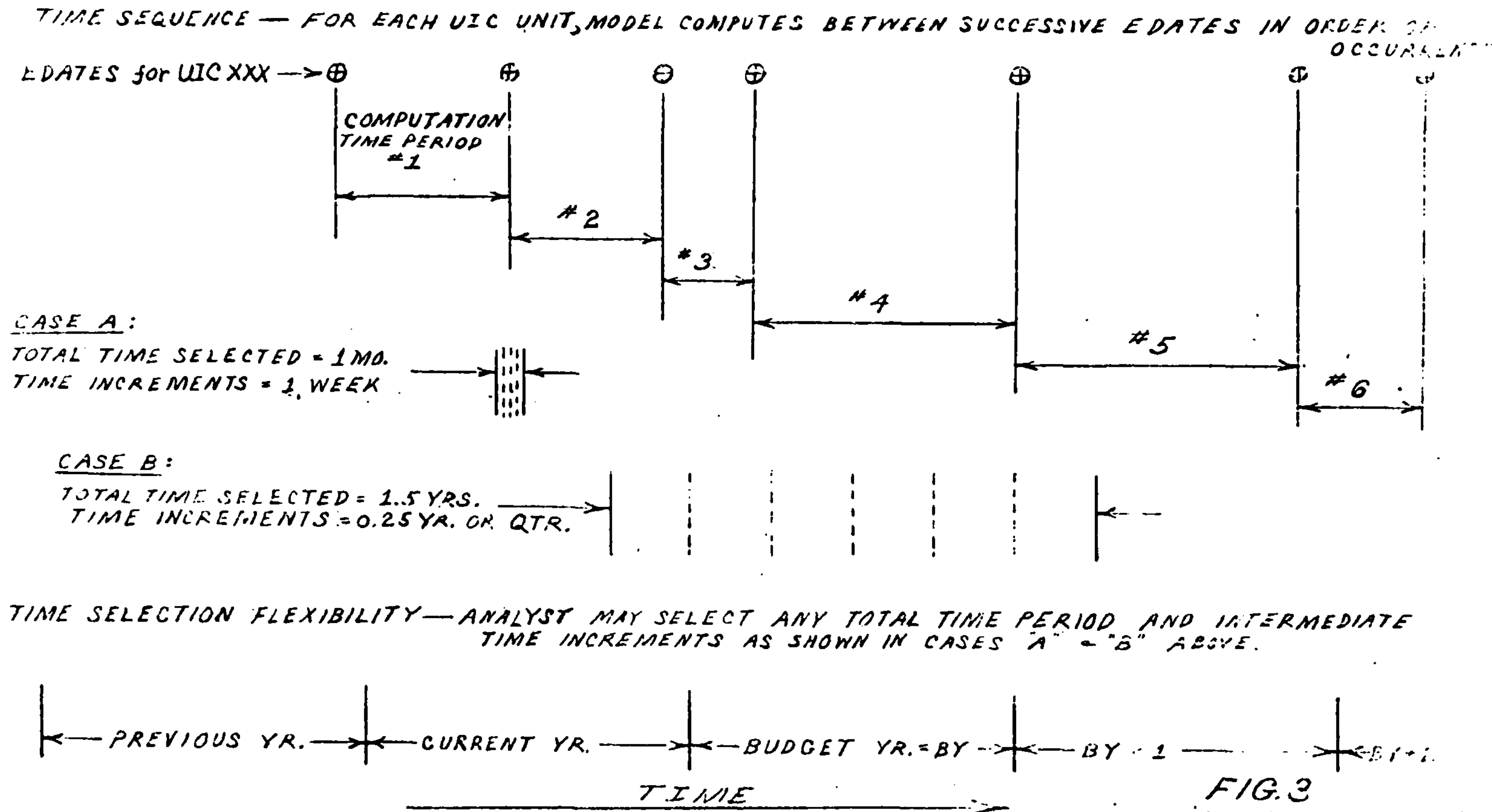


FIG. 3
F.M. CHAKOUR - MAR. 1973

Optimal Allocation of Budget Dollars Among Materiel Procurement Programs

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Ronald G. Magee

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A primary responsibility of the Assistant Chief of Staff for Force Development (ACSFOR) is the establishment of materiel development and procurement priorities to provide guidance for effectively allocating constrained resources to attain defined Army operational requirements. The function performed by the ACSFOR Priorities Committee, and the extensive participation of ACSFOR personnel in supporting the Materiel Procurement Priorities Review Committee (MPPRC) are specifically oriented toward accomplishment of this mission. The MPPRC has direct responsibility for developing multi-year materiel procurement plans directed toward the attainment of Army readiness and modernization objectives. In particular, the MPPRC plays an important role in developing the Army Materiel Plan (AMP) and ensures that future procurement schedules are planned within funding constraints, that procurement and RDTE plans are integrated, and that long range goals are consistent with current needs.

The purpose of this paper is to describe a mathematical programming model currently being developed for use by the MPPRC during the materiel procurement decision process. The objective of the model is to identify the "optimum" level of funding which should be allocated to each materiel program in each year of the planning period to achieve the goals and priorities of the Army within the limits of defined budgetary and production constraints. The model is intended to provide information and insight with which the relative priorities of various materiel programs and the impact of alternative procurement strategies can be readily established and evaluated. It is not intended as a substitute for the considered judgment and deliberation of knowledgeable men.

The materiel procurement process must be viewed as a dynamic problem—constantly changing over time. Budgets change from year to year, new systems are slow to meet performance requirements, old systems become operationally unreliable, and programs become technologically obsolete through recent innovations. This creates a complex multi-year planning problem within which it is necessary to identify a schedule for phasing in new systems and capabilities to attain something approaching "maximum total effectiveness" while maintaining flexibility for continual refinement of the plan as requirements change.

In view of these factors, and the general complexity of the MPPRC decision process, a "goal programming" approach was selected as the most desirable form for the model. The goal programming (GP) model involves the consideration of multiple goals in multiple dimensions. Its solution points out which goals cannot be achieved under the current policy and which tradeoffs must occur.

In the model the deviations between goals and achievements are minimized instead of maximizing or minimizing objective functions directly. The deviations are referred to as slack variables. The objective thus becomes the minimization of the slack variables based on the relative importance, or priority weights, assigned to each variable. The relationship between the value of a slack variable and its relative importance is referred to as a "penalty function." Such a function is shown by the example in Fig. 1. The objective function may also include real variables with associated ordinary or priority weights. These may take the form of explicit "value" functions when there is a specified "benefit" defined over a range of numbers of a given type of system. A typical value function is shown in Fig. 2.

Several types of goal functions have been defined for use in the model although they need not all be used for any particular problem. They include: (1) explicit "value" functions, as previously described, (2) firepower and/or other capability functions, (3) "modernization" functions, (4) system acquisition (AAO) functions, and (5) force element (or force package) fill functions. Minimum and maximum yearly production rate constraints are also defined for each system.

Capability functions are developed by assigning a capability value to a single unit of each system. Examples of types of values which could be used are "firepower scores" and "mobility indices." These are multiplied by the number of systems owned, and then summed over all systems to give a total capability which can be compared against the goal.

The "modernization" functions are of two types: personnel and technology. The personnel functions are used to minimize the total manpower required to field the systems owned. The input data required are the number of personnel needed to man a system in each type of force element: active and reserve personnel are handled through separate functions. The technology functions are used when certain systems have an "advanced technology" capability that cannot be directly measured by a capability function. Such things as all-weather day-night operations, increased survivability, and high maintainability are characteristics which could classify a system as having an advanced technology.

System acquisition functions are based on the concept of uniform AAO shortfall where the objective is to maintain all systems at the highest possible AAO level. However, emphasis can be placed on particular systems, or families* of systems, such that they are allowed to exceed the uniform AAO level.

*A family of systems is defined as a group of systems having the same general purpose. It is characterized by maintaining or improving a capability through the phasing-in of a new system to replace existing systems. The family of HIMAD missiles (HAWK, Improved HAWK, NIKE-HERCULES, and SAM-D) is an example of such a family.

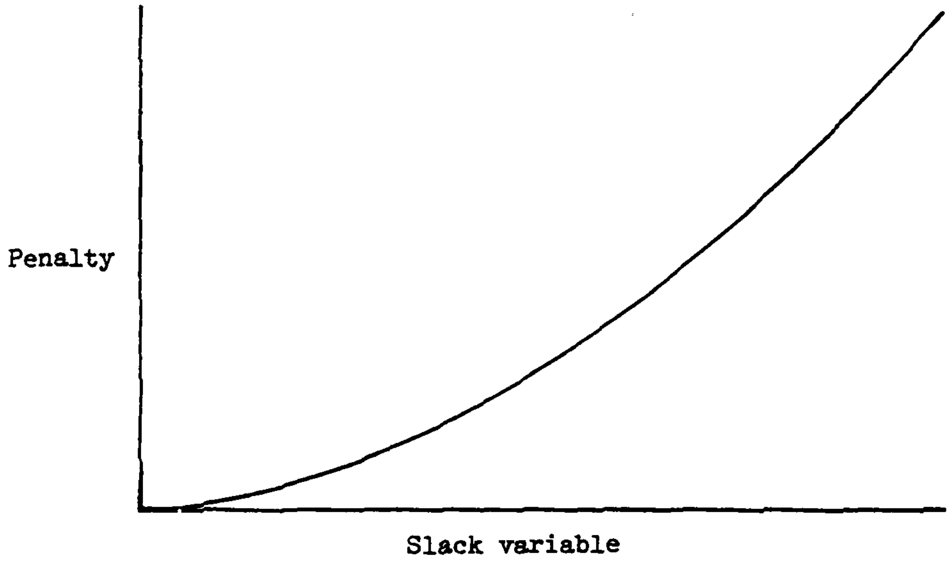

Fig. 1—Penalty Function

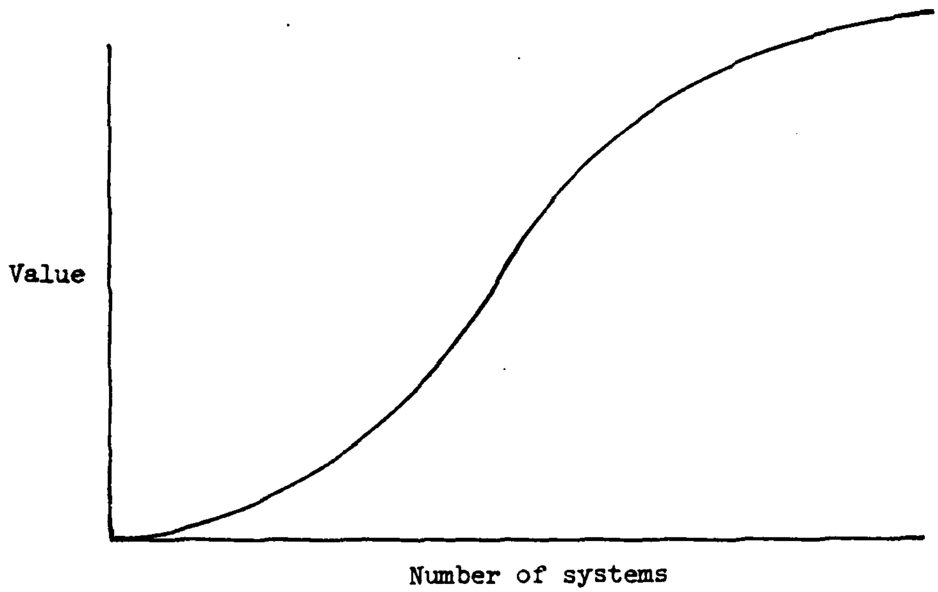

Fig. 2—Value Function

The last group of functions handles force element fill. These functions are related to the system acquisition functions so that specified force elements (or force packages) can be given priority, while others maintain a uniform AAO level. This means that systems are assigned to force elements (such as Mechanized Infantry) or force packages (such as NATO) in such a way that those of higher priority are sustained much closer to TOE requirements than those of lower priority.

The cost functions associated with the problem have been divided into four basic categories: research and development (RDTE), procurement (PEMA), operating (OMA), and personnel (MPA). Associated with each category is a group of budgetary constraints, one for each time period (normally one year) of the problem. In some cases these constraints do not apply to the problem and need not be used. However, when they are used the cost functions must be appropriately defined.

MPA and OMA costs are modeled as average linear costs per system. However, they may vary between force elements. This allows for differentiation between units, especially between active and reserve units. The input data required are the average cost of operating one system in a given force element, and the average cost per man associated with the system in a particular force element.

The PEMA cost functions are variable during each time period of the problem and may take any form that can be approximated by a series of straight line segments. This means that any realistic nonlinear procurement function can be input to the model, including those with step discontinuities.

RDTE costs are handled by considering program alternatives, one of which must be selected. Figure 3 suggests the nature of RDTE costs with respect to the duration of the program. This graph implies that, in general, there is an "optimum" duration which provides a minimum cost for the program. If this time is either extended or reduced, costs tend to increase because of inefficiencies, whatever their cause. Based on this graph, alternative programs which give the minimum cost to provide the system by various dates can be defined. Table 1 suggests such a set of alternatives. These alternatives are entered as input and the model selects one of them (or the alternative of not developing the system) as the schedule for that RDTE effort.

A "branch and bound" algorithm is used to solve the mathematical programming problem. This method can be likened to a "divide-and-conquer" approach because, even though the total problem is unmanageable, systematic partitioning into subproblems leads to an efficient solution procedure. An important feature of the method is that "lower bounds" can be found for each subproblem; that is, a lower limit on the value of the penalties can be determined for <u>all</u> of the possible solutions contained within a given subproblem — and this lower limit (bound) can be determined without evaluating <u>any</u> of the possible solutions within a given subproblem.

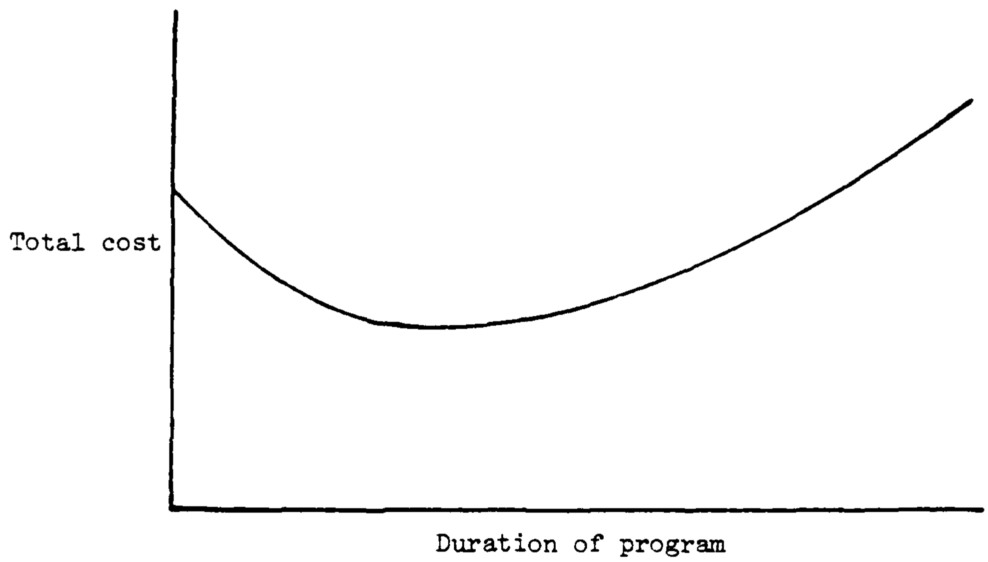

Fig. 3—RDTE Program Cost Function

Table 1

ALTERNATIVE RDTE SCHEDULES

		Year						Total cost
		1	2	3	4	5	6	
Alternative dates	1	10	12	6	-	-	-	28
	2	4	8	10	4	-	-	26
	3	2	4	8	10	4	-	28
	4	2	2	4	8	10	4	30

Interestingly, few if any subproblems themselves are completely solved in the algorithm. Instead, a relationship is established between subproblems which allows one to reject certain subproblems and retain others. Subproblems are rejected because it can be shown they represent a subset of possible solutions that cannot contain the optimal solution. Those subsets which are retained can contain the optimal solution and, hence, as the algorithm proceeds, these subsets are partitioned farther — more and more subsets are rejected — until there exists only one subset and it contains the optimal solution.

At the present time, a "pure" FORTRAN version of the model has been developed and successfully demonstrated on smaller "trial" problems. Developmental efforts are continuing with incorporation of machine dependent computer coding and a full problem demonstration is planned when the work is completed. It is expected that the model will be ready for experimental use in MPPRC deliberations next spring, and on-line shortly thereafter.

HELICOPTER PROGRAM COST MODEL

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ABSTRACT

This paper summarizes work performed to date on a simplified (AMSAA) developed model for calculating first order estimates of total program costs for helicopters. The term "total program cost" is used rather than "life cycle cost" because the time period of concern may not encompass the entire life cycle of the aircraft system. Two models are discussed; one is simplified so it can be programmed on desk calculators, and the other more extensive for high speed digital computer application. A version of the simplified model is presented. It is suitable for programming on desk calculators which have a capacity for at least 800 program steps plus 70 storage registers. The extensive model was developed for use on the Ballistic Research Laboratories Electronic Scientific Computer (BRLESC). The original version of this model was first used on BRLESC early in 1969. Since then it has been modified extensively to suit changing study needs.

INTRODUCTION

The mission of the US Army Materiel Systems Analysis Agency (AMSAA) is, in part, to perform independent cost effectiveness systems analysis studies and comparative analyses of existing and proposed Army Materiel Systems. This includes evaluations of the economic consequences of systems throughout their life cycles. A typical AMSAA Study might require a cost and effectiveness comparison of various types of logistics vehicles in a resupply mission. Another task could require an evaluation of the total cost impact of a newly proposed Army weapon system as specified in a Required Operating Characteristics (ROC) document. In these situations it is necessary to estimate the cost of ownership or total program cost for the systems under study. Obviously there is more involved than the costs for R&D and procurement of end items. Operational costs must also be considered; however, these costs can be difficult to estimate because so many factors are involved. A recent DOD briefing (reference 1) very aptly illustrated the problem as shown in Figure 1. Total program cost is depicted as an iceberg with the tip visible above water representing costs for R&D, procurement, and production overhead. The more ominous portion, invisible beneath the surface, represents the costs associated with keeping the system operational. The question is how big is the total iceberg? A waterlogged iceberg will have a larger portion beneath the surface. The above mentioned many factors involved serve to determine just how waterlogged we can expect our iceberg to be.

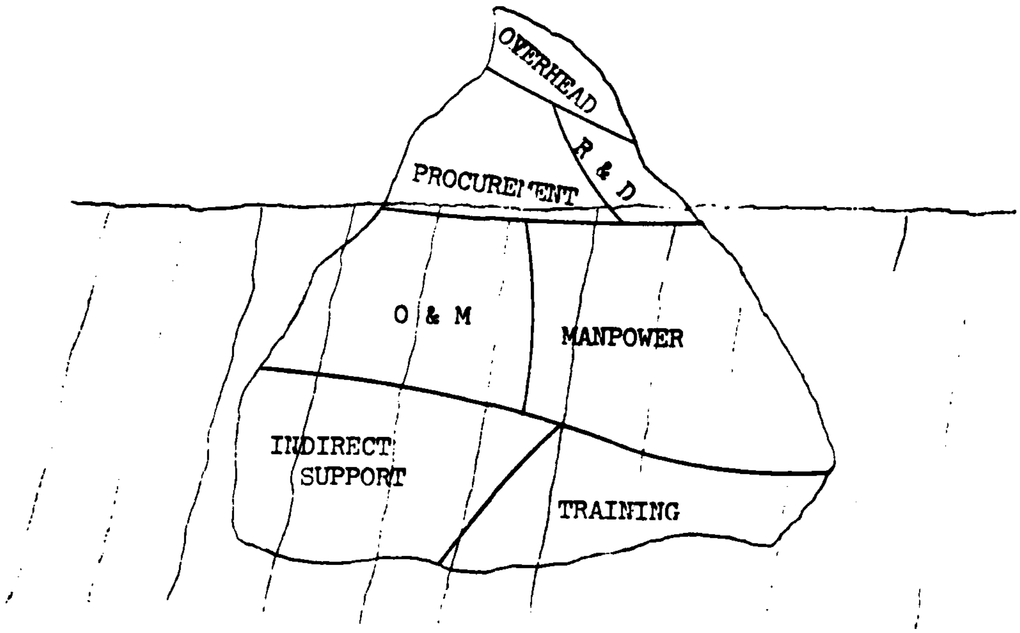

Figure 1. Program Costs - the total iceberg

It should be mentioned that AMSAA is not the official agency within the Army from which to obtain cost estimates; however, many AMSAA studies have very short deadlines which preclude the possibility of obtaining outside help on cost estimates. Moreover, some AMSAA studies are "Red Team" efforts where independent cost estimates are desirable. It is therefore necessary for AMSAA to have an independent capability for making first order estimates of total program costs. One such technique developed within AMSAA is a computer model for estimating total program costs for helicopters. A version of the model and some sample applications are discussed in the following paragraphs.

BACKGROUND

Work on the AMSAA Helicopter Program Cost Model began in the Fall of 1968 when the authors were assigned to a cost-effectiveness study of several helicopter candidates being considered for special Army missions. While some cost data were available on the various candidates, the data were not directly comparable from one candidate to another. A short study deadline and lack of available Army oriented cost models further added to our dilemma. We therefore called upon our own experience in developing aircraft program cost estimates and formulated a cost model tailored to the needs of the study. Since then the basic model has been modified extensively to suit our changing needs. Moreover, the program cost model has been integrated into an AMSAA developed helicopter parametric design analysis model in order to provide a program cost estimate as part of the output for the design solution. This combined program has proven a valuable aid in performing cost sensitivity analyses on helicopter designs and operational parameters important to Army helicopter development programs.

APPROACH

We have endeavored to keep the model described herein as simple as possible. Costs are estimated in terms of 23 input factors and then grouped according to major categories. These categories are Research and Development, Initial Costs, Annual Operating Costs and Other Program Costs. Results are presented on both per aircraft basis and fleet basis. A list of input factors is shown in Table I along with 16 additional factors which are calculated from input data. These factors are used to calculate the cost subcategories through the use of Cost Estimating Relationships (CER's) which are discussed later. These CER's are presented in Table II. The calculated factors of Table I and the CER's of Table II contain many subfactors which must be adjusted periodically to compensate for inflation and variations in design technology. Once these factors are adjusted for a given study, however, many cases can be run on the computer in a matter of seconds. In normal practice the model is updated only once a year, while it is used many times a year to gain insight into the possible total cost impact of existing and future helicopter fleets used in various missions.

At AMSAA we usually base program cost estimates on operational aircraft. This point is mentioned because other Army Cost Models appear to base estimates on production aircraft, and their results may not be directly comparable to AMSAA results. Our reasoning is that the user has a demand rate in terms of operational aircraft. Moreover, the operational aircraft base is more convenient for most studies because the analyst can directly apply the appropriate availability factors without additional manipulation of data. The difference between operational aircraft and production aircraft is that the number in the operational fleet does not include maintenance float aircraft or attrition replacements. Thus if the total inventory includes 10 percent maintenance float aircraft and attrition averages 3 percent per year over a ten year program, operational aircraft would constitute only about 71 percent of the total number of production aircraft, assuming all attrition aircraft are replaced. The ratio between operational aircraft and production aircraft is not a constant, however. It depends on aircraft utilization, maintenance float fraction, and attrition rate, none of which can be considered a constant.

FACTORS AFFECTING COST

A good program cost model must be sensitive to operational variables. In this regard, every cost estimate must be interpreted in full view of the assumptions on operational use. An obvious but often overlooked major variable is aircraft utilization. In peacetime, utilization is generally low; however, if the necessity arises as in the event of a war, utilization might increase by a factor of ten. What impact does this have on total program cost? The cost model can provide insight into such questions. Another factor to consider, however, is system useful life. It has been the normal practice to base cost estimates on a ten year program regardless of the assumption on aircraft utilization This gives rise to a somewhat absurd situation where ten year program costs are calculated for a fleet having an average utilization of 20 hours per month per aircraft (2400 hour program life per aircraft) and compared to the same fleet having a utilization rate of 100 hours per month per aircraft (12,000 hour program life per aircraft). Are the numbers directly comparable? Not really, but such comparisons have been made without even thinking about the great difference in implied system life. Are the numbers realistic? Historically we have not been able to sustain a helicopter utilization rate (per operational aircraft) of 100 hours per month for more than a short period of months and this was done only on the smaller helicopters. A check of the monthly inventory and flying time reports published by the US Army Aviation Systems Command verifies this over the past several years (reference 2). During peacetime the helicopter utilization rate may fall below the low cited value of 20 hours per month. Current data will also substantiate this statement. This leads into another important point. When the system requirements for maintenance and availability are specified in a requirements document (ROC, MN, etc.), they are generally given in terms of a utilization rate (usually the high wartime rate). At times this has led to the assumption that manpower requirements must be based on the wartime rate even when costs are being calculated for peacetime. Cost estimates which include this assumption could be very misleading. A main reason for cutting back on utilization is to save on personnel costs. Furthermore, comparative cost estimates calculated on such a basis are not only distorted, but they tend to favor aircraft concepts which have optimistic assumptions on maintenance requirements. Finally, in today's climate and culture it is unbelievable that the military would be allowed the luxury of excess manpower.

The true program cost picture can often be clouded by simple manipulations of cost estimates. For example, it can often be inferred that a particular system costs more when the developer actually expects to spend less or vice versa. In recent years we have been bombarded with information about tremendous increases in unit procurement costs of some of our advanced military aircraft. A portion of these increases have been caused by amortizing extremely high R&D costs over significantly fewer units than originally planned. The public may be told on the one hand that the cost of the program is being cut while opponents are providing "proof" that program costs per unit have greatly increased. The opposite phenomenon can occur when we expresss costs in terms of dollars per flight hour. As aircraft utilization is increased, fixed costs are amortized over more flight hours. . In this case cost per flight hour would decrease while expenditures are actually being increased.

A learning curve is a marvelous tool widely used in cost estimating. It is a simple expression of the form $Y = aX^b$ which seems to tie in beautifully with ost stimating elationships. The AMSAA Cost Model uses such expressions extensively; however, a word of caution is in order. The classic use of the expression is to estimate costs for production units by the expression:

$$C_N = C_1(N)^b$$

where

C_N is the cost of the N^{th} unit

C_1 is the cost of the first unit

N is the number of units produced

b determines the slope of the curve

The theory is that the more units produced, the cheaper they will be to purchase. In particular the expression states that every time we double the number of units, the unit cost will be reduced by a constant percentage. For instance if we have an 80 percent learning curve (b = -.322) and the first unit costs 100 dollars, the second unit will cost 80 dollars, the fourth 64 dollars, and so on. In the AMSAA Helicopter Cost Model the expressions are adjusted to yield average unit cost over a production run but the principal is identical. It should be mentioned that expressions of the same form are used to estimate many other variables in the model. The word of caution mentioned above is that costs do not always follow the learning curve rule. In some cases requirements for an increased production rate can cause costs to increase even though more units are purchased. Production scheduling is also an important factor. Obviously we cannot start out at year one with all the planned operational aircraft. This would not even be desirable. The sensible philosophy for peacetime weapons procurement would seem to be that production of the basic fleet of aircraft should continue over several years up to at least the time a replacement system is ready for production. Thus there would always be a potential for expanding production to meet war-time requirements should the need arise. Ideally the system should never have to be used in a war, but the need for mass production must never be ignored.

The above mentioned factors can easily distort the classic learning curve and they must be considered in depth during detailed cost studies. For the purpose of first order cost estimates, however, the simplified AMSAA model assumes learning curves to be valid and that the total operational fleet is available immediately. In effect the latter assumption infers that the phase-in and phase-out portions of the total system's life cycle cancel each other and that average program cost per operational unit is not affected.

COST ESTIMATING RELATIONSHIPS

Tables I and II show the input factors, calculated factors and the CER's which comprise the Simplified AMSAA Helicopter Program Cost Model. It should be noted that electronics cost is a direct input as the model contains no CER to calculate this cost. Research and development costs can either be directly input or calculated by two CER's, one for airframe development and one for engine development. A CER for Electronics R&D is not included. The CER for airframe development uses design cruise speed (V_{cr}) as one factor in an attempt to account for the cost of developing increased performance capability. Although the expression is considered preliminary in nature, it appears to yield reasonable ball park estimates for single source airframe development cost in the design cruise speed range of from about 120 kts to 160 kts. Modifications to this CER to include a factor for design maneuver capability and multiple source development are presently under study. It appears that a reasonable rule of thumb for a two contractor competitive development would be to increase airframe development costs by about 50 percent.

In general, costs are estimated as a function of physical size. In this simplified model, empty weight (W_e) is used as an indicator to size rather than airframe weight. This is done strictly for convenience. The difference in results is believed to be negligible. The sea level standard uninstalled military (or intermediate) shaft horsepower rating (SHP_m) is used as the indicator to engine size. In the more extensive AMSAA model for the BRLESC, procurement costs are estimated in terms of eight aricraft subsystems. These subsystems and typical cost factors for them are listed in Table III. The cost factors shown are based on 600 production units. The pertinent subsystem characteristics are an output of the AMSAA model for helicopter parametric design analysis.

Attention is directed to the use of the number of line items (N_{li}) and aircraft utilization (U) as factors in estimating costs for maintenance in the field and for commodity management (Project Manager's Office, engineering support, inventory management, etc.). The predicted effect of utilization on field maintenance costs (labor and material) is probably more closely related to mission length from start-up to shut-down (not necessarily a single sorti). In other words, it is suggested that an increase in utilization is likely to be accompanied by an increase in mission length up to the design capability of the aircraft. The reader should note that scale factors are included in the expressions for calculating field and depot level maintenance costs. The purpose of these scale factors (input values) is to allow for easy sensitivity analysis on controversial maintenance related cost categories. For the baseline case, scale factors are input as 1.0. If it is desired to reduce a given cost subcategory by 20 percent to check sensitivity the pertinent scale factor is entered as 0.8. If it were necessary to check all cost subcategories for sensitivity, scale factors could be included in all CER's; however this would greatly expand the required number of inputs.

The factor for productive manhhours per year per mechanic can be either input directly or calculated. The expression for calculating this factor attempts to compensate for the fact that during wartime or other periods of high utilization, maintenance crews are expected to work more than 40 hours a week. The expression also compensates for time required for other assigned duties.

Costs for training and transportation of pilots and maintenance personnel are estimated as a function of helicopter size (W_e). This merely accounts for the fact that it costs more to train pilots and mechanics to operate and maintain the larger more complex helicopters.

Initial costs for ground support equipment (GSE), publications and miscellaneous items are estimated as a percentage of flyaway cost; therefore for convenience they are grouped into one subcategory and labeled C_{gpm}. Miscellaneous costs for annual operations are estimated as a percentage of the costs for field related subcategories (personnel pay and allowances, POL, maintenance material, and training and transportation of replacement personnel). The only other cost subcategory estimated on a percentage basis is the annual cost for facilities and equipment. This cost is estimated as 20 percent of the initial cost for GSE, publications and miscellaneous equipment. It is intended to account for the cost for maintenance and upkeep of equipment and facilities directly chargeable to the operational unit.

Study of Tables I and II should allow the reader to see the reasoning behind most of the CER's. It is important to emphasize that CER's are not fixed expressions. They should be continually scrutinized for possible revision as more data become available.

PROGRAM OUTPUT

For AMSAA studies, cost output is required in various forms. When total fleet program costs are required the per unit output for initial costs and cost of annual operations must be multiplied by the number in the operational fleet and the result added to the costs for R&D, attrition and commodity management. When the costs are estimated in terms of additional aircraft to be purchased for a special mission, the analyst would likely consider R&D costs and the bulk of commodity management costs as being sunk, and express remaining costs on a per unit basis. The point is, that the output can be tailored to specific needs; however, the analyst must fully understand what costs the particular CER's are designed to estimate. The CER's for R&D, commodity management and attrition are total program costs and must be divided by the total number in the operational fleet to get them on a per operational unit basis. Conversely, the CER's for initial and annual operating cost subcategories provide output on a per operational unit basis and must therefore be multiplied by the total number in the operational fleet to arrive at Fleet Program Costs. Although this may seem to be a confusing basis, it has been the most useful one for AMSAA purposes.

APPLICATIONS

The AMSAA helicopter program cost models have been used extensively in many different applications. Figures 2, 3, and 4 provide typical examples. Figure 2 presents a curve of predicted unit program costs per flight hours for a utility helicopter concept versus aircraft utilization in flight hours per year per aircraft. Key design and cost parameters are listed on the graph. This plot illustrates the point made previously about making expenditures appear to be less than they really are. As utilization increases program costs also increase;

nowever, cost per flight hour decreases. The increase in total cost can be clearly seen by multiplying the cost per flight hour by the utilization values.

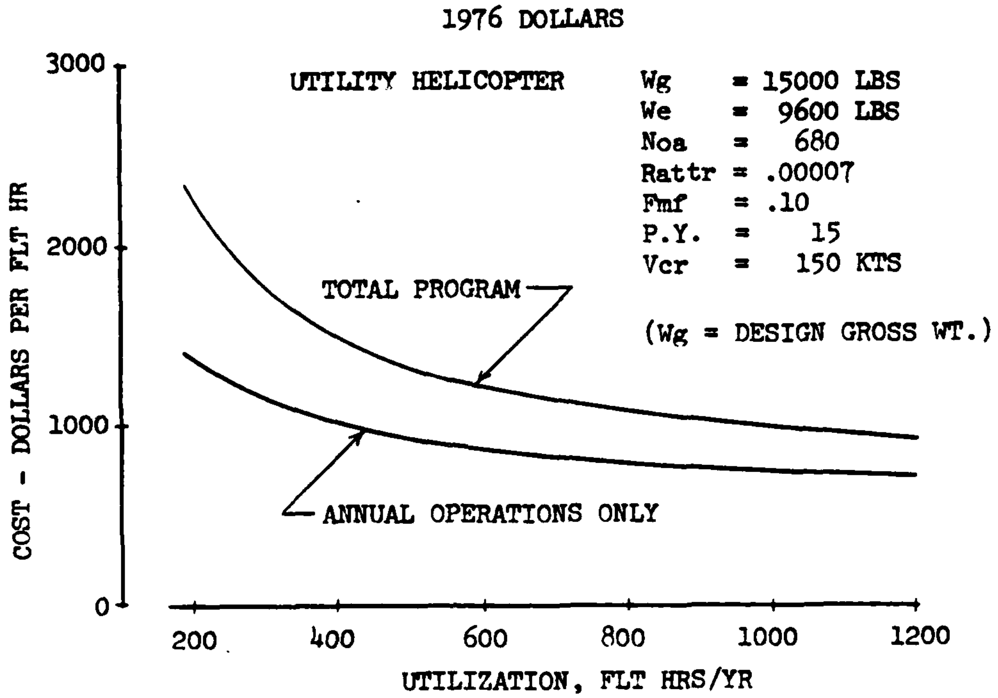

Figure 2. Program Costs versus Utilization.

Figure 3 shows the results of a cost impact study on bands of performance (BOP) for HLH design characteristics. Again the key characteristics and parameters are listed on the graph. In this case an envelope of program cost per operational unit was estimated for the BOP range on payload, take-off conditions, and the number of round trips (mission endurance).

Figure 4 was taken from a study on the feasibility of overdesigning helicopter transmission systems as a possible means to improve reliability and thereby reduce maintenance costs (reference 3). The previously mentioned integrated helicopter design and cost model (based on 8 subsystems) was used to generate data for Figure 4. Total program costs per operational unit are plotted versus a factor called transmission power redundancy factor (TPRF) which is merely an index to the amount of overdesign. At a TPRF of 1.25 it was estimated that maintenance costs would have to be reduced by approximately 20 percent to compensate for increased costs resulting from the overdesign philosophy.

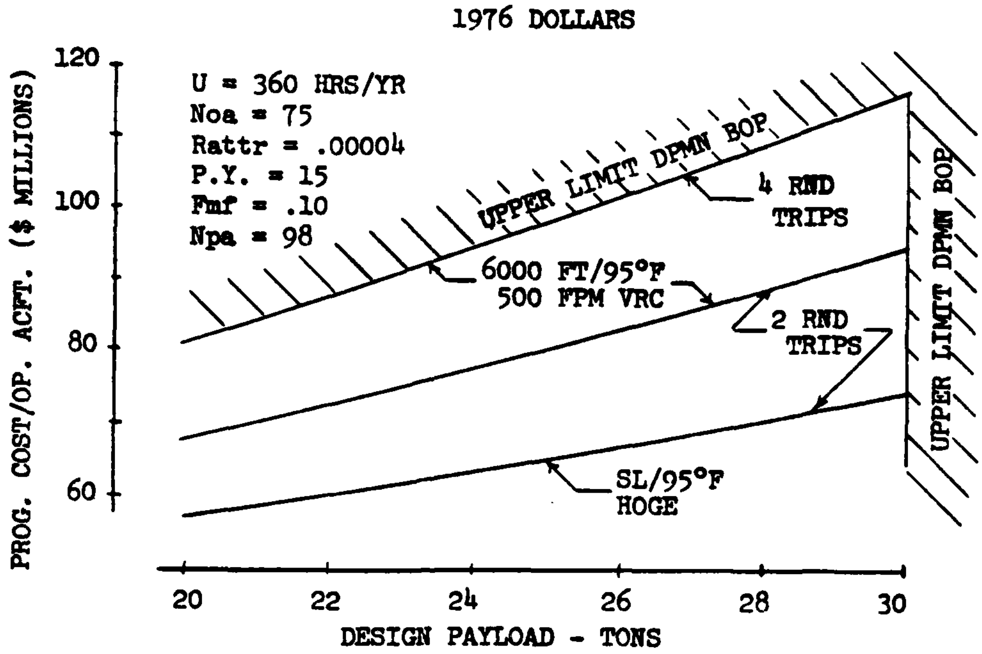

Figure 3. Program Cost Envelope for HLH DPMN.

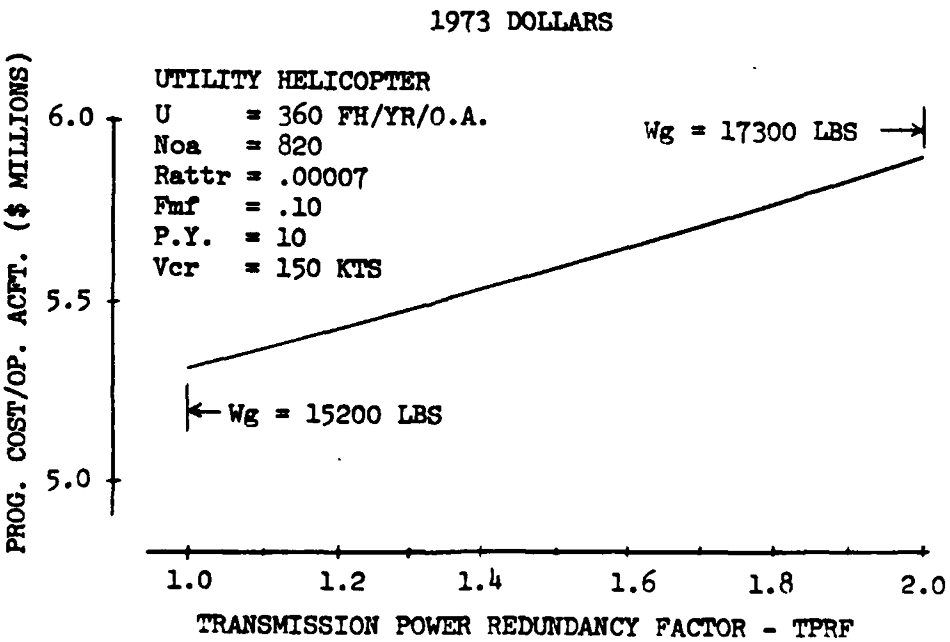

Figure 4. Program Cost versus Transmission Overdesign.

AREAS FOR STUDY

As stated previously the cost analyst continually searches for better ways to estimate costs. Most cost models available today appear not to be sensitive to many important parameters for trade-off studies. Efforts to develop CER's on a helicopter subsystems basis were motivated by studies on the cost impact of overdesigning various helicopter components to improve reliability. It is believed that this is a promising area for future study.

Cost estimating techniques for maintenance manpower and material need to be improved. It is believed that reasonable CER's could be developed in cooperation with Commodity Commands.

Perhaps the most important area for study is the cost of the logistics supply system. An attempt has been made in the CER's for maintenance and depot material to increase costs to account for transportation charges for spare parts. From our studies on components it appears that if you added up all the costs of major sub-assemblies of the helicopter as recorded in the Master Data Record the result would be a cost considerably less than the flyaway cost of the helicopter. On the other hand, if you total up the cost of an automobile made from spare parts in a wholesale parts catalog, the cost could be several times the drive-away cost of the fully assembled automobile. It is recognized that the two cases are not directly comparable; however it is suggested that part of the difference is that pipeline costs are included in the automobile parts case. The point here is that we need a much better handle on inventory management costs. The magnitude of these costs may well be astounding. Much more study is needed in this important but often ignored cost area.

REFERENCES

1. DSARC Cost Reduction Working Group, the "Little Four," final report, "Weapons Systems Cost," 19 December 1972.

2. US Army Aviation Systems Command, St. Louis, MO, "Army Aircraft Inventory Status and Flying Time," published monthly.

3. H. C. Reiher, G. W. Koch, "Cost Effectiveness Aspects of Overdesigning Helicopter Transmission Systems," draft AMSAA report dated 19 June 1972.

TABLE II. COST ESTIMATING RELATIONSHIPS

RESEARCH & DEVELOPMENT:	AIRFRAME:	Crdaf	$= 0.015(We)^{.9}(Vcr)^{3}$
	ENGINE:	Crde	$= 1.4X10^{6}(SHPm)^{.575}$
INITIAL COSTS PER OPERATIONAL AIRCRAFT			
FLYAWAY (Cfa):	AIRFRAME:	Caf	= Kaf(We)
	ENGINES:	Ce	= Ke(SHPm)(Ne)
	ELECTRONICS:	Celpa	= INPUT
INITIAL SPARES:		Cisp	= 0.20Caf + 0.70Ce + 0.35Celpa
MAINTENANCE FLOAT:		Cmf	= Fmf(Cfa)
GSE, PUBS, AND MISC:		Cgpm	= 0.08(Cfa)
TRAINING AND TRANSPORTATION (Citt)			
	PILOTS AND GROUND OFF.:	Cttpo	$= 285(We)^{.6}(Np + 0.3Ngo)$
	MAINTENANCE PERSONNEL:	Cttm	$= 2900(We)^{.13}(Nmp)$
	SUPPORT PERSONNEL:	Cttsp	= 1.4(5500)(Nmp)
ANNUAL COSTS PER OPERATIONAL AIRCRAFT			
PAY AND ALLOWANCES:	PILOTS:	Capap	= 18000(Np)
(Cappa)	GROUND OFF:	Capag	= 16000(Ngo)
	MECHANICS:	Capam	= 8500(Nmp)
	SPT. PERS:	Capas	= 1.4(7000)(Nmp)
REPLACEMENT TRAINING & TRANSP:		Crtt	= 0.5(Citt)
MAINTENANCE MATERIAL:		Camm	= (U)($/FH)amm
PETROLIUM, OIL, LUBRICANTS:		Cpol	= 0.0182(U)(Wf)/(T)
DEPOT LABOR:		Cadl	= (U)($/FH)adl
DEPOT MATERIAL:		Cadm	= (U)($/FH)adm
FACILITIES AND EQUIPMENT:		Cafe	= 0.2(Cgpm)
MISCELLANEOUS:		Camis	= 0.1(Cappa + Cpol + Camm + Crtt + Cafe)
OTHER PROGRAM COSTS PER OPER. FLEET			
CATALOGING:		Ccat	= 500(Nli)
COMMODITY MANAGEMENT:		Ccm	= 30000(Ncm)(P.Y.)
ATTRITION:		Cattr	= (Nattr)(Cfa)

TABLE III. TYPICAL SUBSYSTEM COST FACTORS (1973 DOLLARS)

DOLLARS PER POUND OF BODY GROUP		$ 58.00
DOLLARS PER POUND OF LANDING GEAR		69.00
DOLLARS PER POUND OF DRIVE SYSTEM		95.00
DOLLARS PER POUND OF ROTOR SYSTEM		100.00
DOLLARS PER POUND OF FUEL SYSTEM		85.00
DOLLARS PER POUND OF EQUIPMENT		85.00
DOLLARS PER POUND OF AUXILIARY GEAR		64.00
DOLLARS PER SHP FOR ENGINES	ADVANCED TECH.	67.00
	PRESENT TECH.	52.00

TABLE I. COST FACTORS

INPUT DATA:	SYMBOL
EMPTY WEIGHT	(We)
DESIGN FUEL WEIGHT	(Wf)
DESIGN SHAFT HORSEPOWER PER ENGINE, SEA LEVEL STANDARD	(SHPm)
NUMBER OF PROPULSION ENGINES PER AIRCRAFT	(Ne)
DESIGN CRUISE SPEED, KNOTS	(Vcr)
NUMBER IN OPERATIONAL FLEET	(Noa)
UTILIZATION, FLIGHT HRS PER YR PER OPERATIONAL AIRCRAFT	(U)
PROGRAM YEARS	(P.Y.)
DESIGN MISSION ENDURANCE, HOURS	(T)
ATTRITION RATE, EQUIVALENT AIRCRAFT PER FLIGHT HOUR	(Rattr)
MAINTENANCE FLOAT FRACTION	(Fmf)
NUMBER PILOTS PER OPERATIONAL AIRCRAFT	(Np)
NUMBER GROUND OFFICERS PER OPERATIONAL AIRCRAFT	(Ngo)
PRODUCTIVE MAN HRS PER YR PER MECHANIC (INPUT OR CALCULATE)	(MHm)
NUMBER PREVIOUS PRODUCTION AIRFRAMES	(Nppa)
NUMBER PREVIOUS PRODUCTION ENGINES	(Nppe)
COST OF ELECTRONICS PER PRODUCTION AIRCRAFT	(Celpa)
COST OF AIRFRAME RESEARCH & DEV. (INPUT OR CALCULATE)	(Crdaf)
COST OF ENGINE RESEARCH & DEV. (INPUT OR CALCULATE)	(Crde)
SCALE FACTOR: MAINT. MAN HRS PER FH - ORG, DIR, GEN	(K1)
SCALE FACTOR: MAINT. MAN HRS PER FH - DEPOT	(K2)
SCALE FACTOR: DOLLARS PER FH - ANNUAL MAINT. MATERIAL	(K3)
SCALE FACTOR: DOLLARS PER FH - ANNUAL DEPOT MATERIAL	(K4)
CALCULATED DATA:	
PROGRAM ATTRITION, EQUIV. ACFT. = (P.Y.)(Rattr)(U)(Noa)	(Nattr)
MAINTENANCE FLOAT AIRCRAFT = (Fmf)(Noa)	(Nmf)
PRODUCTION AIRCRAFT = (Noa) + (Nmf) + (Nattr)	(Npa)
PRODUCTION ENGINES = (Ne)(Npa + 0.5Noa)	(Npe)
AIRFR. COST FACTOR, \$/LB (85% L.C.) = $400(Npa + Nppa)^{-.24}$	(Kaf)
ENG. COST FACT., \$/SHPm(93% L.C.) = $420(SHPm)^{-.15}(Npe + Nppe)^{-.105}$	(Ke)
MAINT. BURDEN, ORG, DIR, GEN = $K1(.06)(We)^{.68}(U)^{-.18}$	(MMH/FH)odg
MAINT. BURDEN, DEPOT = $K2(.007)(We)^{.7}$	(MMH/FH)d
MAINT. MAT. COST PER FH = $K3(6.82)(We)^{.6}(Npa + Nppa)^{-.15}(U)^{-.1}$	(\$/FH)amm
DEPOT LABOR COST PER FH = 12.50(MMH/FH)d	(\$/FH)adl
DEPOT MAT. COST PER FH = $K4(.023)(We)^{1.05}(Npa + Nppa)^{-.15}(U)^{-.1}$	(\$/FH)adm
PROD. MAN HRS PER YR PER MECHANIC = $233(U)^{.34}$	(MHm)
MAINT. PERSONNEL PER OPER. ACFT. = $\frac{U}{(MHm)}$ (MMH/FH)odg	(Nmp)
TOTAL ENLISTED PERSONNEL PER OPER. ACFT. = 2.4(Nmp)	(Ntp)
NUMBER OF LINE ITEMS PER ACFT = $500(We)^{.34}$	(Nli)
COMMODITY MANAGEMENT PERS. = $.00034(Nli)^{.95}(Noa)^{.27}(U)^{.3}$	(Ncm)

DESIGN TO COST
TRENDS AND PROBLEMS

LTC Jack Islin
US Army

It is appropriate to include the Design-to-Cost (DTC) concept as a topic for consideration at the Army Operations Research symposium because successful implementation of DTC will have as its base accurate cost estimates prepared by Operations Research Analysts in the weapons acquisition community. In the two years since the Department of Defense (DOD) issued DOD Directive 5000.1, "Acquisition of Major Defense Systems" all of the services have initiated development of new weapon systems under DTC. And recently, in a memorandum dated 18 June 1973, Deputy Secretary of Defense Clements established that in the future all new major programs will have established DTC goals.

There was sufficient reason for DOD to adopt DTC. The DOD budget has been decreasing as a percent of the total federal budget for several years. The defense budget for this fiscal year will have the lowest buying power since 1951 while the need for new and better defense systems is seemingly as great as it has ever been. Defense costs, like other costs, have been rising steadily and even if defense spending could be maintained at the current level there would be an erosion of purchasing power. Force structure has been reduced to compensate for the loss of buying power while the requirement to overcome numerical inferiority with qualitatively superior weapons has become more important. However, the unit cost of procuring new systems has increased to the point where DOD has been prevented from obtaining some essential weapons systems in the quantities required. Buying smaller quantities has been a better alternative than continuing to reduce force structure, accepting reduced quality, or not proceeding with some needed programs. The situation has forced DOD to develop new means to reverse the upward trend of unit costs.

The Military Departments were intent upon pushing the frontiers of technology and the state-of-the-art by stressing technical performance to gain qualitatively superior weapons. Cost and schedule goals did not receive adequate emphasis, thereby creating the situation for contractors to "buy-in" and services to understate costs to gain approval of programs. By the time the resulting overruns became an issue for top level consideration, few alternatives remained available. DOD could either add more funds or cancel the program. While the Air Force elected to add funds for the F-111 and C-5A programs, the Army was forced to cancel the Main Battle Tank and Cheyenne programs. For the Army, the unit cost had become prohibitive.

The DTC concept was introduced in July 1971 in DOD Directive 5000.1 to make cost a major design criterion equal with performance. DTC establishes a unit production cost as a design goal, and a primary design parameter, at a price DOD can afford to pay for the quantities needed. DTC emphasizes the importance of establishing realistic costs for unit production cost goals, and then designing the weapon and managing the program within these goals. The concept requires the Program Manager and the contractors to conduct cost, schedule, and performance tradeoffs to meet the goals.

Established standards must be maintained to prevent procuring inefficient, unreliable weapons because they are cheap. In adopting the DTC concept we must be certain that we are not substituting requirements shrinkage for cost growth until the point is reached where we cannot meet the threat the system is supposed to counter. The issue of determining the threat and affordability is significant when considering the cost associated with the risk involved in developing new technology to counter the threat. Cost growth has caused the cancellation of several programs. Will shrinking the requirements to maintain cost result in program cancellations or will we find ourselves in the same position as the Russians were in World War II when a relatively few, but technically superior force of German aircraft, eliminated the numerically superior force of Russian aircraft in just a matter of days. (Operation Barbarossa).

Recommendations of two current reports stress the problem of determining affordability. One comes from the Defense Systems Acquisition Review Council (DSARC) Cost Reduction Working Group "Little Four" study recommendation to establish Mission Concept papers in DOD, the other is the recommendation by the Commission on Government Procurement (COGP) which would cause DOD to plan, budget, and fund by mission area. DOD would determine the threat, the systems in a mission area to counter the threat, and the funds to be allocated to the mission area and then to the systems within an area. For example, in the mission area of Theater Air Defense DOD would budget funds to be allocated to SAM-D, F-15, etc. The issue is not settled, and the Services are preparing three Mission Concept Papers on a trial basis before accepting or rejecting the Mission Concept Papers. The Army is opposed to the COGP recommendation for DOD to budget and fund according to mission area. Affordability remains as a major issue.

Even after system affordability is determined DTC does not become the solution to all problems. Design to Cost is not a panacea. It is not a management control system, and it is not just a new, and fleeting, buzzword. It is a unit production cost ceiling or threshold for a certain quantity of units, at a certain production rate, established during the development phase of the system. The DTC number for a system is approved by the Secretary of Defense and he must also approve any change.

Obviously DTC cannot stand alone to insure cost control in the acquisition process. The concept must operate in concert with several other means such as "should cost" reviews, maintaining competition among contractors, improving cost estimating, and using cost/schedule control systems criteria for contractors' cost and schedule control systems to insure accurate and objective reporting of progress, estimates to complete, and variance analysis.

DTC has not evolved into a rigid set of rules and procedures. It continues to change as the Services gain experience in implementing the concept. The concern expressed in March 1973 by J. Fred Bucy, in the Defense Science Task Force Report on Reducing Costs of Defense Systems Acquisition, that "the danger is that lip service to this new 'buzz phrase' will be used in place of any real substance in accomplishment of 'design-to-cost'" has not materialized. The Office of the Secretary of Defense (OSD) has recognized problems in implementing DTC and has taken steps to improve the effort.

One of the first systems under DTC was the AX Close Support Aircraft, now designated the A-10. Early in the conceptual effort the Air Force and DDR&E agreed upon a DTC of $1.5 million average "flyaway" unit cost, in FY 70 dollars for 600 aircraft at a production rate of 20 per month. Two contractors, competing in the validation phase, built and tested prototypes for a fly-off and selection by the Air Force. The full scale development contract has maintained the DTC in a Cost Plus Incentive Fee (CPIF) contract which contains a ceiling price, fixed price incentive, production option for 48 airplanes.

The Army's Attack Helicopter program illustrates more a recent application of DTC. After the AH-56 Cheyenne program was cancelled, OSD gave approval for the Army to enter the conceptual phase for a new attack helicopter. A task force developed a cost estimate for the helicopter and when the results were presented to the Defense Systems Acquisition Review Committee (DSARC), the DSARC determined the proposed cost was more than DOD could afford. The Army was allowed to enter the validation phase with an OSD established DTC of $1.6 million, "flyaway" in constant FY 72 dollars. An additional stipulation required an OSD review of costs and thresholds at the end of source selection prior to the award of contracts. The Request for Proposals (RFP) specified floors for certain technical performance parameters, stressed the $1.6 million DTC, and encouraged the bidders to propose tradeoffs to assure the $1.6 million DTC would be maintained. The Source Selection Evaluation Board was to present its findings to the Secretary of the Army for decision, and to OSD for review in June 1973. On 24 May 1973 Dr. Foster, Director, Defense Research and Engineering, sent a memorandum to Secretary Clements that established the requirement for the OSD Cost Analysis Improvement Group (CAIG) to conduct an independent validation of the AAH cost estimates as part of the OSD review. After a preliminary review of the Army cost estimates the CAIG elected to conduct an independent estimate of its own.

Shortly afterward, in mid June, Secretary Clements sent a memorandum to the Services that requested the Services to establish "flyaway" cost goals for all major programs not reaching Milestone III by 31 August 1973. He also stipulated the "flyaway" cost should be consistent with the DOD Budget Guidance Manual.

The Secretary of the Army assigned his Assistant Secretary for Financial Management (ASA-FM) the task of conducting an independent cost validation for his consideration at source selection. Representatives from ASA-FM and the OSD Cost Analysis Improvement Group (CAIG) conducted independent cost validations concurrently. As a result of these efforts several problems associated with DTC surfaced, and new precedents were established.

Each of five contractors responding to the AAH RFP proposed a system that would meet or surpass the performance floors established in the Materiel Need document, at a cost of less than $1.6 million. The SSEB then developed its own estimate of what each contractors' version of the AAH would cost. In most cases the SSEB evaluation was below the $1.6 million DTC goal for the average unit recurring "flyaway" costs as stated in the Development Concept Paper.

Although the representatives from ASA(FM) believed the $1.6 million DTC was attainable the CAIG estimates were considerably higher. The difference in estimates could not be reconciled and when the Army presented its selection to OSD, Secretary Clements approved the selection but stipulated a 30-day cost validation effort to confirm or refute the ability of Hughes and Bell to meet the $1.6 million DTC and to look for tradeoffs that could be initiated to reduce the cost. At the end of the effort the Army gained approval of the estimates and several cost reducing tradeoffs were agreed to by the contractors. This effort established the precedent for the CAIG to validate Army cost estimates at source selection. This is a very important development because it means OSD is faced with a dilemma if the CAIG estimate does not support the Army estimate.

From the AAH source selection efforts significant DTC issues that surfaced included:

- How does DOD determine it can afford a system?

- What should be the definition of the DTC? Is it the "most likely" cost?

- When should the "official" DTC be established?

- Is there a hierarchy of DTC's inherent in a DTC program?

- Is the DTC a goal or a "dropdead" number to cancel the program if it is exceeded?

- If the DTC is expressed in constant dollars for a system that will not be produced until seven years later how do you deescalate the "then" year dollars at the time the proposed production contract is evaluated to insure the DTC established approximately seven years earlier in development will be obtained in production?

- How are life cycle costs reflected in the DTC?

- How are Reliability, Availability, and Maintainability (RAM) costs reflected in the DTC?

- How should MIL SPECS which specify "how to do it" be changed to allow contractors design freedom to meet the DTC/performance goals?

- How can the cost elements of MIL Standard 881 be integrated into the budget manual definitions to insure traceability over the years of development?

Although most of these questions and issues are not settled several on-going actions reveal trends and indicate possible conclusions. The comments presented here reflect the opinions of the author and are not necessarily an established OSD or Army position.

Defining the DTC remains as a major issue. Secretary Clements' memoranda gave responsibility for the DTC definition to the ASD Comptroller and established the budget manual (DOD 7110-1-M) definition of "flyaway" for reporting the DTC. Even the term Flyaway has had several interpretations. The A-X and the AAH used a flyaway cost definition that excluded non-recurring costs from the DTC. If the non-recurring costs, such as tooling, had been included in the estimates, approximately $100,000 would have been required to be allocated for the non-recurring cost and therefore not available for engineering design to meet technical/performance goals. Admittedly, the costs associated with tooling have a direct impact on the cost of procuring the system, but the question is really one of determining whether to include the non-recurring costs in the contracto design estimates or to include those costs "above the line" in the PM's estimate.

Other problems are also associated with using the budget manual defini tions. Page 241-7 establish the definition for "Flyaway" for aircraft, page 243-3 establishes a definition for Missiles, and page 245-15 establishes the definition for "Other." The definitions are different for each category.

Some systems, such as SAM-D, do not lend themselves to strict alignment with the budget manual definitions. SAM-D involves much more than just a missile so it must have a DTC for each major component. The SAM-D contract established one DTC for the missile, one for the Radar Group, another for the Weapon Control Group, and one for the Launcher Group.

Further, what should be the "Unit" designated for the production unit cost when the numbers of missiles, etc., will vary depending upon where the SAM-D is employed? This same problem exists for TACFIRE as its components vary according to where it is employed. In spite of the problems, a single"unit" definition must be developed for the DTC for each system.

Another problem in the definition of DTC was how to specify the unit of production to which the DTC applies. The Advanced Medium STOL designated the 300th, or last, unit of production for the DTC. Currently the "average" flyaway unit cost for 300 airplanes is specified. The difference is obvious. By selecting the last unit on the learning curve it represented the least cost unit. Although the goal is now stated as the average unit flyaway cost in order to accommodate the effect of learning in production, several Army, Air Force, and Navy systems differ in the way they determine the first unit cost and slope, and thereby create inconsistencies among the systems.

Problems associated with the definitions have led to the consideration of a "hierarchy" in the DTC established for a system. With the UTTAS, the Development Concept Paper (DCP) established a DTC for the airframe while for the AAH the DTC was for the complete production unit. A DTC for the airframe is meaningful to the two competing contractors, Boeing and Sikorsky and a separate DTC is meaningful to the engine manufacturer. But what about the total DTC of the AAH? Is it really as binding upon Bell and

Hughes as it should be? As they do not control the cost and schedule of the engine and other GFE included in the DTC can they be held responsible for Army-created problems?

The Program Manager (PM) establishes the DTC in the contracts for the elements of his system - airframe, engine, missile, radar, launcher, etc. They retain their identity as the Contract DTC's. Added on top of the sum of the components the PM establishes funds for Engineering Change Orders (ECO), (management reserve?), GFE, etc. This total is usually the DTC the Army expresses as its agreement with OSD, in the DCP, as the "best estimate" or most likely "flyaway" cost. The funding expressed in the Selected Acquisition Report (SAR) which OSD provides Congress reports an even greater aggregate of costs. The SAR includes "Procurement Cost" which is "Flyaway Cost" plus "Weapon System Cost", plus initial spares. To Procurement Cost, RDT&E and Military Construction are added to become "Program Acquisition Cost" which is also shown in the SAR. Presently there is extensive discussion concerning establishing the Program Acquisition Cost as the "Manage to Cost" for the Service program with an additional Design to Cost, by "Flyaway" definition, stipulated in the DCP. As is now the case, the PM would continue to establish Contract DTC to remain within the "Flyaway" DTC of the DCP.

Many other areas, too numerous to consider here in detail, are also being discussed among the Services, OSD and the Joint Logistic Commanders (JLC). The JLC Design to Cost Guide, currently being developed, will provide the solutions to many of the problems as the Services and the DSARC continue to explore questions such as:

- Is the DTC applied to the program quantities or only the first production contract?

- How to handle changing quantities? If the quantity to be procured is reduced thereby changing the average unit cost is it really a breach of the DTC, thus, requiring additional tradeoff, or is the new cost acceptable as long as it remains on the original DTC learning curve?

- How to handle a change in system components to take advantage of a breakthrough in technology? For example, if a true fire-and-forget missile should become available for the AAH to replace the TOW would the increased cost require additional tradeoffs or would OSD revise the DTC?

- Will Congress use DTC as a lever to exert greater control over DOD? Note that Senator Eagleton attempted to set a ceiling on costs for the XM-1 tank that did not allow any reserve in development or in production. Currently a threshold is established for development but not for production.

- How to insure life cycle costs are considered in setting the DTC?

- How and at what level should ground support equipment/special equipment enter the DTC? For example, consider engine containers for an engine used in more than one system.

- Can or should the work breakdown structure (to the fourth level) be the same for Development and Production?

- What is the best way to handle inflation factors with DTC?

- How should different ammunition used by competing weapons - as with the Bushmaster - be considered in DTC?

- How should "management reserve" be established? Who should control it? Is it specified for certain areas of risk after risk analysis or is it expressed as a lump sum? At what level is it expressed? What will Congressional impact be upon it?

- How can award fees be structured and implemented to provide a real cost control incentive?

- How to define the relationship of MIL Standard 881 cost elements to the Budget Manual definitions and the handling of Q&A, etc., in projections?

- How does a manufacturer keep his subcontractors in line to maintain the DTC?

- How to insure the Services keep cost on the same level with performance and provide flexibility to military specifications to allow tradeoffs without degrading the essential qualities of the equipment.

- How to monitor DTC during the years of development?

- How to exchange cost estimating data among the Services to improve DTC cost estimates?

There are no easy answers to these questions and there are no simple solutions to the problems. However, the trends illustrated reinforce the earlier statement that successful implementation of the DTC concept must have as its base accurate cost estimates. The Commission on Government Procurement, mentioned earlier, recognized the requirement and included in its recommendations:

- Strengthen each ageny's cost estimating capability for:

(1) Developing lifetime ownership costs for use in choosing preferred major systems.

(2) Developing total cost projections for the number and kind of systems to be bought for operational use.

(3) Preparing budget requests for final development and procurement.

- Estimate program cost within a probable range until the system reaches the final development phase.

- Use contracting as an important tool of system acquisition, not as a substitute for management of acquisition programs.

The Army must continue to improve its ability to develop parametric estimates for preliminary program decisions, engineering estimates for evaluating and validating proposals, and life cycle estimates for total program costs. Armed with sound cost estimates decision makers and managers within the Army can implement the DTC concept for acquisition programs with confidence and not rely on contracting as a substitute for management. Merely putting a DTC in a contract does not mean the program will gain OSD approval and it does not substitute for, or eliminate, the requirement for sound management practices. Cost estimates supporting the DTC must be acceptable for OSD to give program approval, and to the PM so that he can rely upon those estimates in his management to meet the DTC goals.

How serious is the problem of gaining OSD acceptance of cost estimates? Even if all other DTC problems were solved today the Army would still encounter difficulty gaining approval of its programs because its cost estimates have lacked credibility. To illustrate the problem, reexamine the example of the OSD review of the Army's source selection of the AAH. Inspite of the thorough preparation by the Source Selection Evaluation Board and the independent validation by ASA(FM), OSD CAIG did not agree that the cost estimate presented by the Army was really the "most likely cost" estimate. According to the CAIG the DTC ceiling would be broken because the Army estimate was "optimistic" and not "most likely." Lack of confidence in the Army estimate could have suspended this program indefinitely. In this case the problem was solved in thirty days and the Army accepted a management reserve added above the DTC (recurring flyaway) to account for the CAIG "most likely" cost.

Emphasis must remain on improving the credibility of our estimates. The CAIG and the DSARC will not recommend approval for our programs if they do not have confidence in the Army estimates. If we cannot convince the CAIG and the DSARC that the contractors selected by the Army can meet the Design to Cost in the programs, their lack of confidence in Army estimates will cause our weapons programs to face the possibility of delay, redesign, or cancellation.

AD P000640

BASE DEVELOPMENT PLANNING

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THE ENGINEER STRATEGIC STUDIES GROUP

In a typical theater of operations (TO) approximately one-third of the engineers are planned for construction and construction support missions. These operations are known as base development (BD). JCS defines BD as "the improvement or expansion of the resources and facilities of an area or a location to support military operations." Thus, BD involves all of the actions required to define and carry out improvements to facilities in a TO. This paper is assigned to give an overview of BD planning and its related processes and responsibilities.

The current emphasis and concerns regarding BD planning stemmed from our experiences in Vietnam. In June of 1967, the Director of Construction in Vietnam (Major General Raymond) submitted critical observations on the construction program. His primary conclusion was that inadequate BD planning has preceded the operation. He therefore recommended that BD agencies be established to plan for future contingencies. This report triggered several other JCS and service studies and board actions, including the Joint Logistics Review Board, which reached essentially the same conclusion regarding major planning deficiencies.

All of these review efforts culminated in a comprehensive JCS directive on BD planning. This directive took the form of Change 2 to Publication Number 3, titled Joint Logistics and Personnel Policy and Guidance, dated November 1969. The directive is now included in the Joint Operations Planning System, commonly referred to as the JOPS. Responsibility for preparing joint BD plans (BDP) was assigned to the unified commanders, who in turn look to the components for preparation of supporting plans. In the many cases where one component's interests are dominant, that component prepares the entire joint plan. The component commands have available to them the basic information needed for this type of detailed planning (e.g., logistics, forces, and facilities). JCS also established precise BDP formats to insure completeness and standardization of final reports.

The Army, however, had not waited for the JCS to press service and unified command actions. In 1968, the DCSLOG asked the Chief of Engineers to prepare a BDP for each of the Army component commands. This planning support was provided by the Engineer Strategic Studies Group (ESSG).

Department of the Army also established a continuing BD board that identifies and provides solutions to the more important BD problems. This board reports to the DCSLOG; it is headed by the Director of Installations, ODCSLOG and is made up of representatives of OACSFOR, ODCSOPS, OCRD, and OCE. The board meets at the call of the Chairman to address key issues.

With the advent of JCS interest in BD planning, and because of ESSG's experience in this planning arena, the Chief of Staff tasked the Chief of Engineers to establish a planning assistance office to directly support the Army components in preparing BDP. The Chief of Engineers designated ESSG as his agent in this matter, with the role of a staff element in the component commands. Of course, full responsibility for the content of the plans remains with the component commander.

Figure 1 provides a schematic view of the BD process. BD begins by comparing the facilities required in the theater of operations with those that actually exist. A particular OPLAN serves as the genesis for all gross facility requirements. From this comparison, planners can develop the materiel, manpower, and equipment requirements necessary to transform the existing facilities into those required by the force to be supported. All of these factors are tempered by any constraints within the theater such as local resource conditions, projected enemy activity, time limitations, and weather. The end result is the BDP. After completion of the plan, the identified requirements and other details impact on force structuring and may result in materiel acquisition. Upon execution, all remaining materiel is procured and the engineer forces begin the construction program.

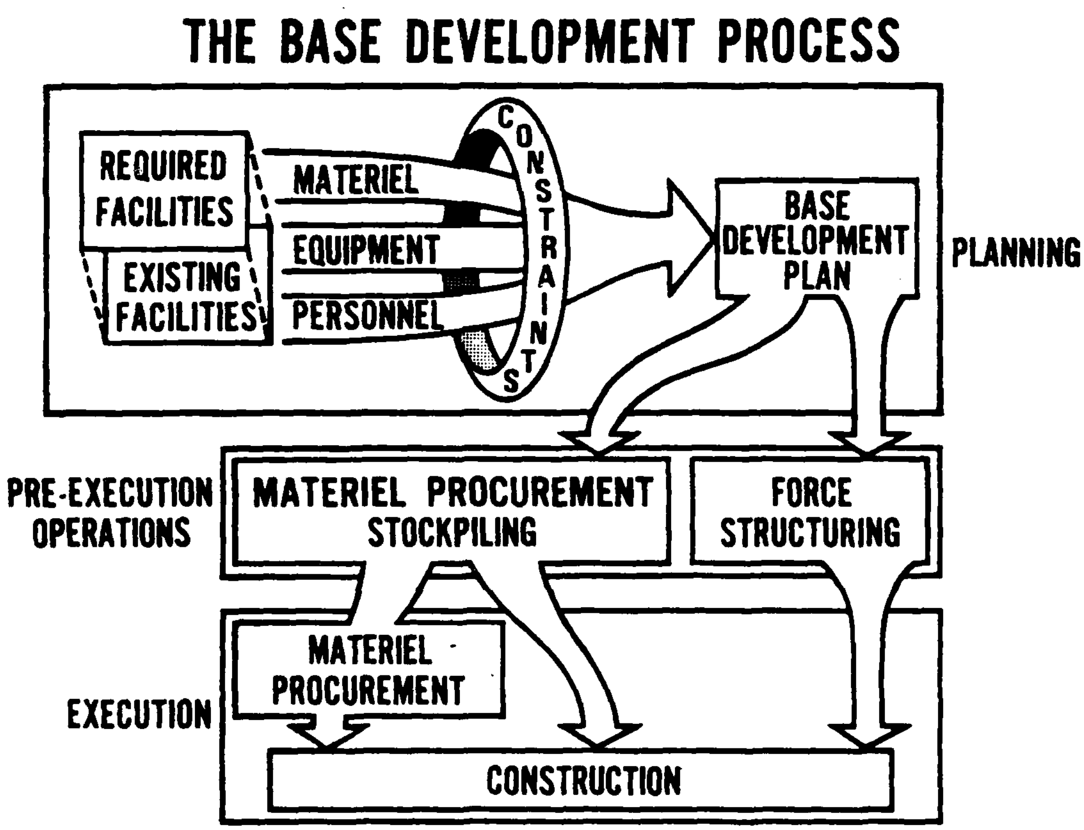

Figure 1

The prime focus of the planning effort is to compare existing with required facilities and to precisely define the resources required. OPLAN limitations and necessary flexibility considerations highlight the many variables involved. As a result, BD planning is crystal-balling at its best. Detailed intelligence is an essential ingredient in this process. Our Vietnam experience, as noted by the Joint Logistics Review Board, emphasized the need for sound but flexible BD planning. All of the "what ifs" involved in moving and supporting large forces into new areas must be investigated. The completed plan provides an excellent point at which to begin execution.

BD planning is necessary and integral to contingency planning. Figure 2 depicts the iterative nature of these planning efforts. As the mission, threat, environment, resources, and costs change significantly, their impacts on the various plans must be assessed. Reviews and reanalyses are critical to maintaining a viable contingency plan for a specific TO.

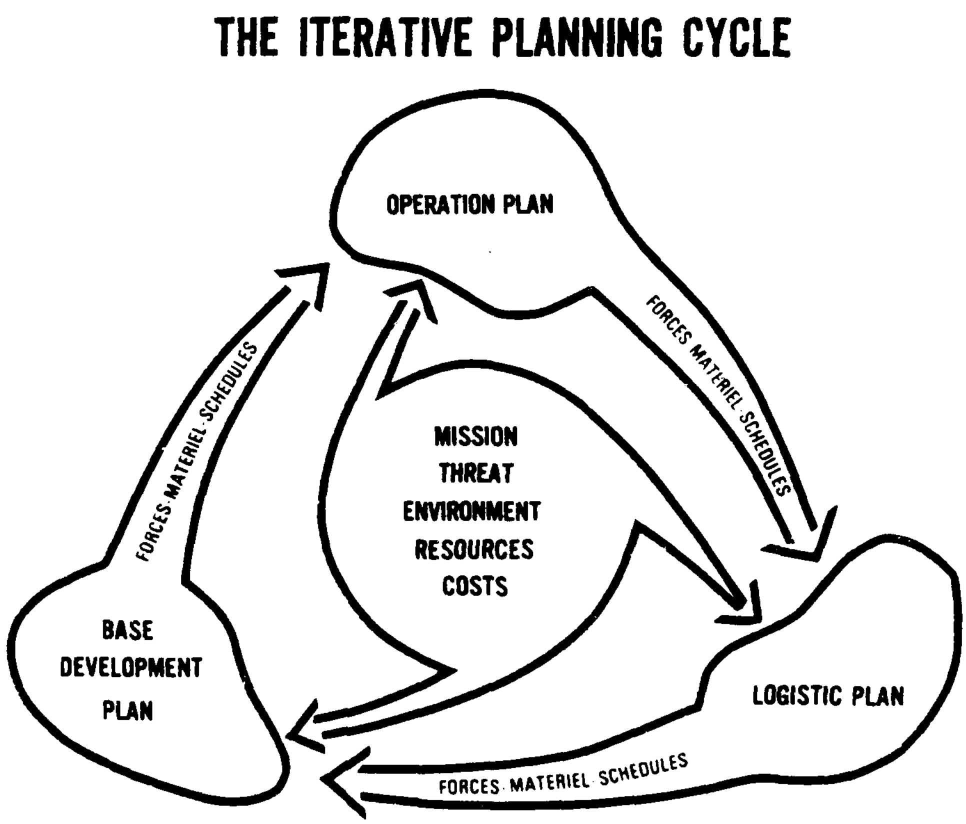

Figure 2

Early in its BD planning experience, ESSC determined that it was imperative to automate the process to the maximum extent possible if they were to be responsive. ESSG used in-house programer assets to develop a computerized system for estimating construction requirements, for assessing a given engineer force's capability to complete the required BD tasks, and for providing an output in the format and level of detail required by the JCS and the CINCs. That system is called CASTLE (Computer Assisted System for Theater Level Engineering). It has been operational since late 1971 and was used in the preparation of BD plans for both Europe and Korea.

The CASTLE system is made up of more than 60 computer programs, grouped into several functional runstreams. All programs are written in FORTRAN V, and have been developed for efficiency and ease of maintenance under the EXEC 8 operating system on UNIVAC 1108 computers. A typical CASTLE run for a major plan would consume approximately 45 minutes of Central Processing Unit time.

Figure 3 is a general CASTLE system flow chart. Theater OPLANs are the basis for logistic planning. The scenario details used in the planning process include strategic warning and other major assumptions, D-day forces in theater, troop deployment information, and theater layout data.

CASTLE SYSTEM FLOW CHART

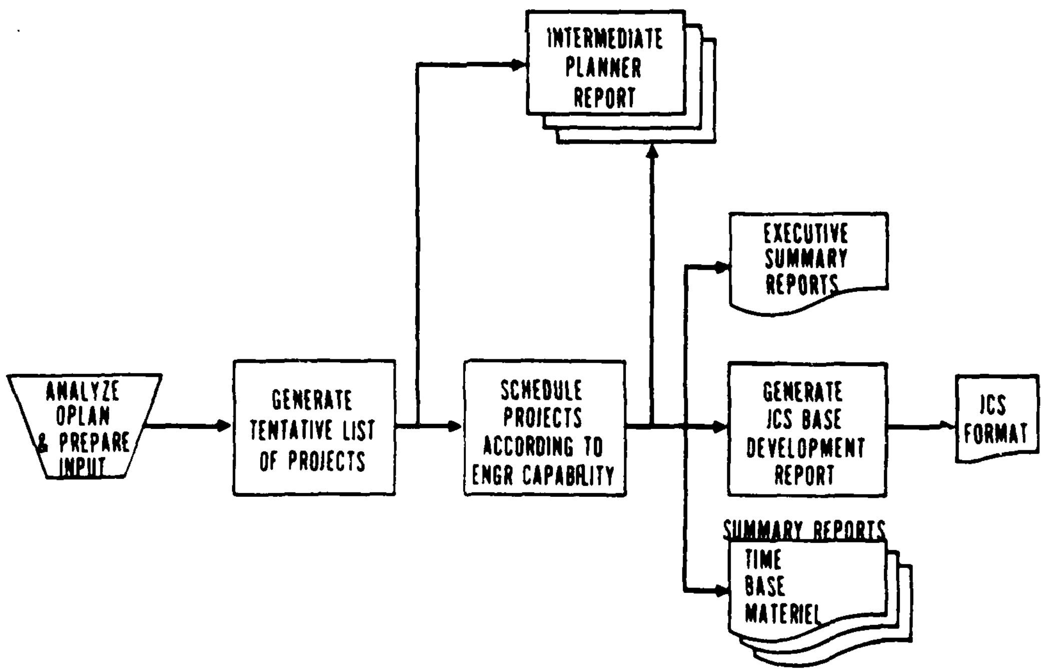

Figure 3

ESSG must coordinate with the theaters to ascertain critical elements of the logistic plan, namely: the medical evacuation policy; stockage objectives and supply policies; available facility assets by location; construction priorities of specific engineering projects; desired completion dates of critical projects; and the level of indigenous support that would be available, to include both personnel augmentation and contractor effort. War damage estimates are also needed on a time-phased basis by type of facility. The most important input is the time-phased force and deployment list (TPFDL); this automated listing provides the theater estimate of arrival dates for all units in the force, their mode of travel, and geolocation. CASTLE is designed to use existing automated files to the maximum extent; these files include: the TPFDL, Army Facilities Components System (AFCS), unit code files, and Real Property Asset Files.

Most BDPs cover only the deployment phase of a contingency, usually 180 days. Once execution of the plan is underway, theater planners must extend the BDP for post D+180 day requirements and must adjust the basic BDP as necessary.

The AFCS is an essential planning support system which has catalogued pre-engineered standard type facility designs for the full range of possible TO construction requirements. It provides building estimates for such facilities as a 1,500-man cantonment, a 100-bed hospital, a POL tank farm, or a 1,000-man stockade. Standards of facility construction provided within this system range from the most austere practicable to those which would reflect expected 5-year usage. A series of manuals readily provides information which planners and engineers can use to support the BD effort. Engineering design, cost, and logistic data are organized, coded, and maintained in data banks to insure their currency. TRADOC and OCE are constantly updating and modernizing the AFCS.

The CASTLE system assimilates the rather extensive input data discussed and generates a tentative (or unconstrained) list of support facilities. These gross construction requirements are referenced to the DOD Category Code system. Time-phased facility requirements are generated using three basic methods: first, consumption and space allocation factors are applied to population densities to yield such data as quantities of supplies, storage needs, hospitals, administrative space, troop camps; second, by predetermined unit allocation for facility requirements such as those needed for a general support maintenance battalion; and third, manually derived requirements such as those for airfields, pipelines, and port facilities. The gross facility requirements identified are then reduced by the usable facility assets in theater. This subtraction results in a listing of net requirements or facility deficiencies. At this point, the net construction requirements are still unconstrained and unscheduled.

The next major step in the process is to schedule the construction requirements based on the capabilities of the given engineer force, the imposed construction priorities, and other constraints. These construction requirements are made up of both new facilities and the repair of enemy war damage. The construction priorities are so established as to insure air support (Air Force and Army aviation facilities); receipt of initial reinforcements (ports and beaches, inter-theater airfields); and immediate logistic support (POL and critical ammunition storage). By assuming certain risks, some types of projects can be deferred (e.g., troop facilities, hospitals, general depots, and improved LOC).

The scheduling routine is the most sophisticated portion of CASTLE. This algorithm considers both net construction facility requirements and the capabilities of the given engineer force using a breakdown into 31 individual engineering skills. Construction requirements and engineer force capabilities are then compared to ascertain how much of the construction can be completed on a time-phased basis considering all constraints. This process is accomplished separately for each region within a TO and is assessed on a daily basis.

The scheduling algorithm also allows for skill substitutions; when a project cannot be scheduled because of a particular skill deficiency, other appropriate unused skills are substituted in its place. This process considers substitutions based on a predetermined priority listing, and introduces these substitute skills at specified efficiency levels. Unused skills are drawn from the US engineer force and the indigenous augmentation available from the host country.

The output from this scheduling analysis is a detailed construction schedule, with project completion dates and listings of both scheduled and deferred projects.

This construction feasibility assessment provides the basis for the detailed reports which are presented in BDPs. These reports are generated directly from the CASTLE system and reflect the following information: base requirements, facility assets and deficiencies, scheduled construction projects, and materiel deficiencies; an integrated time-phased listing of construction projects by region (this is a summary of the base requirements within each region); consolidated construction materiel requirements; and a construction force utilization report.

BD planning has been greatly enhanced over the past several years by the JCS impetus to standardize the process and by the development and adoption of the CASTLE system as an analytic tool. DA and theater involvement in the BD process has resulted in the development of comprehensive plans. This planning function will be a continuous requirement, since completed plans will need periodic reanalysis and several new plans remain to be addressed.

COST ESTIMATING FOR R&D PROGRAMS

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Introduction

Thousands of volumes have been written on technical forecasting and planning for R&D, both within the government and by private companies. However, most writers completely ignore the nagging but vital task of estimating program costs. This may or may not be a conscious attitude, but in most text books, journal articles, and regulations, discussions of techniques for estimating R&D expenditures are conspicuous by their absence.

Estimates which are presented can, for a single program, vary widely depending upon individual or organizational variations in methodology or interpretation.[1] The task is further complicated by lack of precedent, unpredictable technical problems, unforseen technical advances, shifting requirements based on new knowledge, scheduling difficulties and inability to meet a specified schedule, optimism of technical personnel, the human productive variable, especially in creative situations, and the bias of the estimator.[2]

One of the major problems in predicting R&D costs is a gross inadequacy in historical data. In many instances, R&D costs are buried in an overhead account, charged to production orders or to an order related to another item or component, or not identified at all. This produces a tendency in the organization to under estimate subsequent R&D efforts. In other instances effort not properly changeable to R&D, such as production engineering, initial production tooling, advertising, etc., are charged to the R&D account. This results in subsequent overestimates in the R&D account.[3] Both situations have significant detrimental effects on planning.

(a) An accepted underestimate invariably produces a situation in the future where a task must be cancelled or postponed, or additional finding allocated to the R&D program.

(b) An overestimate may result in a potentially worthwhile program being rejected in favor of less promising ones.

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[1]Daniel D. Roman, R&D Management, (New York: Appleton-Century Crafts, 1968), p. 314.

[2]Ibid., 303.

[3]Allan Skinner "Accounting for R&D Costs", Management Accounting, May, 1971, p. 29.

In this paper, the various techniques of cost estimating as applied to R&D programs will be discussed. In addition, their limitations and shortcomings along with the hazards inherent in their use will be discussed. Techniques will be presented for evaluating the uncertainty in the estimate, a facet usually ignored in R&D estimating. Finally, appropriate conclusions and recommendations will be made.

Estimating Techniques

Several divergent methods have been proposed for estimating R&D costs.[4] The four basic estimating techniques are analogy, statistical prediction, engineering methods and expert opinion. The technique or combination of techniques used is dictated primarily by the type of data available, the current status of the item being estimated, the expertise available, and time constraints.

1. Analogy. This approach is based upon the application of previous experience to current problems. It seeks features of prior systems or items and likens these cost experiences to the systems or components under consideration. Differences between the analogous system and the one under study must be identified and assessed as to their cost impact. While a better analogy can usually be developed at a subsystem level, the approach may also be appropriate at the total system level. This method has the advantage of providing rapid results. Its precision is dependent solely upon the skill by which the estimator selects the analogous system and the judgement applied in assessing unique differences.

2. Statistical prediction. This approach is based upon the application of proven statistical tools to historical costs to relate those costs to various physical, performance, and operational characteristics of a current or proposed system. The results of a statistical prediction are expressed usually as a relationship between a dependent variable (predicted cost), and an independent variable such a weight or some other design parameter. Regression analysis is the most common statistical tool used in cost estimating. In applying statistical methods to historical costs, care should be taken to assure that the historical data are truly relevant to the current problem. The range of values covered by the data base should be such that the estimating requirement falls within that range. It is not an accepted practice to base estimates upon extrapolation far beyond the range of raw data and in turn use the statistical characteristics of the sample to describe the worth of the estimate.

[4] Army Weapons Command Pamphlet No. 37-1, p. 9.

3. Engineering method. This approach is based upon a component by component analysis and implies that there is a sound basis for each factor considered. Each component is costed by engineering judgement with respect to labor, materials, overhead, tooling, etc. The distinguishing characteristic of this method is the detailed analysis and step-by-step buildup of the whole estimate. Engineering methods have limited application in the early life cycle phases of a system, and while they should be given consideration, they should not be considered the preferred method for all situations.

4. Expert opinion. This essentially involves opinion from authoritative personnel who represent the best available source of knowledge, and is usually characterized by a lack of detailed rationale and analysis. While estimates compiled by expert opinion are at times both useful and necessary, they normally have a low confidence rating and should not be used when there is time and means for development of a more thorough analysis. Unsupported contractor estimates are usually considered in the same light.

The foregoing discussion implies that each of the estimating techniques are applied independently. This is usually not the case since most estimates involve a combination of several techniques. In addition, the techniques are not always readily identifiable. For example, an analogy estimate at a detailed level could be considered an engineering estimate and a statistical estimate is in reality a special form of analogy. The classification of estimating techniques is useful for definition purposes, but of greater importance is the proper application of all the techniques to fulfill an estimating requirement.

Applications

1. Ruskin and Lerner hypothesize that the actual cost to develop a new technological system can be forecast from initially negotiated costs along with other administrative details that are available at the time of negotiation.[5] Based on 73 Air Force contracts, cost growth was shown to correlate closely with (a) the initial negotiated cost and period of performance (b) whether or not the entire system, as opposed to a subsystem is investigated, (c) whether or not a significant change in scope is anticipated at the outset of the program, (d) whether or not the effort is as a study or as a hardware development effort, and (e) personal characteristics of the contracting officer, i.e. how he handles his contracts. Although this study covers only one small division

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[5]Arnold M. Ruskin and Rober Lerner, "Forecasting Costs and Completion Dates for Defense R&D Contracts,"IEEE Transactions and Engineering Management, Vol EM19, No 4, Nov. 1972, p. 128.

in the Air Force, there appears to be sufficient consistency in the cost factors to make reasonably accurate forecasts of final cost on a general basis.

2. Historically, defense system development cost estimates have usually been based on contractor cost estimates.[6] These in turn relied on the industrial engineering or grass roots estimating approach. This approach relies on detailed simulation of all operations and an exhaustive list of all materials required to develop and produce a unique and specifically defined piece of equipment. This also makes use of detailed standards built-up from time and motion studies, vendor quotes, labor requirements by work center, etc. The estimate is, in essence, built-up from the labor and material imputs required to do the job, and is based on subjective judgement relative to these requirements.

3. DOD is currently placing much emphasis the use of parametric cost estimating both as an independent technique and as a check on engineering estimate.[7] The parametric approach considers system output characteristic, such as bore size, muzzle velocity, impact energy, etc. rather than input characteristics. Historical system cost experience is used to develop relationships between functional characteristics and system cost. The basis of this procedure is that development costs of a system are related in an approximate but quantifiable way to its physical and performance characteristics. It eliminates the subjective judgement inherent in industrial engineering estimates. It does not rely upon a detailed cost of each building block in the system, many of which may not be understood or not yet identified or anticipated.[8]

4. Fisher describes R&D cost as primarily a function of desired performance characteristics and complexity of the proposed system. Costs are estimated to be R_a, R_b, and R_c at alternative levels of complexity of P_a, P_b, P_c respectively where R_a, R_b, R_c and P_a, P_b, P_c. This indicates relationships such as the following:

$$R = Ap$$
$$R = A^p$$
$$R = Ap^b$$

The first equation indicates a linear relationship, the second

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[6]Gene H. Fisher, Considerations in Systems Cost Analysis, (New York: American Elsevier Publishing Co., Inc., 1971), p. 66.

[7]Donald W. Srull "Parametric Cost Estimating Aids DOD in System Acquisition Decisions, "Defense Management Journal", April 1972, p. 2.

[8]Fisher, p. 169.

an exponential relationship, and the third a constant exponent relationship. Use of these complexity factors and assignment of constants involves the use of subjective judgement and is thus biased by the experience of the estimator.

5. Dodson makes an attempt to relate development cost to a quantified value related to potential state of the art (SOA) advancement.[9] This requires definition of the existing SOA, and the SOA determining characteristics should be among those ascertainable during the early decision making stage of the system life cycle. The hypothesis is that SOA advance, the output of R&D, is a determinant of R&D resource requirements including funding. The following relationship is suggested:

$$\log C = a_0 + a_1 \log S + a_2 \log T + a_i f_i$$

where C = development cost
S = measured SOA advance
T = development time
a_i = parameters to be estimated
f_i is related to external advances not resulting from the R&D program.

The a's are determined through a multivariable regression analysis based on actual data from past programs.

Uncertainty

Every cost estimate is uncertain from the initial engineering cost estimate up through the aggregation of system costs.[10] It is important to differentiate between uncertainties in the cost estimate and uncertainties in exactly what is to be costed. The most serious errors in the cost analysis can usually be traced to the assumptions and interrelationships upon which the cost estimates are based. Cost estimating uncertainty is the statistical uncertainty caused by errors in the cost data, inaccurate cost estimating relationships and differences between the various cost analysis approaches. An important aspect of treating uncertainty in estimating is that of sensitivity analysis. This is a term used to refer to methods of analyzing areas of uncertainty in an estimate and projecting the impact upon the total estimate. For example, the learning curve associated with the production cost of the life cycle cost estimate, while stated as 90%, may actually be subject to a variation of 5%. The production cost can then be simulated at both 85% and 95% learning curves to judge the impact of a 5% error in the original estimate.

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[9] Edward N. Dodson, "Resource Analysis for R&D Programs," IEEE Transactions on Engineering Management, Vol. EM 19, No. 3, August 1972, p. 78.

[10] AMC Pamphlet No. 706-191, Engineering Design Handbook for System Analysis and Cost-Effectiveness, Prepared by Arinc Research Corp., Annapolis, Md., 1966.

One technique for determining uncertainty in the cost estimate involves the use of the beta distribution to provide cost ranges.[11] This method requires the use of three estimates for each cost entity:[12]

m = the most likely cost, i.e., the mode, or that which would evolve through Delphi techniques.

a = the lower bound, i.e., the cost below which the actual cost would fall one time in a hundred trials.

b = the upper bound, i.e., the cost above which the actual cost would fall one time in a hundred trials.

The mean cost of an individual entity can be approximated by:

$$C_i = \frac{a_i + 4m_i + b_i}{6}$$

And based on the Central Limit Theorem, the total cost:

$$C = \sum_{i=1}^{m} C_i = \sum_{i=1}^{m} \frac{a_i + 4m_i + b_i}{6}$$

The variance can likewise be estimated by:

$$\sigma^2 = \sum_{i=1}^{m} \sigma_i^2 = \sum_{i=1}^{m} \left(\frac{b_i - a_i}{6}\right)^2$$

From these relationships, a symmetrical bata, or normal distribution curve can be constructed which will present a clear picture of the potential R&D cost.

This technique has been further refined by DOD, and involves construction of the distribution curve through computerized Monte-Carlo simulation.[13] This technique permits skewness of the distribution and

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[11]U. S. Army Missile Command, Redstone, Alabama "Statistical Methods for Measuring Uncertainty of Cost Estimates." by E. L. Murphy, February, 1970, p. 3.

[12]Kenneth C. Case, "On the Consideration of Variability in Cost Estimating", IEEE Transactions in Engineering Management, Vol. EM-19, No. 4, November, 1972, p. 114.

[13]U. S. Army Weapons Command Pamphlet 71-10, "Uncertainty in Cost Estimating: Methodology," August, 1971.

allows for uncertainty in the estimated values. To the input data discribed in the preceding section; m, a, and b, must be added more definitive probabilities of the cost being less than a and more than b. Assuming the input data reflect the true cost distributions, the technique will describe the total cost distribution with an accuracy approaching 97% or 99%, depending upon whether 1,000 or 10,000 iterations of the simulation routine are used.

If each cost factor in the uncertainty matrix is independent of all others, potential under-runs in one area will tend to cancel over-runs in other areas. The optimistic and pessimistic total costs determined by simulation will actually be much closer to the mean value than a summation of individual optimistic and pessimistic costs would indicate. The analysis permits the following types of statements to be made with a high degree of confidence:

(a) There is a 50% probability that the total cost will equal or exceed $X where X is the mean.

(b) There is a 90% probability that the total cost will fall between $Y and $Z, where Y and Z are determined by counting points on the cost frequency plot.

(c) There is a 95% probability that total cost will be greater than $Y (or less than $Z).

A good uncertainty analysis is invaluable in risk-management. Management must establish limitations on the financial risk it is willing to take in performance of a development program, or in bidding on a development contract.[14] Limitations and constraints should be expressed specifically and quantitatively since quantitative analysis is facilitated by the graphs. The following types of guidelines should be stated:

(a) There must be at least a 50% chance of earning a specified profit.

(b) There must be no more than a 10% chance of losing more than a specified amount on the R&D effort.

(c) Total cost to the company must not exceed a certain amount.

Normally, an estimated cost allows for the many small areas of uncertainty, but includes no allowances for major risk areas. Increased costs in these areas will reduce profit or cause an overall loss unless

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[14] Richard M. Anderson, "Handling risk in defense contracting", Harvard Business Review, July-August, 1969, p. 90.

additional contingencies are provided. To satisfy the criteria noted in the preceding paragraph, it will often be necessary to increase the initial bid (or estimate to management). For example, if an estimate is based on the mean of an uncertainty analysis, there is a 50% chance this cost will be exceeded, but also a 50% chance that at least the anticipated profit will be realized. The cost frequency plot will clearly show the probability of exceeding this estimate by a specified amount, and the highest cost that is likely to occur. Through appropriate modification of the bid or proposal, the financial guidelines can be met with a high degree of confidence.

Management Ramifications

By their very nature, R&D programs are beset with planning and control problems whose influence are felt strongly throughout the management structure. The gains to be acheived with an effective cost planning and control system include:[15]

(a) A basic improvement in planning allowing for superior decision making prior to initiation of new programs.

(b) A greatly improved ability for comparing programs with original objectives.

(c) Facilitation of execution for complex development programs within original cost and time estimates.

(d) Improvement of potential for actual cost savings, increased efficiency, and higher profits.

(e) Improved communication among personnel working toward the common goal.

(f) The opportunity for tradeoffs among time, cost, and performance criteria (cost effectiveness).

The mental exercise involved in deriving a sound cost estimate will tend to minimize the risk inherent in R&D planning and facilitate the benefits cited above.[16]

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[15]David B. Uman, "Planning and Control of Development Programs," Systems and Procedures Journal, November/December 1968, p. 12.

[16]James D. Cuff, "Risk Analysis", Ordance, May/June, 1972.

The question often raised by management, that the estimators judgement may be biased or faulty, can be countered by a parametric estimate which utilizes historical data. This information can be used to determine whether R&D cost might preclude development of a system. It might also be used in conjunction with an effectiveness study to arrive at a conclusion relative to cost effectiveness.

The data presented to the decision maker should be in the form of an estimated cost with appropriate back-up rationale along with the uncertainty of the estimate and the possible variation in terms of dollars, and associated probabilities. The manager must then decide (1) what risk he can take of exceeding a specified maximum cost, and (2) the likelihood that appropriate funding will be available when required.

The uncertainty plot described previously should give the manager the type of visibility and understanding of cost estimates not usually available. This in combination with an unbiased or objective cost estimate could avoid unfortunate cost overruns. If the overruns are not eliminated, they will al least be explained, and to some degree predicted by the uncertainty analysis.

The uncertainty analysis will have another benefit. Usually when a point lies outside of two standard deviations from the mean, there is a reason other than pure random selection. When this occurs at any checkpoint during R&D, the decision maker should look for an assignable cause rather than write if off to good or bad luck. This goes for low as well as high costs since there is always the risk that some important factor might have been overlooked. Excessively high costs, at any point in development, could mean that the engineers overestimated the potential of the system. Possibly, the objective is not attainable with present technology.

A large variation between the engineering estimate and the parametric estimate may act as a red flag right at the beginning of the program. Obviously, one of the two estimates is in error. Perhaps the wrong parameters are being looked at, or they are not being considered in the right form. For example, a second order relationship rather than a linear one might be more appropriate for one or more of the parameters. Perhaps the engineering estimator made an error in judgement in assigning a complexity factor. The parametric estimate is far easier to correct. It is usually necessary only to find a relationship that fits past data. It should fit the new system assuming no state-of-the-art extrapolations are required.

All techniques naturally have their limitations. First, there must be adequate historical data if a parametric analysis is to be performed. Despite the existence of such data banks as the Army Material Command cost index abstract system, the precise figures needed are not always readily obtainable. Often it is necessary to search several sources to obtain the required information. Overlapping cost figures must be identified and the overlap reconciled. As a last resort it may be necessary, based on insufficient data, to estimate a historical cost. This estimation is necessary because, as previously pointed out, engineering, testing, administrative and laboratory costs are not always properly identified.

If the system to be analyzed requires extrapolation of either cost data or technical data, the possibility of a limitation on any linear relationship is significant. In cases such as these, interactions, if they exist, are all but impossible to isolate. A corresponding error can be expected in the cost estimate.

Care must be taken to assure that the proper parameters are evaluated. If a critical factor is omitted from the analysis, the derived relationship will be faulty. Likewise, the critical parameters should be evaluated in the proper form. If a critical relationship is logrithmic or exponential, a linear equation will not yield a true picture of costs.

The uncertainty analysis requires subjective judgement in assigning probabilities to optimistic and pessimistic estimates. Unless these probabilities are assigned with care, the picture presented to the manager could be extremely misleading. To minimize this potential hazard, it may be advisable to obtain several opinions. This type of analysis may be limited to studies where the parametric relationship shows relatively high correlation.

Conclusions and Recommendations

While scientific and engineering techniques can be applied to estimating the cost of R&D programs, the estimating task is not, and will probably never be an exact science. An idea of the precision of the estimate can be obtained through use of an uncertainty analysis. This provides the odds related to potential program cost, and a manager with a feeling for statistics should be able to render a sound decision based on this data. An attempt to relate the results of several cost uncertainty analyses to actual costs would undoubtedly be a fruitful area for future effort.

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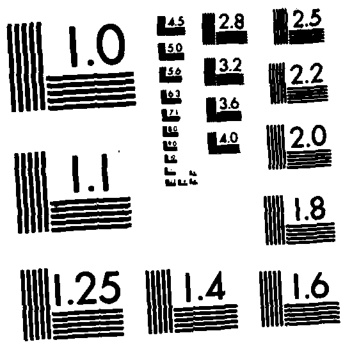

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AN IMPACT ASSESSMENT ALGORITHM FOR R&D PROJECT RISK ANALYSIS

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SUMMARY

Materiel acquisition program/project management is concerned with impacts, should the project experience perturbations in terms of changes in schedule, funds, and performance goals. The management must analyze the potential impact to derive a priori information as to possible outcomes and to formulate alternative courses of actions, with risk as the fourth dimensional measure for trade-off considerations. This paper presents a technique to facilitate the problem of impact assessment, particularl technical uncertainities. The technique incorporates potential problems, consequences of such problems in the event that they occur, judgment as to efforts needed to resolve those problems, and assessment as to schedule and cost impacts to the project. It provides a simple approach to the collectio of data from technical and managerial personnel. The most significant part is that an automated algorithm has been developed which computes probability of program success, total cost impact, and probability distribution curves for cost impact in terms of likelihood of program success.

I. INTRODUCTION

For a research and development organization which is primarily involved in basic research, applied research development, and portions of advanced development including the demonstration of technology, the objectives are to establish a strong and usable technology base and to transform ideas and technology into materiel which fulfill future needs. Typically, R&D management is concerned with major decision problems as to whether or not research objectives will be accomplished by a particular course of action, or program layout, with some specified resources committed to the particular efforts. On the other hand, when a project reaches that stage of the materiel acquisition process that it becomes a project managed item, the project manager is also concerned with similar decision problems as to whether or not the item will be produced in accordance with the specified course of action and resources. Since a manager lives in a world of uncertainties, program decisions are more properly called decisions under uncertainties. As managers are in need of a priori information so as to be in a position to anticipate outcomes, to apply alternative courses of action, and to reduce uncertainties associated with the realization of cost, time, and performance goals, the subject "decision risk analysis" has been emphasized.

One phase of decision risk analysis is concerned with the problem of impact assessment. This addresses the areas of potential problems, consequences of such problems in the event that they occur, judgment as to efforts needed to resolve those problems, and assessment as to schedule and cost impacts to the entire program. This impact assessment is designed to provide the decision-makers with a better understanding of the transitional period from initiation of program with allotted resources and defined goals to the completion of the program.

The basic approach to impact assessment subscribes to the standard decision-tree technique and follows the steps shown below:

1. Aggregate all R&D efforts into major phases.

2. For each phase, identify potential problems, and assess probabilities of occurrences.

3. For each problem, evaluate consequences of failure.

4. Enumerate means to resolve problems, and attach probabilities of success to each.

5. Estimate impacts on cost.

6. Fold back for expected values, and obtain distribution curves.

The information in steps 2-5 are collected from knowledgeable technical personnel and can be easily accomplished by questionnaires with the following heading:

Potential Problems	Prob. Occur.	Consequences	Resolutions	Prob. Success	Cost Impact

In the remainder of this paper, an algorithm is presented which facilitates data processing for the impact assessment. Preceeding the presentation of the algorithm, we need to exhibit some basic concepts and the logic for the assessment. An example is provided to exhibit some typical results of the assessment.

II. BASIC CONCEPTS

Let's consider some basic concepts.

1. If there are n values $x_1, x_2, \ldots, x_n$ of a random variable Z for which the value of probability mass function $f_Z(x_i)$ is greater than zero, then we define the expected value of Z to be

$$\sum_{i=1}^{n} x_i f_Z(x_i)$$

2. Suppose a program only has two independent potential problems X and Y with probabilities of occurrence p_X and p_Y respectively. If the corresponding resolutions to the problems have been determined to have probabilities of success p_X^R and p_Y^R respectively, then the probability of success for the program in view of these two potential problems can be calculated as the following:

$$[1 - p_X (1 - p_X^R)] \, [1 - p_Y (1 - p_Y^R)]$$

3. Consider a program with only three independent potential problems each with its probability of occurrence p_o. After assessing the consequence of failure, possible resolutions, R, are enumerated, each with a probability of successful resolution, p_s. Each resolution has an associated cost impact C. Suppose the collected data from technical engineers are as shown:

Potential Problems	Probability of Occurrence	Possible Resolutions	Probability of Success	Cost Impact
1	p_o^1	R_1^1	p_s^1	C_1
2	p_o^2	R_1^2	p_s^{21}	C_{21}
		R_2^2	p_s^{22}	C_{22}
3	p_o^3	R_1^3	p_s^{31}	C_{31}
		R_2^3	p_s^{32}	C_{32}

A decision-tree diagram can be drawn, assuming the second resolution is applied only if the first resolution failed. It is important to note that "program failure" means that a problem cannot be resolved within the time frame and the cost projected as impacts. It implies that a project manager would need to review the program, exercise his judgment, and apply other mea to resolve the problem. Techniques involving decision analysis are found in Raiffa (1968), for instance. An alternative method in solving decision-tree type problems is presented here which can be easily accomplished via a calculation sequence shown in Table 1. It is equivalent to the decision-tr approach, and the interested reader can verify the equivalence.

The results of the calculations for the collected data are summarized below:

		FIRST RESOLUTION			
	(1)	(2)	(3) = (1) x (2)	(4)	(5) = (1) x [1-(4)]
Potential Problem	Prob. Occur.	Cost Impact	Expected Impact	Prob. Success	Prob. Failure
1	p_o^1	C_1	$p_o^1 C_1$	p_s^1	$p_o^1 (1 - p_s^1) = p_{os}^1$
2	p_o^2	C_{21}	$p_o^2 C_{21}$	p_s^{21}	$p_o^2 (1 - p_s^{21}) = p_{os}^2$
3	p_o^3	C_{31}	$p_o^3 C_{31}$	p_s^{31}	$p_o^3 (1 - p_s^{31}) = p_{os}^3$

SECOND RESOLUTION			OVERALL PROGRAM		
(6)	(7) = (5) x (6)	(8)	(9) = (5) x [1-(8)]	(10) =1-(9)	(11) = (3)+(7)
Cost Impact	Expected Impact	Prob. Success	Prob. Failure	Prob. Success	Total Impact
NA	NA	NA	$p_o^1 (1-p_s^1)$	$1-p_o^1(1-p_s^1)$	$p_o^1 C_1$
C_{22}	$p_{os}^2 C_{22}$	p_s^{22}	$p_{os}^2(1-p_s^{22})$	$1-p_{os}^2(1-p_s^{22})$	$p_o^2 C_{21}+p_{os}^2 C_{22}$
C_{32}	$p_{os}^3 C_{32}$	p_s^{32}	$p_{os}^3(1-p_s^{32})$	$1-p_{os}^3(1-p_s^{32})$	$p_o^3 C_{31}+p_{os}^3 C_{32}$

TABLE 1. CALCULATION SEQUENCE

Probability of program success =

$$[1 - p_o^1 (1 - p_s^1)] [1 - p_{os}^2 (1 - p_s^{22})] [1 - p_{os}^3 (1 - p_s^{32})].$$

Total expected impact on cost =

$$p_o^1 C_1 + (p_o^2 C_{21} + p_{os}^2 C_{22}) + (p_o^3 C_{31} + p_{os}^3 C_{32}).$$

4. Since the above scheme only provides the information as to the expected cost impact, it is more important to inquire as to the probability distribution functions of the impact. More specifically, we are interested in the questions: "What is the probability of program success if only a portion of the expected cost impact is actually allocated to the program?", or "How much should the contingency fund be to assure a 90% probability of program success?".

Consider a program with two potential problems, each with only one resolution:

Potential Problem	Probability of Occurrence	Probability of Successful Resolution	Cost Impact
A	.2	.7	$10
B	.1	.8	$20

If potential problems are considered as sets in a space, the complete outcome space consists of the following four disjoint sets:

$\bar{A}\,\bar{B}$, $A\,\bar{B}$, $\bar{A}\,B$, and $A\,B$,

where the overscore indicates the complement of a set, and XY means intersection of sets X and Y.

The probability of occurrence of the above can be calculated quite readily, with the corresponding cost impact C:

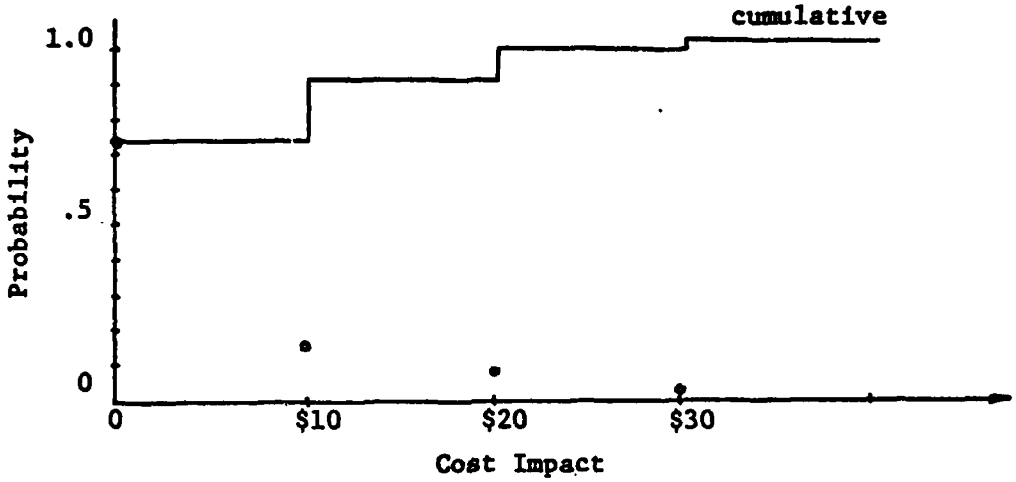
$p(\bar{A}\,\bar{B}) = (1 - .2)\ (1 - .1) = .72,$ $\qquad C(\bar{A}\,\bar{B}) = 0$

$p(A\,\bar{B}) = (\ .2\ )\ (1 - .1) = .18,$ $\qquad C(A\,\bar{B}) = \$10$

$p(\bar{A}\,B) = (1 - .2)\ (\ .1\ ) = .08,$ $\qquad C(\bar{A}\,B) = \$20$

$p(A\,B) = (\ .2\ )\ (\ .1\ ) = .02,$ $\qquad C(A\,B) = \$30$

It is easy to generate a plot of probability of occurrence with respect to cost impact and plot of cumulative probability.



Since each outcome is composed of a successful subset and an unsuccessful subset, it is easy to calculate the probabilities of program success:

$$p(A\,\overline{B} - \text{success}) = (.18)\ (.7) = .126$$

$$p(\overline{A}\,B - \text{success}) = (.08)\ (.8) = .064$$

$$p(A\,B - \text{success}) = (.02)\ (.8)\ (.7) = .011$$

The above calculated probabilities yield the following cumulative probabilities for cost impacts and program success:

$ - impact	Cumulative Probability
0	.72
10	.846
20	.91
30	.921

A second plot can be generated, and the interpretation is quite readily obtained. For example, it is assessed that there is a 90% chance that the cost impact is less than or equal to $10 with a probability of program success of .85, in view of two potential problems with at least one occurring at 28% chance. Similar interpretations can be formulated for the other values.

5. One final feature which deserves mention involves n-tuple and binary arithmetic. In general, if there are n potential problems A, B, ..., N,

an ordered n-tuple can be constructed whereby each entry designates either the occurrence or the non-occurrence of the problem. A typical example is as shown below:

$$(A, B, \overline{C}, \overline{D}, \ldots, \overline{N})$$

means only A and B occur and the over-score indicates non-occurrence.

Secondly, since we are concerned with either the occurrence or the non-occurrence of the potential problems, the entry in the ordered n-tuple can use the binary representation of 1 and 0 respectively. The above example would be as follows:

$$(1, 1, 0, 0, \ldots, 0)$$

Thirdly, given n potential problems, or sets, the total number of possible combinations, or total number of subsets, is simply 2^n. To generate 2^n combinations for n potential problems, we can take advantage of binary arithmetic. If we start with 0 and increment by 1 each time, we can generate 2^n combinations:

Occurrence or Non-occurrence of Potential Problems	N-tuple Representation	Binary Arithmetic
$(\overline{A}, \overline{B}, \ldots, \overline{L}, \overline{M}, \overline{N})$	(0, 0, ..., 0, 0, 0)	0
$(\overline{A}, \overline{B}, \ldots, \overline{L}, \overline{M}, N)$	(0, 0, ..., 0, 0, 1)	1
$(\overline{A}, \overline{B}, \ldots, \overline{L}, M, \overline{N})$	(0, 0, ..., 0, 1, 0)	10
$(\overline{A}, \overline{B}, \ldots, \overline{L}, M, N)$	(0, 0, ..., 0, 1, 1)	11
...	...	...
(A, B, ..., L, M, N)	(1, 1, ..., 1, 1, 1)	11-11

For large n, 2^n is a very large number and cannot be handled by a computer economically. In the algorithm presented in the next chapter, a combination of n-tuple binary arithmetic and Monte-Carlo simulation is used to generate the probability distribution curve.

III. AN ALGORITHM

All basic concepts presented in Chapter II are now incorporated into the algorithm for impact assessment of R&D project risk analysis. Specifically the algorithm is designed to compute the following two types of information:

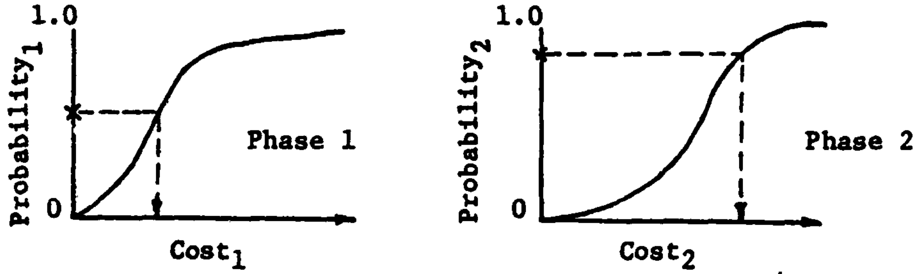
1. Probability of program success and total expected impacts on cost.

2. Probability distribution curves for cost impact in terms of likelihood of occurrence and likelihood of program success.

Item 1 follows the exact sequence of calculations exhibited in part 3 of Chapter II.

The second portion, namely probability distribution curves of item 2 above, require some additional explanation. The generation of probability distribution is accomplished in two parts. First, for each phase of the R&D program, cumulative probability distributions of occurrence and success are generated via n-tuple/binary arithmetic technique exhibited in parts 5 and 4 of Chapter II. Secondly, to find the cumulative probability distributions of occurrence and success for the entire program incorporating all phases, we apply a Monte-Carlo simulation*. The following diagrams and procedure describe the basic logic involved.

a. Suppose from the first part of calculations, we have the following two phase cumulative probability distributions:



b. Generate one random number, and obtain associated $cost_1$ indicated by arrow in the left diagram above.

c. Generate second random number, and obtain associated $cost_2$ in the right diagram.

d. Add $cost_1$ and $cost_2$ for resultant cost impact.

e. Repeat above to generate cost impact density curve.

f. Cumulate to obtain distribution curve.

IV. AN EXAMPLE

Let us illustrate by an example of a program involving five major airmobile R&D phases: rotor subsystem, drive subsystem, engine subsystem, flight control subsystem, and cargo handling subsystem. Date collected include the following:

*Convolution is the proper concept, Parzen (1960).

1. Potential problems and probabilities of occurrence.

2. Consequence of failure.

3. Means to resolve problems and probabilities of success.

4. Impacts on schedule and cost.

By using the automated algorithm, calculations are made to assess cost impacts and distributions of impacts. The calculated results are shown in the following pages. A summary of the outputs is as follows:

	Subsystem	Cost Impact in $-K	Prob. of Success for Subsystem
1.	Rotor	740.7	0.650
2.	Drive	128.0	0.860
3.	Engine	1,747.2	0.953
4.	Flight Control	245.5	0.894
5.	Cargo Handling	672.5	0.822
	Overall Program	$3,533.9	0.391%

The cost impact distribution curves for the probability of occurrence and probability of success are on the next page. The former curve provides answers to the question "What is the probability that the cost growth is less than or equal to x amount?" The latter provides information to the question "Given x amount of cost growth, what is the probability of program success?" Computer outputs are shown on the page following the graphs. It is noted that the cost column represents the end points of each interval; consequently, the probability values should be plotted in the mid-points of intervals.

The curves show that probability of success of the program is estimated to be around 40%, even with unlimited amount of funds devoted to the program. It is also indicated that the program will incur technical difficulties which will result in cost growth.

V. CONCLUSIONS

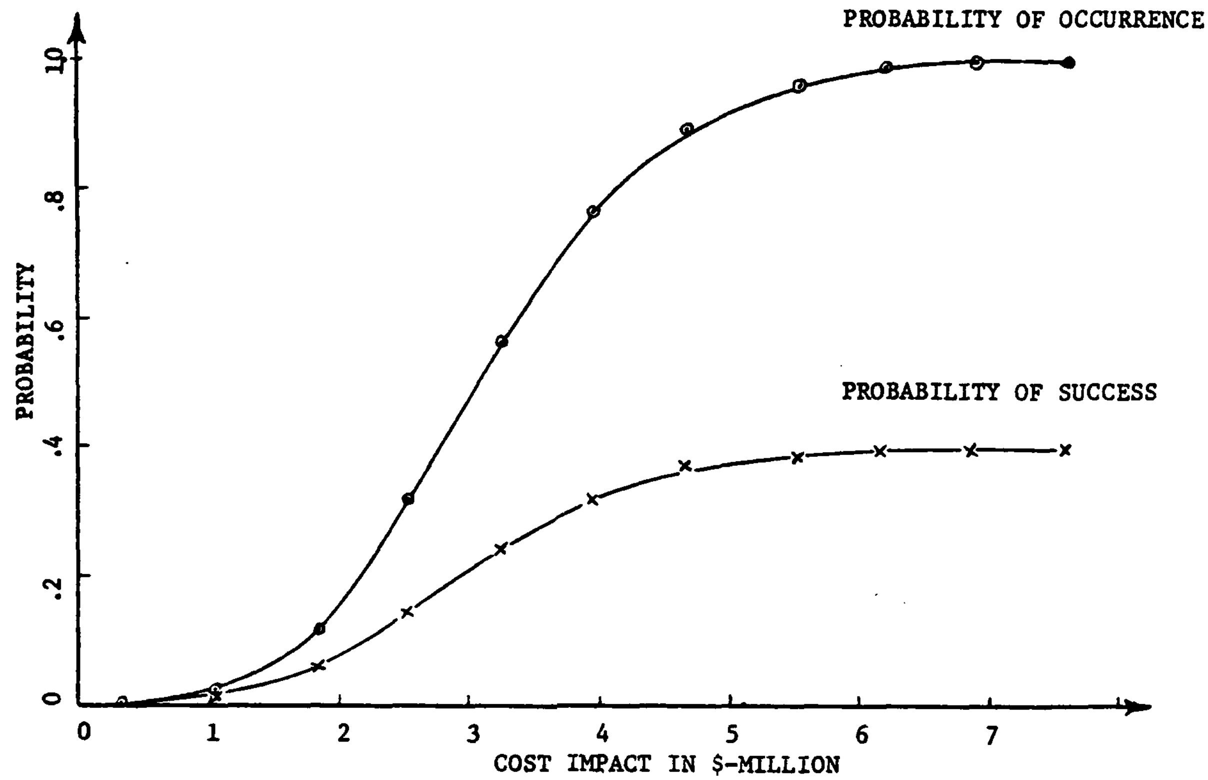
In this paper, we presented an impact assessment algorithm for R&D project risk analysis. It is shown data can be collected quite readily, and the collected data can be easily processed to yield various types of information vital to decision-making.

It is cautioned that the generated numbers are not necessarily the key information. Sensitivity analysis must be carried out to obtain trends and to formulate alternative courses of actions. Therefore, a close examination of the technical data must be accomplished.

POTENTIAL PROBLEM	PROB OCCUR	PROBABILITY SUCCESSFUL RESOLUTION(S)	COST IMPACT ($K)	PROBABILITY SUCCESS	EXPECTED COST IMPACT (K DOLLAR)
1. Rotor Subsystem:					
1	.1	.85	300	0.985	30.0
3	.2	.9	1,000	0.980	200.0
4	.3	.9	200	0.970	60.0
5	.3	.9	50	0.970	15.0
6	.3	.9	90	0.970	27.0
7	.25	.9	30	0.975	7.5
8	.2	.9	100	0.980	20.0
9	.3	.95	50	0.985	15.0
10	.3	.97	500	0.905	150.0
11	.35	.85	75	0.947	26.2
12	.40	.85	200	0.940	80.0
13	.50	.9	70	0.950	35.0
14	.3	.85	250	0.955	75.0
TOTAL				0.650	740.7
2. Rotor Subsystem:					
1	.1	.99	150	0.999	15.0
2	.4	.9	40	0.960	16.0
3	.1	.99	75	0.999	7.5
4	.2	.98	80	0.996	16.0
5	.8	.99	20	0.992	16.0
6	.2	.9	50	0.980	10.0
7	.2	.95	60	0.990	12.0
8	.3	.95	75	0.985	22.5
9	.3	.95	20	0.985	6.0
10	.7	.95	10	0.065	7.0
TOTAL				0.860	128.0

POTENTIAL PROBLEM	PROB OCCUR	PROBABILITY SUCCESSFUL RESOLUTION(S)	COST IMPACT ($K)	PROBABILITY SUCCESS	EXPECTED COST IMPACT (K DOLLAR)
3. Engine Subsystem:					
1	.5	.9/1.0/.7	400/700/200	1.000	235.0
2	.8	.8/.9/.6	800/1,200/200	0.994	835.2
3	.25	.95/.9/.5	1,300/1,000/200	0.999	337.8
4	.65	.5/.9	0/100	0.968	32.5
5	.5	.9/.65/.65	600/100/100	0.992	306.7
TOTAL				0.953	1,747.2
4. Flight Control Subsystem:					
1	.15	.9	900	0.985	135.0
2	.5	1.0	0	1.000	0.0
3	.3	.85	60	0.95	18.0
4	.2	.9	50	0.980	10.0
6	.15	.8	450	0.970	67.5
7	.3	1.0	50	1.000	15.0
8	.3	1.0	0	1.000	0.0
TOTAL				0.894	245.5
5. Cargo Handling Subsystem:					
1	.6	.85	500	0.910	300.0
2	.7	.9/.9	300/500	0.993	[illegible]
3	.3	.9	50	0.970	[illegible]
4	.5	.5/.5/.5	100/100/300	0.937	112.5
TOTAL				0.822	672.5
OVERALL PROGRAM				.391%	$3,533.9

* Multiple resolutions and impacts are separated by slashes.



COST IMPACT DISTRIBUTION

COST (K$)	PROBABILITY OCCURRENCE	CUMULATIVE PROBABILITY	PROBABILITY SUCCESS	CUMULATIVE PROBABILITY
0	0.000	0.000	0.000	0.000
724	0.004	0.004	0.001	0.001
1,445	0.022	0.026	0.014	0.015
2,172	0.094	0.120	0.045	0.060
2,896	0.202	0.322	0.086	0.146
3,620	0.243	0.565	0.097	0.243
4,344	0.200	0.765	0.076	0.319
5,068	0.128	0.893	0.046	0.365
5,792	0.066	0.959	0.019	0.384
6,516	0.027	0.986	0.007	0.391
7,239	0.010	0.996	0.002	0.393
7,963	0.003	0.999	0.000	0.393
8,687	0.000	0.999	0.000	0.393

It is also recommended that a program be tracked in view of the data and generated results for purposes of validation.

Impact on time is not easy to calculate. The actual time of occurrence of the problems may or may not actually cause a schedule delay. For instance, a problem may occur early in the developmental phase and is corrected without delaying any other developmental effort; this situation may have only increased the cost of the program, but it did not affect the schedule of the program. On the other hand, a problem may delay the program, for it directly affects other efforts. In either case, this is a difficult problem and not totally resolved.

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DECISION RISK ANALYSIS

of

The impact on the Heavy Lift Helicopter Advanced Technology Component (ATC) Program of Alternative Methods of powering the ATC Dynamic System Test Rig.

PREPARED BY

RISK ANALYSIS TEAM

3 February 1972

US Army Aviation Systems Command
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INTRODUCTION

The Boeing Company, Vertol Division has a contract with the US Army (DAAJ01-71-C-8040) for the Advanced Technology Component (ATC) Program. The objectives of this (ATC) Program are to:

(1) Demonstrate component technology to reduce development risk applicable to a 22.5 ton HLH at the lowest total HLH system cost.

(2) Secure a cost data base adequate to assure that cost estimates using that data base are credible and acceptable.

(3) Provide the Government with improved technology and reduced risk for program definition for large payload helicopters.

(4) Advanced level of industry expertise in HLH components.

The purpose of the contract is to seek maximum reduction of technical and cost risk associated with the Engineering Development of an HLH System through the design, fabrication, demonstration and test of selected critical HLH components. Engineering Development or full Flight Qualification of any component or concept is not the purpose of the contract.

Within the ATC program is an effort to build, and instrument a Test Rig which will be used for testing of the Integrated Rotor/Drive System. The Test Rig, as now planned, uses as a power source the 501-K-18 engine manufactured by Detroit Diesel Allison, a Division of General Motors Corporation. The 501-K-18 engine is not the engine which will be used on the Heavy Lift Helicopter as it is not an aircraft engine.

Since the award of the original ATC contract, the Army has decided to develop an engine for the HLH. Allison is expected to be selected to develop its M62 engine for the HLH on subcontract to Boeing-Vertol. The engine development will be contracted for as a modification to the ATC contract. It would be desirable to demonstrate the compatibility of the ATC developed dynamic components in a test rig powered by a flight representative engine (M62B) if it can be done without delaying the completion of the ATC contract or that portion of the contract having to do with the Test Rig.

The analysis presented in this paper is limited to two alternatives, both of which include the use of M62B engines. The continuation of the ATC contract using the K-18 engine without consideration of the M62B program is not included in the body of the analysis which assumes that the use of the M62B in the Dynamic System Test Rig (DSTR) justifies the attendant cost and ATC test risks because of the additional information which will be gained from the use of the flight representative engine in the DSTR. If the ATC contract was not modified, the risks associated with acquiring a K-18 engine only and a test rig customized to the K-18 are minimal 1/ Fund availability (the major cause for uncertainty in alternatives 1 and 2) is a certainty because funding for the K-18 is already included in the ATC contract. The net cost attributable to this course of action is $800 thousand.

PROBLEM STATEMENT

To evaluate the impact on the HLH ATC program of alternative methods of powering the Dynamic System Test Rig (DSTR).

ALTERNATIVES

1. Acquire M62B engines for the DSTR; design test rig for M62B engine only.

   Option A - no fund applied until total release.

   Option B - K-18 funds ($800,000) applied to M62 Program, 15 Feb 72.

2. Acquire K-18 and M62B engines for the DSTR; design test rig to accept either the K-18 or M62B engines.

1/ The concensus of the risk analysis team was that the K-18 engine only was the lowest risk approach, probability of functional DSTR equals .95, based on the following elements:

K 18 engine	.95
Test Rig	.999
Funding available	1.0

ASSUMPTIONS

A decision must be made on 10 Feb 72. This is time zero for all actions being considered below.

A delay in the completion of the ATC program is unacceptable. This analysis assumes that engines must be available not later than 1 Nov 73 and the test rig assembled by 1 Feb 74 in order to avoid delays in the ATC program.

Cost Estimates will be only incremental program costs which will occur as a result of this decision.

An M62B program cannot be initiated until funding is obtained. The probability of funding is:

.70 by 29 Mar 72

.15 by 10 May 72

.10 by 10 Aug 72

.05 after 10 Aug 72

There are $800 thousand in the current ATC program.

If alternative 1 is chosen, the $800 thousand could be frozen until funding is approved for the M62B engine (Option A) or it could be released for application to the M62B prior to receipt of total fund approval for the M62B (Option B). It is assumed that if $800 thousand is applied immediately, it will sustain the M62B engine effort 3 months.

If alternative 2 is chosen, the $800 thousand will be used on K-18 efforts and the M62B will be delayed awaiting funding.

METHODOLOGY

A risk analysis team was formed and presented with the problem statement and assumptions. A network of the ATC integrated rotor/drive system demonstration test program, as it is presently scheduled, was then constructed. (See Figure 1). Figures 1 - 4 display the interaction effects between the engine schedule and the design and construction of the test rig, as viewed by this risk analysis team. It was apparent from the network that slippage in the engine schedule would adversely effect the test rig schedule.

Based on the two engine program alternatives, four time schedules for starting engine development were considered (see table 2). These time schedules were based on the probability of receiving funds within these time frames. The probability of receiving the required funding by a given date was given as 70% by 29 Mar 72, 15% by 10 May 72, 10% by 10 Aug 72, and 5% after 10 Aug 72.

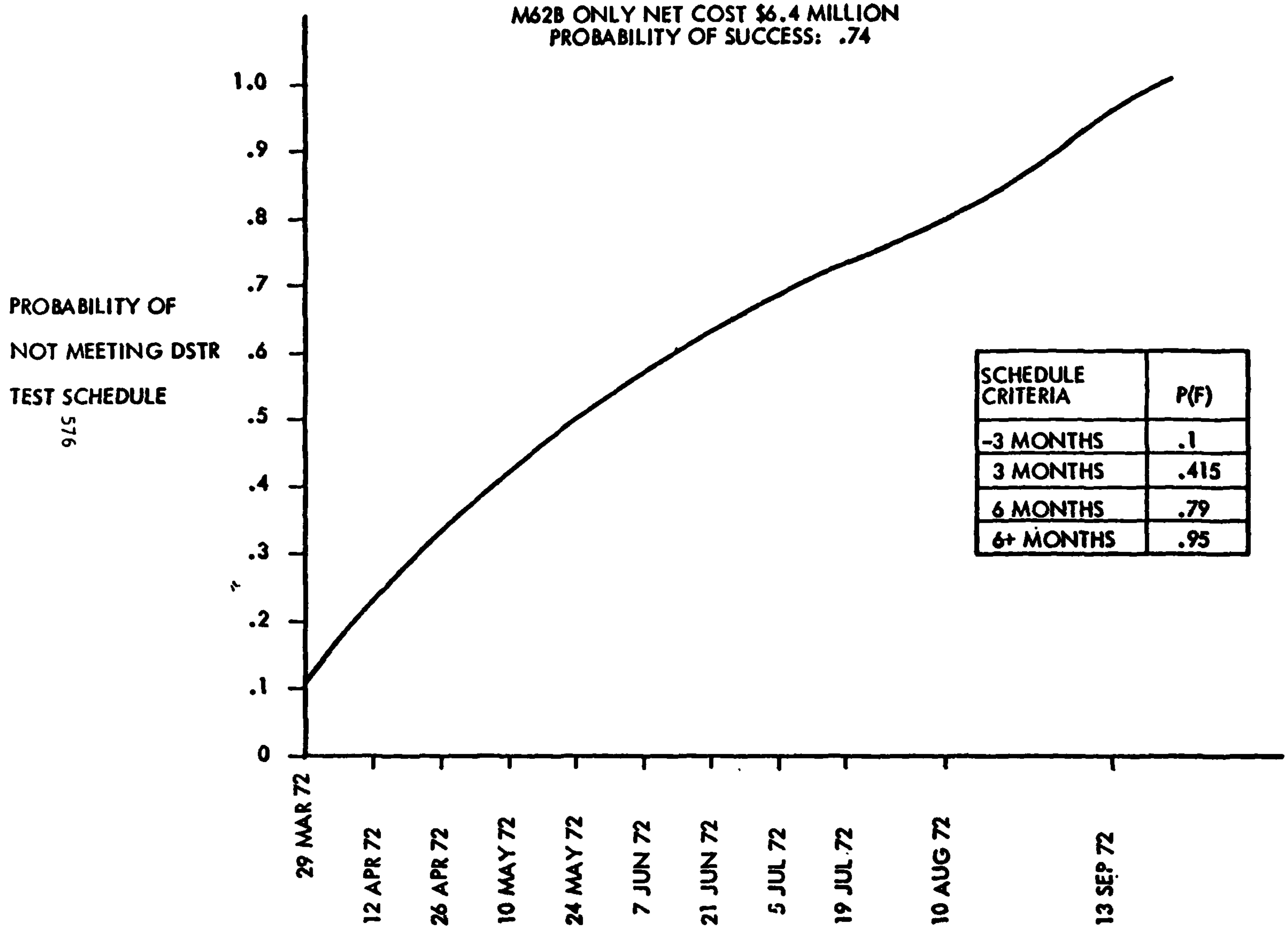
Since the receipt of funds is prerequisite to starting either engine program, the schedule was slipped to each of the above dates and the resulting interaction efforts between test rig completion and engine availability were analyzed. For each schedule slip, the risk analysis team estimated the probability of having an engine available and the probability of having the test rig constructed by 1 Nov 73 (see figures 1-4). The decision not to allow the scheduled completion of test rig construction to slip past 1 Nov 73 was based on the fact that this milestone is critical to completing the demonstration tests on time.

The resulting probabilities of successfully completing the test program as scheduled were derived by assuming stochastic independence of the estimated probabilities. The probability of successfully completing the test program conditional upon receipt of funds under each alternative is the product of the respective three probabilities of success. These three probabilities are: (1) the probability of getting funds for engine development, (2) the probability of having engines available by 1 Nov 73 and (3) the probability that the test rig construction will be completed by 1 Nov 73. The total probability of success is the sum of the four products derived for the four possible funding dates.

Table 2 is a compilation of the costs associated with each alternative and the probabilities developed by the risk analysis team. The costs shown are gross estimates developed by the team.

GRAPH 1
ALTERNATIVE 1 OPTION A

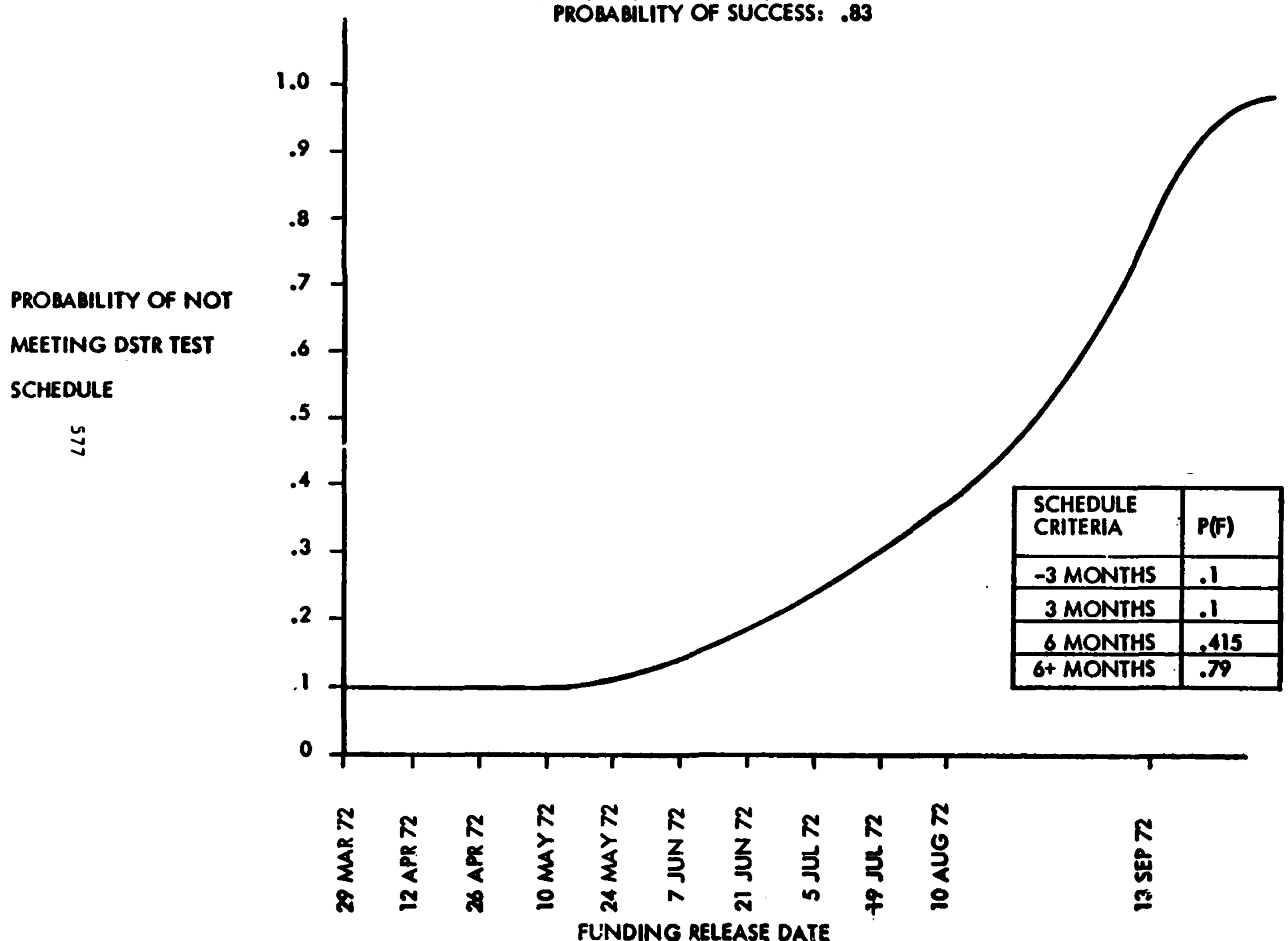
M62B ONLY NET COST $6.4 MILLION
PROBABILITY OF SUCCESS: .74



SCHEDULE CRITERIA	P(F)
-3 MONTHS	.1
3 MONTHS	.415
6 MONTHS	.79
6+ MONTHS	.95

GRAPH 2
ALTERNATIVE 1 OPTION B

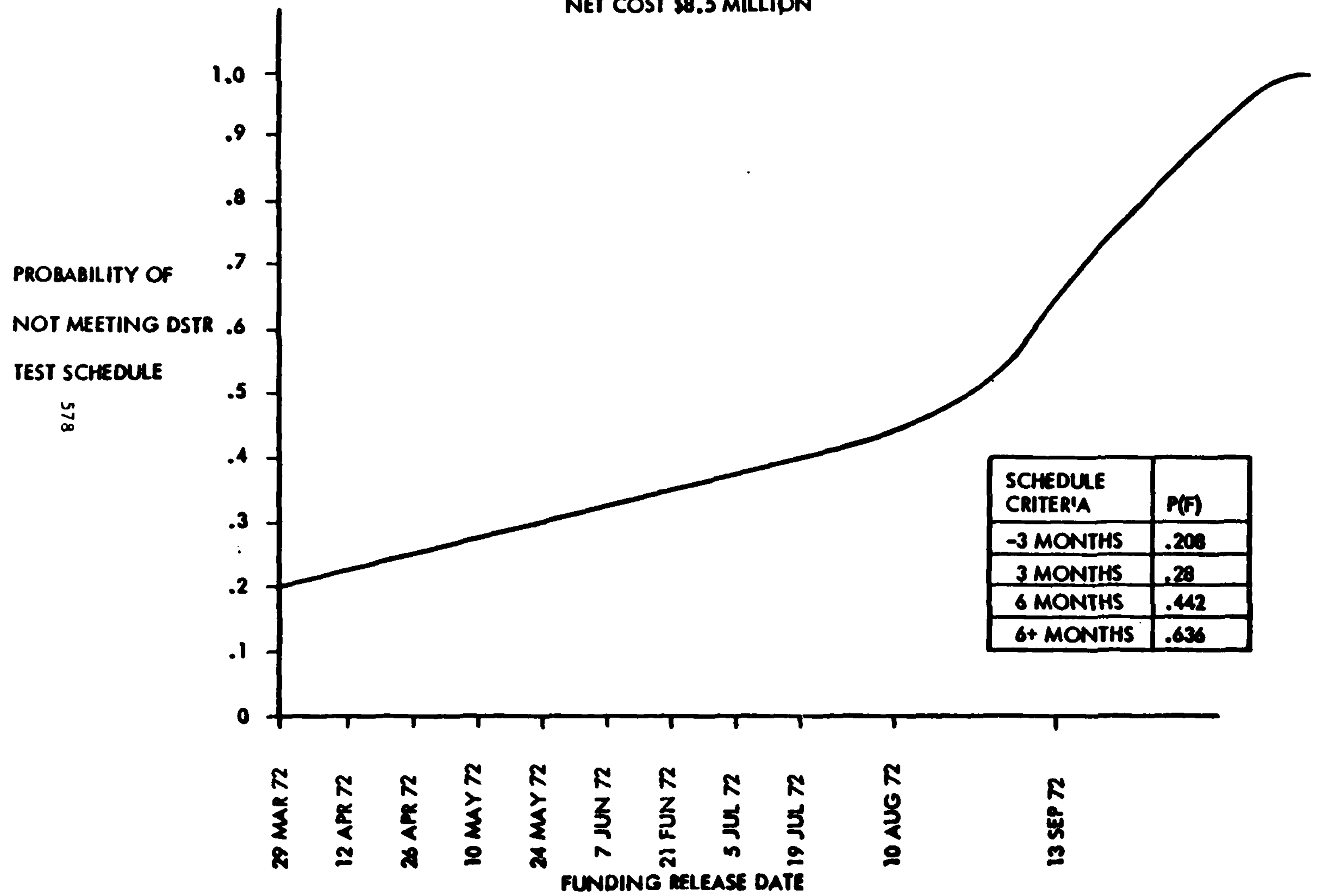
M62B ONLY NET COST $6.4 MILLION
PROBABILITY OF SUCCESS: .83



SCHEDULE CRITERIA	P(F)
-3 MONTHS	.1
3 MONTHS	.1
6 MONTHS	.415
6+ MONTHS	.79

GRAPH 3
ALTERNATIVE 2

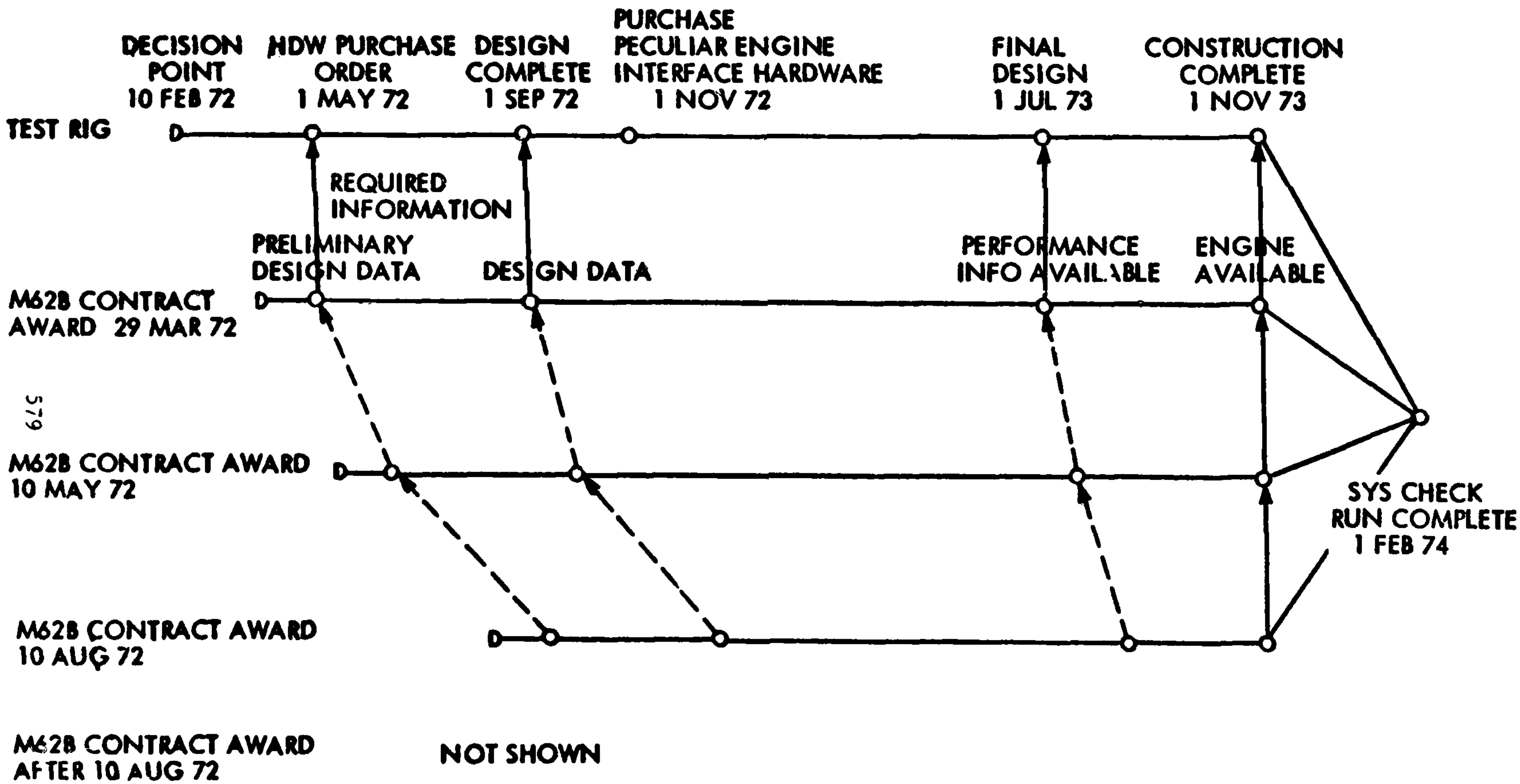
PURSUING M628 AND K-18
PROBABILITY OF SUCCESS: .74
($800 THOUSAND APPLIED TO K-18 ONLY)
NET COST $8.5 MILLION



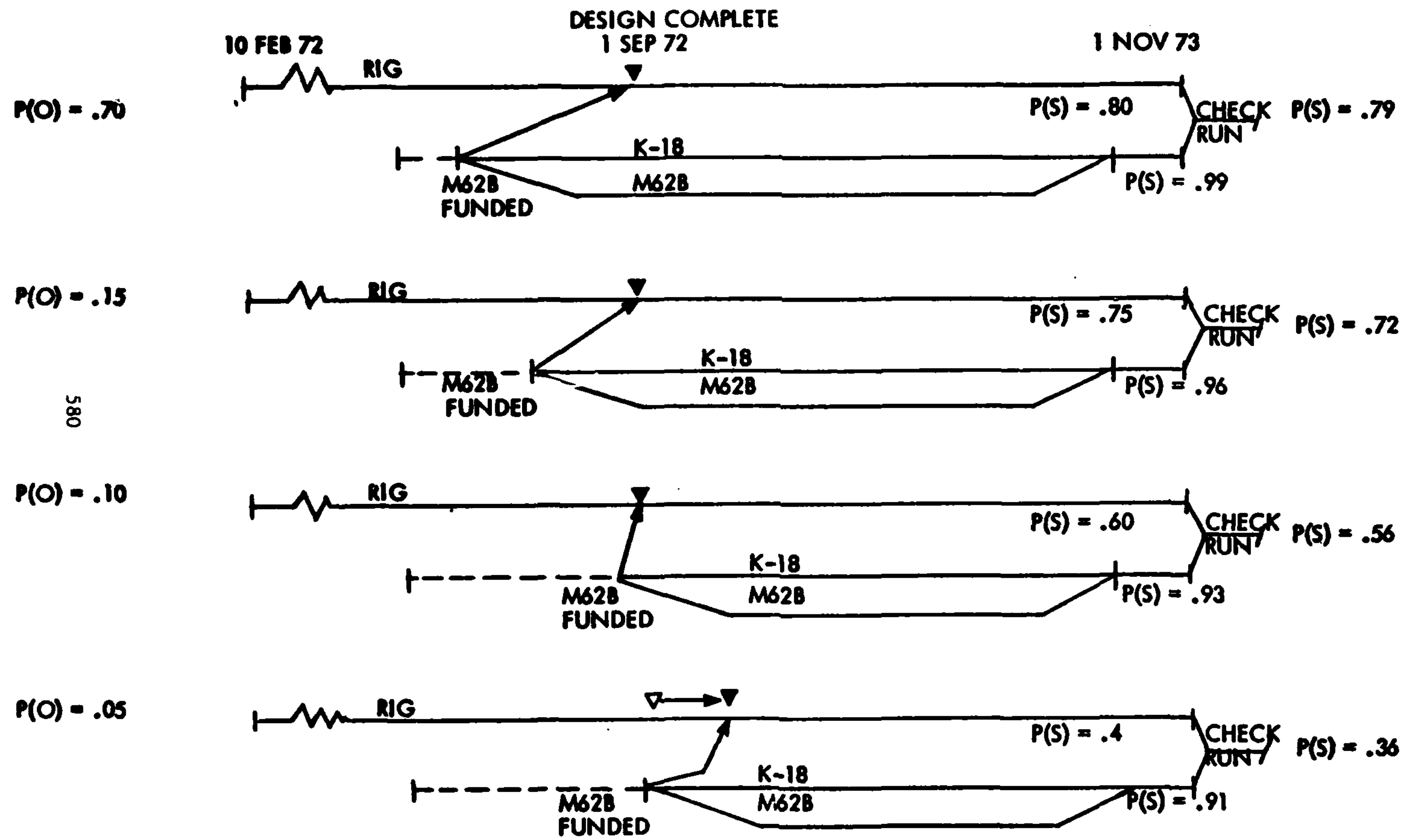
SCHEDULE CRITERIA	P(F)
-3 MONTHS	.208
3 MONTHS	.28
6 MONTHS	.442
6+ MONTHS	.636

FIGURE 1

DYNAMIC SYSTEM TEST RIG–M62B SCHEDULE

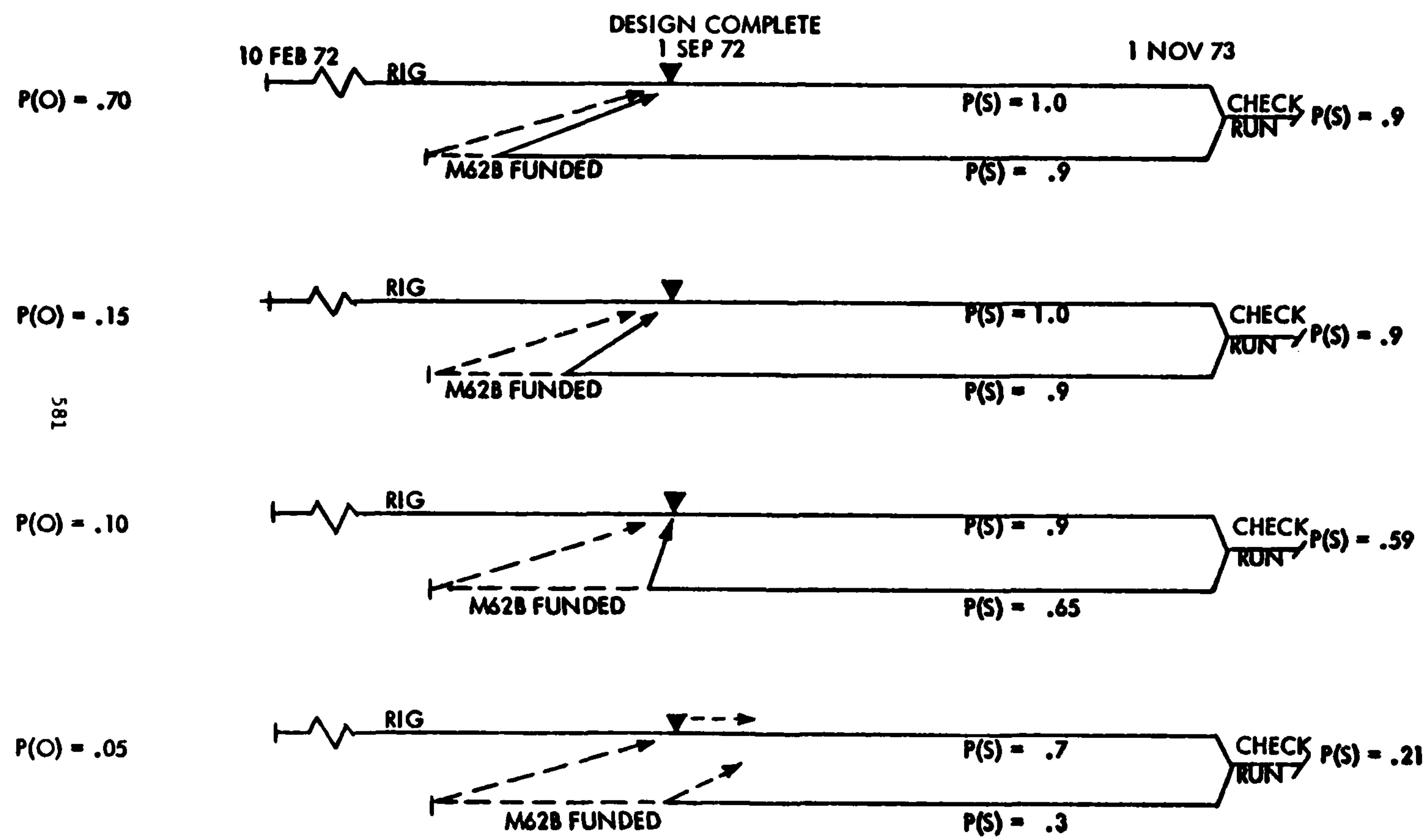


ALTERNATIVE 2
PURSUING M62B AND K-18
PROBABILITY OF SUCCESS: .74
($800 THOUSAND APPLIED TO K-18 ONLY)
NET COST $8.5 MILLION



P(O) = PROBABILITY OF OCCURRENCE
P(S) = PROBABILITY OF SUCCESS

FIGURE 3
ALTERNATIVE 1 OPTION B
M62B ONLY NET COST $6.4 MILLION
PROBABILITY OF SUCCESS: .83
($800 THOUSAND APPLIED TO M62B ON 15 FEB 1972)



P(O) = PROBABILITY OF OCCURRENCE
P(S) = PROBABILITY OF SUCCESS

TABLE 2

PROBABILITY MATRIX

PROBABILITY OF FUNDS RECEIPT AT DATE / ALTERNATIVE	29 MAR 72 P = .70		10 MAY 72 P = .15		10 AUG 72 P = .10		AFTER 10 AUG 72 P = .05		TOTAL PROBABILITY OF SUCCESS		COST (M)	
1. M62B ONLY	OPTION A	OPTION B	OPTION A	OPTION B	OPTION A	OPTION B	OPTION A	OPTION B	OPTION A	OPTION B		
ENGINE	.9	.9	.65	.9	.30	.65	.10	.3			$7.000	3 ENGINES/SPARES
TEST RIG	1.0	1.0	.90	1.0	.70	.9	.50	.7			.200	RIG MODIFICATION
											$7.200	
PROBABILITY OF FUNCTIONAL DSTR GIVEN SPECIFIED START DATE	.9	.9	.585	.9	.21	.585	.05	.21			- .800	CREDIT K-18
PROBABILITY OF SUCCESS CONDITIONAL UPON RECEIPT OF FUNDS	.63	.63	.088	.135	.021	.059	.0025	.0105	.74	.83	$6.400	NET COST
2. RIG TO ACCOMODATE M62B OR K-18												
ENGINE	.99		.96		.93		.91				$7.000	3 ENGINES/SPARES
TEST RIG	.80		.75		.60		.4				1.500	RIG MODIFICATION FOR UNIVERSAL HOOKUP
											$8.500	NET COST
PROBABILITY OF FUNCTIONAL DSTR	.792		.72		.558		.364					
PROBABILITY OF SUCCESS CONDITIONAL UPON RECEIPT OF FUNDS	.554		.108		.056		.0182		.736			

NOTES: P'OBABILITY OF SUCCESS FOR THE ENGINE AND TEST RIG IS DEFINED AS THE PROBABILITY THAT THE ENGINE/RIG WILL BE AVAILABLE AND FUNCTIONING PROPERLY IN ACCORDANCE WITH B.V.S "ROTOR/DRIVE SYSTEM PHASING" SCHEDULE SO AS TO NOT COMPROMI[illegible] THE DYNAMIC SYSTEMS INTEGRATED TESTS SCHEDULED TO BEGIN FEBRUARY 1974 (SEE APPENDIX FOR "ROTOR/DRIVE SYSTEM [illegible]ASING")

AD P00064

PRE-D-DAY FLEET MARINE FORCE MATERIEL REQUIREMENTS
AND DISTRIBUTION SYSTEM 1975-1980

Mr. H. B. Wilder, Jr.
Naval Warfare Research Center
Stanford Research Institute

For Commandant, U.S. Marine Corps (AX)

It is our purpose today to discuss with you the principal findings of our investigations into one of the most important--and difficult--subjects in Fleet Marine Force Support: The Pre-D-Day Materiel Requirements Determination and Distribution System for the support of Fleet Marine Forces (FMF) of the 1975-1980 era. The Commandant of the Marine Corps recently approved our report and the principal findings are now being implemented.

As you know, this system is generated in response to JCS guidance and is a principal element of the means by which the Commandant fulfills his responsibility for the logistic support of the FMF when it is committed to objective area operations. At the heart of the problem is the Prepositioned War Reserve Stocks (PWRS). However, our assignment was more broad and included the entire system by which these and other supplies required for the support of operations are distributed to FMF users until objective area stockage objective is attained and "normal" wartime resupply systems are in operation. Projected changes in Marine Corps systems, procedures and concepts of operations and logistics occasioned this research.

Our charge was to develop the systems required to provide responsive, balanced support to all elements of the Fleet Marine Force Air Ground Team in such a way that the systems will remain viable into the future.

Our study had four objectives. The principal objective was to describe the Pre-D-Day Materiel Requirements Determination and the Pre-D-Day Materiel Distribution System required to support the 1975-1980 era Fleet Marine Forces including the mobilization and support of the Fourth Marine Amphibious Force. Specifically, to provide the necessary guide lines to the Marine Corps for it development of necessary plans, procedures and techniques.

The other three objectives involved identification of constraints agains achieving an optimum system, a draft plan for implementation and recommended procedures for reviews of the system once implemented.

In the pursuit of these objectives, our research effort included the collection and analysis of the basic factors affecting the problem including policy, operational data of past Marine Corps experience as well as plans for the future. The analysis examined methods for selecting materiel into the system, factors affecting the distribution system, and the determination of materiel quantities. The evaluation of system elements in the light of these many factors resulted in the development of the Pre-D-Day Materiel Requirements Determination and Distribution System which we shall be discussing here today.

It is my plan to discuss only the first of the objectives - the description of the Requirements Determination and Distribution Systems. Even so the press of time will require a fairly general treatment in order that you get a reasonable overview of the proposed changes.

Current Marine Corps planning points to two significant new trends which affect the Pre-D-Day system. First there is the trend to emphasize deployment of smaller Marine Air Ground Task Forces (MAGTFs) rather than the Marine Amphibious Force (MAF) while retaining the capability for deploying the larger forces. The second is the significant change in traditional Marine Corps concepts of logistic support implicit in the trend to seabased landing force operations and seaborne mobile logistic support. Yet the Pre-D-Day system must be responsive to either concept of support: conventional shorebased or seaborne mobile logistic support, and it must be effective in the support of the whole range of MAGTFs.

Because there are significant differences among the Marine Corps Pre-D-Day System and those of other services it is appropriate to briefly describe the major features of the USMC current system. First, the major assets of the PWRS are actually a protected level in the Marine Corps Stores System--that part of the Marine Corps supply system within the Supporting Establishment. This level comprises a group of identical blocks of supplies calculated to support a Marine Amphibious Force for 30 days of combat. These are called Automatic Resupply since the distribution plan is to push the 30 day blocks to deployed Marine Amphibious Forces (MAFs) automatically, i.e., according to a predetermined schedule. The contents of the 30 day blocks are calculated on the basis of MAF population/equipment density and system usage factors according to criteria established by CMC. The balance of the Marine Corps Pre-D-Day stocks is a 30 day block for each MAF physically held in the FMF and called Mount Out. CMC policy establishes certain constraints and requires that the individual unit commander both determine the depth and range of his Mount Out and maintain physical custody in a ready-to-mount out status. In the case of the WesPac ground units an additional 30 day block called Mount Out Augmentation is held by the FMF. Marine aviation-peculiar Pre-D-Day materiel follows Navy procedures and consists of 90 to 105 days of operating stocks in the hands of the Marine Aircraft Group.

Now in the light of this background, let us begin to examine the revisions we proposed to the FMF Pre-D-Day Materiel Requirements Determination and Distribution System. Actually two systems are involved. One, a system to determine requirements and assure that assets are prepurchased or otherwise assured to be available when needed for issue in the future. And, two, a system for the distribution of these assets to the FMF once the need occurs. Although obviously the Distribution System cannot distribute assets that do not exist, our work indicates the Distribution System has a greater effect on the Requirements Determination System than the reverse. Further, that once you have defined what items of supply and equipment you will support in the Pre-D-Day system, the Distribution System has the major influence on depth and range of assets required. For this reason we will describe our proposed revisions to the Distribution System first, working from the objective area operation back through Mount Out and Withdrawal and finally discuss revisions to the Requirements Determination System.

Understanding the demand pattern of the assets--the total materiel required to support the committed FMF units--is prerequisite to the design of the system to acquire and distribute them. Clearly the best information on the combat demand behavior of Marine Corps supply items is the Viet Nam data. On the other hand, great caution is required when using such data, for a variety of reasons. We judiciously used Viet Nam accounting data to examine the demand behavior of Marine Corps line items in order to ascertain first, whether clearly defined subsystems of resupply could be identified and second as a guide for input to testing the effect of revised procedures of dealing with such subsystems or subpopulations of the whole populations of required items of supply.

Two characteristics of the Viet Nam supply accounting data became evident during this analysis. Cross checks of different time periods, different records and different elements of the same records indicate a rather surprising degree of self consistency for the purpose we used them--macrostatistics or demand patterns.

More important, the demand behavior follows the classic patterns of the behavior of large inventories. This is important since it allows us to use the classic methods for handling ordinary supply and concentrate on specialized solutions to the specialized problem areas in FMF support.

We took the Master Balance Files for the USMC Fleet Stock Account (FSA) activities operating in country for the late 1968 through mid 1969 period and subjected them to a series of analysis. When the recurring demand and movement counter patterns were analyzed they were remarkably regular and were clearly a log normal pattern. The plot of the data could have been taken from a text book on control of large inventories.

For every Federal Stock Number (FSN) for which we received an appreciable number of requisitions, there are others which appear to be needed only randomly, since they are requisitioned so seldom. Equally important is the fact that most of all FSNs requisitioned are requested very infrequently--other tests show that the infrequent requisitions also tend to be for low numbers of units of issue. For example, in the data base we have been discussing about 4.5% of the requisitions of the total submitted were for FSNs with less than two movements in six months and these requisitions created about 2% of the total units of issue demanded. Yet 71% of the active records in the combined Force Logistic Command balance files had fewer than two movements.

Thus, these low-no demand items pose a severe problem in FMF support especially in the objective area. They very greatly extend the number of lines which must be carried if full direct local support is to be rendered. This compounds the inventory control problem, warehousing problems, inflates lift requirements and drains off personnel and equipment resources far out of proportion to the support rendered.

There is another important aspect to this problem. While the aggregated data behaves very normally and is predictable, the behavior of the individual line item in the infrequent demand category is not. In this category, which FSN will be required--when, is the actual problem. Certainly there are means to improve our ability to forecast individual line item demand behavior and we should continue to try to make these improvements. But pragmatically, the problem will remain a major one and means to mitigate its effect are important.

Our solution is to categorize the total spectrum of required items into demand categories and design subsystems to handle each of these according to its characteristics. There are four such categories: high demand repair parts and common hardware, other high demand items, critical insurance items and finally non-critical low demand items.

On this basis, let us now look at the Objective Area Distribution System revisions we suggested. Tracing the flow backward from destination to source, at the bottom are the various FMF user units, whose support is the very purpose of the whole system. Just up stream are the Fleet Stock Accounts in the Combat Service Support Element supporting the various users, and, of course, exterior to the objective area, is the Stores System and the other major suppliers to the FMF.

The high predictable demand items flow into the objective area to users via the Fleet Stock Account. These high demand items are scheduled into the area as a function of expected demand rate, shipping constraints, and the ability of the FMF to process it. They are issued to the users on the basis of demand. This high demand category of supply represents the great bulk of supply requirement.

However, a vital category of supplies not included is critical insurance items. These are the supply items that you do not really expect to use often but when the need occurs, not to have the item available would critically impair operations. Their identification may be laborious but it is straightforward. Now, by definition, these items are not required frequently nor in great number.

As a result, a few items can provide as much insurance as many, if visibility of the assets on hand can be maintained. On the other hand, if every unit carries its own critical insurance items, much duplication and redundancy occurs at little or no improvement in insurance. Furthermore, frequently these items are costly and their purchase reduces resources available for other support.

We proposed that a concept of an Insurance Item Minimum Stockage List (MSL) is the solution to this difficult problem of special low demand supply items. Where the need for the critical insurance items is peculiar to very few units, the MSL should be held by the using unit. On the other hand, where the potential use may be in any of number of units, in order to maintain visibility and reduce redundancy, locate the MSL at the appropriate Combat Service Support level where a few items can insure many units. Resupply is by high priority requisition.

Now within the category of high demand supply is a special set of supplies: repair parts (Materiel Identification Code-Bravo) and common hardware (MIC-KILO). Our Viet Nam experiences clearly indicate that these items require special treatment since they are a major key to equipment availability. These FSNs have several characteristics. In total, they represent a significant fraction of the total line items. Yet for the most part, each repair part and to a lesser extent, each piece of common hardware, has a specific application and if you have packed a part for a piece of equipment which is subsequently replaced by another model, the original repair part is worthless to you. Another characteristic is that, regardless of how they are requisitioned, parts tend to be used in relatively small numbers of units of issue at a time. Moreover, they tend to follow the general pattern of the whole population of supply items, i.e., a few items represent most of the demand and the balance are used with much less frequency, although each need is an important one.

As a result of these and other factors, we proposed that repair parts and common hardware be handled as a special subsystem of moving supply items. For selected items of high and frequent demand, each using unit holds a moderate supply level of repair parts and common hardware. This, sufficient to maintain productive repair operations. The balance of the items would be held in Fleet Stock Account over-the-counter issue points - with the number and location of these points appropriate to the local situation. By consolidation at the Fleet Stock Account, much improved visibility would occur - in fact SASSY (The Supported Activities Supply System) moves in this direction - and as a result fewer parts would support a larger population. Over-the-counter issue would reduce to a minimum the requisition response time so as to minimize the equipment deadline, improve repair operations and maintain user confidence. It would also have the effect of improving FSN identification at the time of issue. This procedure would also make possible a reduction in inventory control and supply accounting requirements if the issue points were treated like shop stores activities.

Now, remaining, are the vast number of supply items whose requirement is not immediately critical to continued operations, but which are required randomly, and usually in small numbers of unit of issue. It seems clear that these items do not belong in the objective area. In their aggregate, they represent a vast burden but individually do not contribute significantly to the Force. A relatively shallow depth of items for each FSN would support the entire Marine Corps at any point in time. Maximum visibility is required and most advanced inventory control and warehousing is needed for this category of demand. Accordingly, we proposed that these items be retained in the Stores System. Upon need the users needs are requisitioned directly to the Stores System by the SASSY Management Unit which records demand in order to recognize changed patterns of use. The Stores System then provides direct to user with an expedited delivery system appropriate to the stated priority. Our report shows that only a few hundred tons per month of expedited shipment would be required to handle these items. For example for a single MAF all transactions for FSNs with three or fewer movements per six months would generate an average requirement for shipment of about 110 short tons or 181 measurement tons per month and would reduce stockage in the objective area to only about 8500 Requisition Objective (RO) line items. These proposals are the subject of further study by the Marine Corps prior to implementation.

Now let's move backward in time and geography and examine that part of the Pre-D-Day Materiel Distribution System occurring prior to deployment. Incidentally this phase of the system is the usual state. It is here that we must bear the cost in manpower, dollars and other resources to maintain readiness for an uncertain deployment at an uncertain time. For this reason, as well as for effectiveness at the time of deployment, the pre-deployment procedures of FMF support must be as close as possible to the procedures planned for subsequent operations.

Begin with the Mount Out. These are the supplies now carried in by the individual units on D-Day. Our Distribution Analysis indicates that it is imperative that a significant level of preplanned stock be in the vicinity of the supported units, ready for movement when they move. A major problem in determining Mount Out composition is that FMF ground equipment, for the most part, is not operated in a similar fashion in the Force in Readiness mode as it is in combat. Otherwise, the method of constituting Mount Out from operating stocks that is used in aircraft support systems would be a most attractive method of calculating Mount Out for the entire FMF. If this could be done, a great deal of uncertainty in determining what should be provided could be eliminated. Unfortunately, this is not the fact and estimates both for range and depth of support continue to be required. However, one revision in current Mount Out policy could make a contribution to the solution: plan to mount out units with their operating stocks, screened of course to eliminate items peculiar to the garrison and unneeded in the objective area. Several advantages immediately occur. The operating stocks provide insurance against unavoidable mistakes in the contingency-planned Mount Out. For example, they reflect the repair parts appropriate to the actual equipment held by the units. They extend the depth of supply afforded early in the operation at no additional resource costs since they are already brought out of the Stores System. This is the area in which the individual unit commander is most competent to exercise logistic discipline and demonstrate logistic responsibility by maintaining his operating stocks current. This policy would promote more accurate lift requirements projection with least last minute adjustment at time of mount out because most of the op stocks may well mount out in any event. Adoption of this policy implies that op stocks be maintained in working containers ready for embarkation.

Second, we propose that as a matter of policy, most of the mount out supplies be held at the appropriate Combat Service Support level. This consolidation would serve several purposes. It reduces the proliferation of effort required to maintain the stocks in store. It recognizes the fact that most of the Mount Out usually is returned to the FSA after deployment and at the worst time to adjust inventory and storage records. And, because such consolidation eventually is required in order to reflect the fact that forces mount out in task organizations, not necessarily in whole units.

The third revision to the Mount Out phase of the Pre-D-Day Distribution system is to institute precalculated blocks of Mount Out appropriate to planned operations. FMF commands now regularly constitute a variety of blocks per task groupings but another stratification is required to place these blocks in consonance with planned operations - specifically that different levels of different supplies are planned for Assault Echelons and Assault Follow-On Echelons. Further, as seabasing becomes the rule, the 30 day basis for blocks becomes less realistic because of different replenishment cycles.

Replacement end items of Mount Out probably should be designated as a protected level of Operational Readiness Float of replacement equipment.

Fourth, we proposed that selected replacement end items be withdrawn from the Supply Center Ready Lines and introduced into an expanded Operational Readiness Float at the appropriate maintenance activities if there is any doubt that the Supply Center can meet withdrawal time requirements. Several reasons sponsor this suggestion. A major potential bottleneck exists at the Supply Center Ready Line and in transportation to Ports of Embarkation, if simultaneous withdrawal of several MAFs is implemented. Further, for items in scarce supply, there is a strong possibility that limited substitute items might be issued, thus vitiating Mount Out support planned for another model.

In addition to circumventing these potential problems, some positive advantages to the FMF could obtain. Improved overall equipment readiness at any point in time should result from the expanded float. With more frequent use, the equipment should be in better condition for combat than that hastily prepared for shipment. Now, it is recognized that this policy would obtain these advantages at a cost, mostly in increased demands on FMF personnel and facilities. Revision to current float issue policy would probably be required and constant maintenance discipline would be necessary to prevent buildup of equipment deadline. On the other hand, these costs, part of the cost of maintaining a Force in Readiness, would make an immediate contribution to FMF readiness and response times and a longer range contribution in improved base of service support.

Finally, we suggest that the trend toward Seabasing will have an effect on current Landing Force Operational Readiness Materiel--LFORM. Currently, we preload selected items of supply into operating amphibious squadrons, essentially based on requirements of a notional Marine Amphibious Brigade (MAB), in order to reduce Mount Out time and prevent loading and offloading materiel with each change of afloat unit. The concept appears to remain essentially sound. In the future, however, as afloat basing and support from afloat become standard, a careful and periodic screening of LFORM will be required, since there will be greater competition between LFORM and other requirements of the embarked forces for limited space. At a minimum, each deployment will require balancing the LFORM with the Mount Out requirements of the embarked Force, offloading and adjusting to assure responsive stocks of issue loaded materiel.

Let's examine, now, proposed revisions to the Withdrawal element of the Predeployment phase of the Pre-D-Day Materiel Distribution System. These revisions apply to procedures within the Stores System at the time the Pre-D-Day System is activated and supplies are withdrawn from the Preposition War Reserve Stocks in the Stores System for support of deploying active FMF forces or mobilization of IV MAF.

In order to establish that precalculated flow of high demand items into the objective area Fleet Stock Account which was discussed a moment ago, we proposed that withdrawal should be precalculated for appropriate task organizations, as they are currently, but with a significant difference. This would be a schedule of materiel shipments, stratified by demand patterns, with withdrawal increments constrained by time required for withdrawal, shipping schedules and availability, and the ability of the Combat Service Support Element in the objective area to accept the materiel. These precalculations will provide a basis for FMF validation of planned support and logistic feasibility. Our final report furnishes an algorithm by which to make these calculations. Briefly, it minimizes stock outages in a supply list that must conform to given constraints. It is from the classic KARR-GEISLER KNAPSACK Algorithm. We have adapted this classic procedure to use approximation techniques that reduce the formidable number of calculation steps required to obtain the exact solution and the necessity to completely recalculate the entire list when any change in any of the parameters occurs.

Now, a very real potential bottleneck exists at the Stores System level if mobilization requires the simultaneous withdrawal of several MAFs, and is especially critical, if this coincides with withdrawal for mobilization of the Marine Corps Organized Reserves.

One of the project tasks was to produce and run a simulation model of the Marine Corps Supply Center withdrawal process. The specific findings of this experiment are not appropriate for this meeting but generally we found that a high degree of prepackaging and preservation was imperative to meet the required schedules. Accordingly procedures to mitigate this bottleneck are in order.

Our analysis of alternative shipment modes indicated that compared to conventional break bulk surface shipment, use of containerized surface cargo shipments would result in about one and two thirds more responsive a system; the use of air shipments would yield two and a half times improvement. Unfortunately neither of these systems are always appropriate for support of Marine MAGTF.

We proposed that selected items of withdrawal for either active Forces and IV MAF be withdrawn and prepositioned at the Remote Storage Activity (RSA) in the vicinity of supported force. The selection criteria should emphasize usefulness of the materiel in the Force in Readiness and long shelf life. This procedure is especially attractive for Integrated Manager Items since this is a method of prepositioning these items at a location that permits stock rotation. Such prepositioned materiel should be containerized for minimum care in store and stratified so as to permit stock rotation without destroying the entire block.

With the revised Materiel Distribution System thus defined, we turn to the other major element in the Pre-D-Day System, the Materiel Requirements Determination System.

This is the system element that must assure assets required by the FMF are actually available at the time of need. The Logistic Guidance currently defines this asset level in terms of Division/Wing months, with one level for two active MAFs, another for the other and a third period for the reserve MAF. The major uncertainties of forecasting range and depth of items required in the future must be faced here. At the same time, the major readily identifiable dollar costs of the Pre-D-Day System occur here. Thus the tendency to over-estimate requirements in order to forestall uncertainty, rapidly comes up against the constraint of budget dollars.

Our proposals for revising this system are chiefly aimed at improving the methods by which we calculate requirements but they also provide for necessary modifications because of budget constraints and permit assessment of the effect of the constraint on support level.

As you know, we currently calculate the PWRS by estimating 30 days usage and then multiply this requirement by the total number of months of support. This assumes a rather precise knowledge of requirements and also that all usage occurs in thirty day increments. Neither assumption is valid. As a result many items are overestimated and many required ones are completely thrown out of the requirements determination list. Costs are inflated and support depreciated.

Our first suggested revision to the Materiels Requirement Determination System is that this 30-day-block-approach to requirements determination be abandoned. Instead, requirements should be calculated on the basis of the entire support period planned for the PWR segment supporting a particular Force, say 180 days. By this device, high demand items will be calculated on the basis of expected and predictable demand and be regularized. Lower demand items will be covered but not replicated. Very low demand items of high criticality can be inserted to provide required insurance but do not enter the problem again since they are held by the FMF once procured. The range and level of assets required, then, is based on best estimate of total future requirements and is not confused with a schedule of distribution. Our analysis indicates that sizeable reduction will occur in numbers of items generated, which items taxed the system but did not appreciably improve support rendered.

Once these total requirements are determined, the assets should be stratified into demand categories to facilitate scheduling of procurement as well as withdrawal and distribution.

Our study of the problem also brought us to propose that the requirements determination process, including Mount Out, should be centralized at FMF Headquarters level. Certainly subordinate commands are a part of the requirements determination process, especially for Mount Out, but only at FMF Headquarters level is there sufficient capability to draw together the myriad facets bearing on the problem. This is an operational responsibility, and this is the senior operational level of the FMF. The FMF Commander is the link between Mount Out and the Stores System PWRS. It is only at this level that all of the operational plans of the Force are drawn together.

Review of these FMF generated requirements at HQMC is required to assure that meeting the requirements is within the capability of the Commandant in the light of Marine Corps wide commitments and requirements and priorities. This, since it is only at Headquarters that all of the constraints and requirements placed on the Marine Corps are known.

Finally, the requirements determination process must continue to assure that all cognizant levels of FMF command review the appropriate requirements generated. First, to assure adequacy of the requirement by intensive examination, and, equally important, to assure the continued logistic consciousness of each level of command. Changes indicated by this process must be reviewed and adjudicated at the next level of command thus assuring that valid changes were made for all similar units. Current indications are that a good part of this review is being made today, but adequate feedback does not always reach the I.C.P. and thus the effort is wasted.

Now, once total materiel requirements have been determined, a major problem still exists in scheduling procurement to attain the required asset position. In the era of constricting budget levels, this problem has many ramifications. We propose that procurement priorities be determined by demand projection of the various categories constrained by budget level.

The modified KARR-GEISLER Algorithm is an appropriate vehicle for this determination. By this means, the support level attained can be directly linked to dollar costs.

Now, in conclusion, let us summarize the major revisions we have suggested to the Pre-D-Day Materiel Requirement Determination and Distribution System for support of the 1975-80 era Fleet Marine Forces.

First, the revised objective area distribution system. High demand supplies move by precalculated flow into the Fleet Stock Accounts (FSA) for issue to users. Critical insurance items are provided by Minimum Stock Lists held by users if the insurance items are user peculiar and by the FSA if a variety of users require the insurance. To reduce requisition response time, improve visibility of assets, reduce redundancy and supply resources required, repair parts and common hardware are consolidated at Fleet Stock Account with over-the-counter issue points. And the wide range of low demand noncritical supply items are handled direct between the Stores System and the random user. By these devices, we have reduced the range and depth of supplies required in the objective area significantly, focused supply resources into manageable areas and improved responsiveness to the FMF users. And equally important, the system is as applicable to Seaborne Mobile Logistic Support as to support from conventional ashore support facilities. HQMC is subjecting these proposals to further study.

We proposed that the Pre-Deployment phases of the Pre-D-Day Materiel Distribution System be modified as follows. Mount out forces with their operating stocks. Consolidate most Mount Out at the appropriate Combat Service Support level. Precalculate increments of Mount Out, not only for task organizations, but for supply levels appropriate to planned operations. Provide replacement end items initially through an expanded Operational Readiness Float located in FMF maintenance units. And balance LFORM with Mount Out for Seaborne Mobile Logistic Support operations.

In the Withdrawal Element of the Pre-Deployment Phase of the Pre-D-Day Materiel Distribution System our principal proposals were: precalculate withdrawal to establish the scheduled flow of materiel into the objective area. In order to ease a potential bottleneck, preposition selected withdrawal at the appropriate Remote Storage Activity.

We proposed that the Pre-D-Day Materiel Requirements Determination System be revised by: calculating requirements on the basis of total period of support, and stratifying total requirements into demand categories for distribution and procurement. Requirements determination should be centralized at FMF Headquarters level, reviewed at HQMC for Marine Corps wide policy and priority consonance and at all FMF command levels for validation. Finally, procurement priorities should be established on the basis of demand projection constrained by budget.

Our final report consists of two volumes. Volume I Analysis and Findings is Secret AD524394L and Volume II containing a description of the algorithm for constructing the Table of Supply under constraints and the simulation of the Supply Center withdrawal system is Unclassified AD907741L. Distribution control is by CMC (Code AX).

REPLACEMENT UNIT/REPAIR LEVEL ANALYSIS MODEL

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The evolution of management theory since World War II has been greatly affected by the increased use of mathematical and statistical models in the decision-making process. Decision making can be divided into three phases: determine the need for a decision; develop alternatives; and determine the best alternative. Modeling has been used in all phases of the process, but the largest use has been to evaluate and select the best alternative. Generally speaking, modeling is used to simulate the behavior of a system over a range of conditions, thus providing a means to evaluate the alternatives. The advent of the computer age extended the use of models to problems which are too large for manual treatment.

Models in varying degrees are abstractions of a real-world system. A model permits the analyst to study a system under varied and controlled conditions much more readily than he can study the real-world system itself. The model is a means of structuring a system which enables one to answer certain questions about the system through proper manipulation of the model. The ultimate value of any model is its ability to predict conditions within the real-world system. Models provide one of the more effective means for predicting performance. The use of models during decision making provides managers with a way to view alternatives without actually putting a strain on the system. The model described in this paper is designed to provide logistics support planners with the ability to predict support requirements, thus improving the quality of their decisions.

The Replacement Unit/Repair Level Analysis Model (RURLAM) was developed as a part of PROMAP-70--Program for the Refinement of the Materiel Acquisition Process in 1970. This was a program pursued by the Army Materiel Command aimed at improving the materiel acquisition process. One of the tasks under PROMAP-70 was to reduce the requirements for logistics support resources and systems changes by integrating the elements of logistics support into all phases of system acquisition. The Army Management Engineering Training Agency (AMETA) was asked by the Integrated Logistic Support Division of the Directorate of Maintenance, Army Materiel Command, to define the parameters and design an analytical model for determining an optimum replacement unit and repair level of a weapon/equipment system while considering tactical deployment, system availability, maintainability, and reliability.

The Replacement Unit/Repair Level Model is an analytical type to be used early in the weapons life cycle when all vital information needed to make an extensive study is not available but where decisions regarding logistics must be made. The model is intended to be used in a comparative manner; that is, the decisions are between two or more alternatives. As more information becomes available and used in the model, the information will more closely approximate the results of other forms of analysis. The model is designed to accept a minimum amount of information such as would be available during the Contract Definition Phase of the weapon/equipment life cycle, yet provide for using more detailed information as it is developed. It should be pointed out that the mainstay of the model is failure rate information. The analysis is performed at the level of assembly for which a failure rate has been determined. When only a failure rate for the total system is available, an allocation to major assemblies will need to be undertaken. The model does not allocate the failure rates. If failure mode analysis is to be performed, a failure rate for each mode will be needed. The subassemblies and parts at levels below the failure-rated assembly are treated as parts consumed and are considered by applying the properly weighted usage factor.

The Replacement Unit/Repair Level Analysis Model is intended to aid logisticians and engineers in making decisions relating to the weapon/equipment system configuration by providing maintenance and logistics support information. The model provides three basic types of information: the repair policy, the maintenance configuration, and the logistical support posture. Equipment designers may use the model to determine whether parts should be "throw-away" or repairable, or to test the sensitivity of design parameters such as failure rate, weight, and cost. The model provides the maintenance analyst with information about the level(s) at which assemblies should be replaced and repair work performed, the expected maintenance cost and maintenance downtime, and quantities, locations, and costs of repair and replacement parts stocked.

The Replacement Unit/Repair Level Analysis Model permits consideration of equipment to varying levels such as the end item or equipment level, the assembly level, and the part level. Assemblies are considered to be units which may be either repaired or discarded. Parts are used to repair failed assemblies; replaced parts are discarded. As far as the model is concerned, equipment, assembly, and parts are merely hierarchies in the end item being studied.

There are three key parameters which are basic to the solution of this model: (1) maintenance cost, (2) equipment downtime, and (3) a stocking factor. The stocking factor may be selected to be one of the following: stock cost, stock weight, or stock volume. These parameters provide the foundation for the selection of the best maintenance policy. Initially, the user specifies which of the key parameters is to be minimized. One or both of the remaining parameters may then be constrained. Working within the constraints, the model determines a support posture which minimizes the specified key parameter.

The model recognizes that optimizing some variables such as maintenance cost or downtime, etc., at the expense of the remaining variables is an idealized solution. In order to provide a more realistic situation, there is incorporated into the model a two-variable constraint option. The user is allowed to minimize or constrain annual maintenance cost, maintenance downtime, and stocking factor. The stocking factor represents the assemblies and parts needed to effect the repairs. It

Replace Only Mode

	Replace Level				
	ORG	DSU	GSU	PCS	DEP
Assemblies Stocked	x	x	x	x	x
Assemblies Not Stocked	x	x	x	x	

Repair Only Mode

	Repair Level				
	ORG	DSU	GSU	PCS	DEP
Parts Stocked	x	x	x	x	x
Parts Not Stocked	x	x	x	x	

Replace and Repair Mode

	Replace Level	Repair Level				
		ORG	DSU	GSU	PCS	DEP
Parts and Assemblies Stocked	ORG	x	x	x	x	x
	DSU		x	x	x	x
	GSU			x	x	x
	PCS				x	x
	DEP					x
Assemblies Not Stocked	ORG	x	x	x	x	x
	DSU		x	x	x	x
	GSU			x	x	x
	PCS				x	x
	DEP					

Figure 1. Maintenance Alternatives

can be, at the user's discretion, computed as the parts costs, parts weight, or parts volume, but only one can be selected and designated as the stocking factor. The user, when selecting his constraints, must specify the primary and secondary constraint along with the values of each. When the user does not select the constraints or fails to identify the value for the constraints, the program will select two constraints and set them at 10,000,000,000. If no constraint value is specified in the input data, the computer assumes the value is zero; therefore, it is necessary to set the constraint at a high value.

The model was developed keeping in mind the speed and ability of modern ADP equipment. It is programmed in Fortran IV for the IBM System 360 OS/MVT. The program consists of approximately 2400 instructions to analyze a weapon system of up to 100 assemblies; for each assembly, up to 500 parts may be considered. The program further restricts the user to no more than five levels of maintenance with no more than fifty locations at the lowest level, twenty-five locations at the second level, fifteen locations at the third level, six locations at the fourth level, and four locations at the fifth level.

The program allows a system failure to be corrected at any of the five maintenance levels; but once the level has been designated, then all locations (organizational units) at that level are allowed to perform the repair. The program, in selecting the best solution, does not allow for the performance of maintenance at more than one level simultaneously; it assumes that all the maintenance will be accomplished at the optimum level.

The basis used by the model for selecting the best maintenance alternatives is the expected maintenance costs and times computed for a one-year time period during the constant failure rate portion of the weapons system life cycle. The costs and times are computed by considering labor costs and times, transportation costs and times, parts costs, and storage costs.

The treatment of a <u>failure</u> as the "unit" for analysis allows the user to carry out more than one kind of analysis simultaneously. The user can code up the same assembly several different ways to observe the resulting effects. This gives the program the ability to perform failure mode analysis, repair policy analysis, and deployment analysis.

The model considers three maintenance modes. The repair only mode is defined to be repair of the assembly <u>on</u> the equipment. Therefore, the <u>entire</u> end item must be evacuated to the maintenance level where the <u>repair</u> work is done. The replace only mode is equivalent to what is termed "throwaway" or "discard" maintenance. The failed assembly is replaced with a good one from stock and the old assembly is discarded. The replace and repair mode is defined as replacing a failed assembly with one from stock, and then the removed assembly is repaired <u>off</u> the equipment. When the assembly has been repaired, it is placed in stock to be used in a future replace action. The repair may be done at the level of replacement or at a higher level. In the replace only and replace and repair modes, the entire end item is evacuated to the replace level.

Typical examples of each are illustrated below:

Replace Only - Seal beam headlights, glass windows, etc.

Repair Only - Minor vehicle body repair, tune-up, brake system repair, etc.

Replace and Repair - Carburetor, power steering pump, generator, etc.

The user exercises control over the modes by coding the assembly level cards for specific options of interest. The user may choose any level or levels for a replace only and repair only mode. For the replace and repair mode, the user can choose any level or levels for replace and any level or levels above and including the level of replace for repair. The program will not consider replacement at a level higher than the level of repair.

RURLAM cannot handle explicitly a "repair vs. discard" analysis for the equipment assemblies. However, this type of analysis can be performed in one run of the program by preparing two data sets for the same assembly--one coded for replace only and the other coded for replace and repair. The replace only set represents discarding the assembly on replacement; while replace-and-repair set is to replace the assembly and repair the removed one. The program treats these as two different assemblies; therefore, this type of "one-run" analysis should be done only when no constraints are involved in the determination of the maintenance policy. Also, end item support costs and downtime should be disregarded since they will include two versions of the same assembly. The "repair vs. discard" decision can be made by examining the annual maintenance costs of each version of the assembly.

The initial phase of the model consists of data input and calculation of the values of key variables corresponding to alternate levels of maintenance support for each equipment assembly. Data are read from punched cards and stored either in memory or on a peripheral storage device (disc or tape) for later recall. As the assembly, maintenance, and repair parts data are read into memory for each equipment assembly, the model calculates the key variable values. The first value computed is the expected number of failures per year for an assembly. This computation is based on failure rate, mission length for the equipment, and the number of missions per year. Next, the number of repair parts (if any) is computed on the basis of a usage factor supplied by the user. The model must next identify the type of maintenance to be performed on the assembly being analyzed: (1) replace the failed assembly (and discard); (2) repair the failed assembly; or (3) replace the failed assembly and repair it as a separate maintenance action. The user selects the maintenance alternatives--type of maintenance and level at which it is to be performed--through appropriate coding of the input data. For each maintenance alternative, the model calculates labor cost and time to perform maintenance on the assembly, transportation cost, and time to transport the equipment to the maintenance location (if required), and transportation cost and time to transport repair and replacement parts to the maintenance locations if the maintenance level does not stock such items. In addition to direct maintenance costs, the costs associated with purchase, storage, and transportation of repair and replacement parts is also considered and is included in the maintenance cost figures. The model also computes the total weight and volume of repair and replacement parts stocked. The results of the calculations for the assembly are stored on a peripheral storage device for later recall. The model then returns to read data for the next assembly and to carry out the required calculations.

The input requirements basic to this model are as follows:

1. Equipment/system identification including weight, number of missions in which it is expected the equipment will be engaged each year, and the expected length of each mission.

2. Identification of the maintenance parameter to be minimized and the specification of parameter constraints, if any.

3. Transportation costs and times.

4. Facility information, including name, organization level, name of next higher facility, distance between facilities, leadtimes for ordering repair parts, storage costs, labor costs, number of equipments supported, and stock objective.

5. Assembly and repair part information, including part number and name, failure rate, weight, storage space required, and unit cost.

6. Maintenance information for each maintenance level, including times to diagnose the difficulty, repair time, replace time, and indication of the type of maintenance (i.e., replace and/or repair) which can be done at each level.

The next phase of the model is the optimization phase. In the optimization routine, the maintenance alternatives for each assembly are sorted and arranged in order of preference in accordance with the key parameter to be minimized. The values of the key parameters for an assembly can be pictorially represented as a layer of data with the best option in front and the worst option in back, (Figure 2). The information which was calculated during the calculation routine and stored on discs or tapes is brought back into memory in layer form for each assembly so that all the information can be considered to be in a large cube where each assembly is represented as a layer of data as previously described, (Figure 3).

Following the organization of the data into the "cube," the model obtains an initial solution for the equipment/system maintenance configuration. The initial solution is obtained by adding together the values of the key parameters (maintenance cost, maintenance downtime, and stocking factor) for the best option for each assembly. In terms of the cube, this is accomplished by adding together the values from top to bottom in the front row. The resulting sums are the values of the key parameters for the equipment/system and represent the best or minimum solution ignoring the constraints. The initial (minimum) solution and its corresponding totals for the constrained parameters are

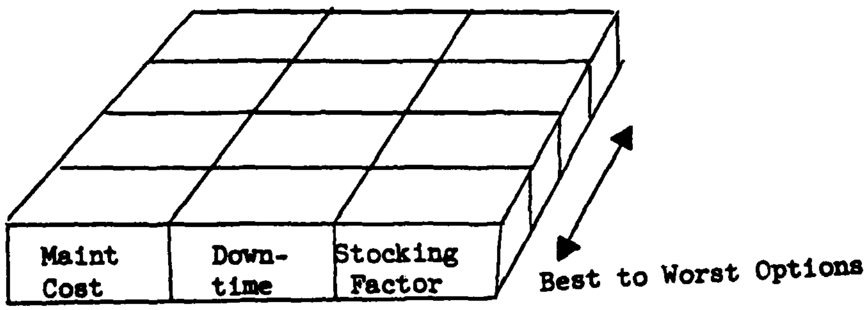

Figure 2. One Layer from Optimizing Cube

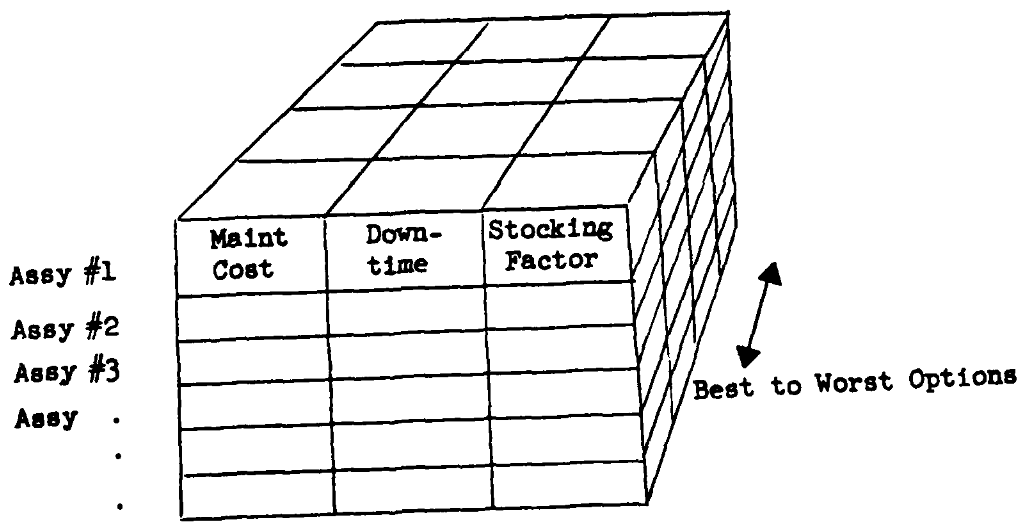

Figure 3. Optimizing Cube

to the user specified constraint values. If the constraints are satisfied, the solution has been reached, and the minimum solution is the optimum solution.

If the initial solution does not satisfy the constraints on the parameters, the model begins a search for a new solution which will satisfy the constraints and be optimal in terms of the key parameter being minimized. The procedure used by the model in searching for a new solution may be described as a stepping process. The model considers the difference between the best option and the second best option for each assembly. The assembly that has the smallest difference is selected for further checking, because if the second best option brings the constraint totals to within the user specification, the increase from the minimum would be the smallest, thus giving the best solution from a system point of view. In other words, the new solution is one which will have the least effect on the key parameter being minimized and the greatest impact toward satisfying the constraints. The totals for the minimized variable and constraints are then changed to reflect the new option selection. The new totals are compared to the old totals and the following rules are followed:

1. If the new totals are closer to the user specified primary constraints, the new option is selected and the old discarded.

2. If the new totals are not closer to the user specified primary constraints, the new option is discarded and the program returns to look for the next best untried option.

This process continues until the primary constraint is satisfied or all options from all assemblies have been tried and the constraint is still unsatisfied.

When the primary constraint is satisfied, the program advances to the secondary constraint selecting and trying options as before. One additional check must be made before a secondary constraint is selected; that is, the option must not force the primary constraint outside the user specified limit. The process of selecting options and trying continues until all options are considered or the secondary constraint is met. The selection of an option in this manner for each assembly results in an optimal solution for the factors under consideration.

The final phase of the model is the output phase. The user has the option of selecting any or all of five different output reports. These are: (1) Assembly Maintenance Costs, (2) Assembly Maintenance Configuration, (3) Labor Requirements, (4) Repair Parts Stockage by Level, and (5) Tool Costs. Each of these reports is described in paragraphs which follow.

The reports provided from each run are contained in a single listing. The first page is a cover sheet identifying the run, followed by the reports requested. The cover sheet lists the type of analysis and particular systems information considered when calculating and optimizing the assemblies being analyzed. It also lists objectives and constraints specified for this run, the total number of equipments supported, the total number of facilities considered, and the stock out probabilities.

The Assembly Maintenance Cost Report is intended to aid designers in determining the repair policy for a given assembly. It provides, for each assembly, the annual maintenance costs for all possible maintenance locations specified in the input data. The report includes the recommended maintenance alternative based on the objectives and constraints specified.

The Assembly Maintenance Configuration Report is intended to provide the user with a view of the maintenance configuration for the specified objective and constraints. The printout lists the assemblies, the maintenance levels, annual maintenance cost, downtime, lowest level of parts storage, parts cost, parts weight, parts volume, and tooling cost.

The Labor Requirements Report provides information about the total annual labor manhours required to perform both the diagnosing and repairing of a failure. This report is an assembly-by-assembly listing of the manhours required at each level, with a summary of the total manhours required at each level, with a summary of the total manhours at the end.

The Parts Stockage by Level Report is intended to provide the user with the range and level of spare parts to be stocked at each level. The report provides information about each assembly and the parts that are used to make the repair. It also provides the number of parts stocked at each level, the total number of parts stocked, the cost, weight, and volume of the stocked parts.

The Tool Costs Report is a summary of the tooling costs for each assembly at all locations where the repair can be made based on the maintenance configuration described in the Assembly Maintenance Configuration Report.

The computer program for RURLAM has been run successfully by the AMC Maintenance Support Center, as well as by USAMETA. RURLAM admittedly is not the ultimate model for replacement unit/repair level analysis. However, it is a viable tool that can be used to assist in level of repair analyses.

AD P00064

A MODEL FOR LOGISTIC SIMULATION (SIMLOG)

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BACKGROUND

Several years ago, in the process of analyzing logistic parameters for a fielded missile system, it was determined that feedback data from field experience is not accurate for simulation studies. The problem with such data is that demand experience not only reflects consumption but stock requirements, level adjustments and a combination of factors. Since consumption data based on maintenance failures is needed, a simulation model to develop such data was designed.

This model, termed SIMLOG, was constructed to input reliability data, or estimated maintenance incident rates (in the absence of actual failure data) in an equation including an operating time fraction, life cycle, and quantity of end items fielded to derive estimated failure data.

MODEL DEVELOPMENT

To develop the SIMLOG model three operational functions had to be simulated to establish the model. These functions are as follows:

Sub-System I End Item Deployment
Sub-System II Maintenance Failures
Sub-System III Component/Part Failures

Sub-System I records the distribution of failures by a random process to end items as deployed in the field. Once the end item failures are established for the life cycle, Sub-System II, by a random process, records the schedule of failures throughout the life cycle. These failures are attributed to a component or a part failure. This is recorded in Sub-System III which reflects the number of times each part failed and for which end item deployed.

In SIMLOG reliability is expressed as the probability that the end item will perform its intended function for a specified period under specific conditions. End item (EI) reliability is considered as the average of all component (C) reliabilities and component reliability as the average of all parts (P) reliabilities. This relationship for reliability (R) may be expressed mathematically as:

$$REI = RC_1, RC_2, RC_3, \ldots, RC_N$$

$$RC = RP_1, RP_2, RP_3, \ldots, RP_N$$

If the reliability of the end item is 0.999 per 1000 hours, the one failure per 1000 hours may be translated into a maintenance incident rate of 0.001.

Figure 1 shows SIMLOG development of failure data based on 10 failures of an end item. By translating component reliability into failures and random failing the components, the 10 end item failures can be attributed to components. In turn by translating parts reliability into failures and random failing the parts, the component failures may be attributed to the parts level. In Figure 1 the process is simplified to depict a single end item. In an actual study the requisite number of end items expected to be fielded is used. Based on an expected average operating time per year, over the system life cycle, a complete logistic analysis can be made.

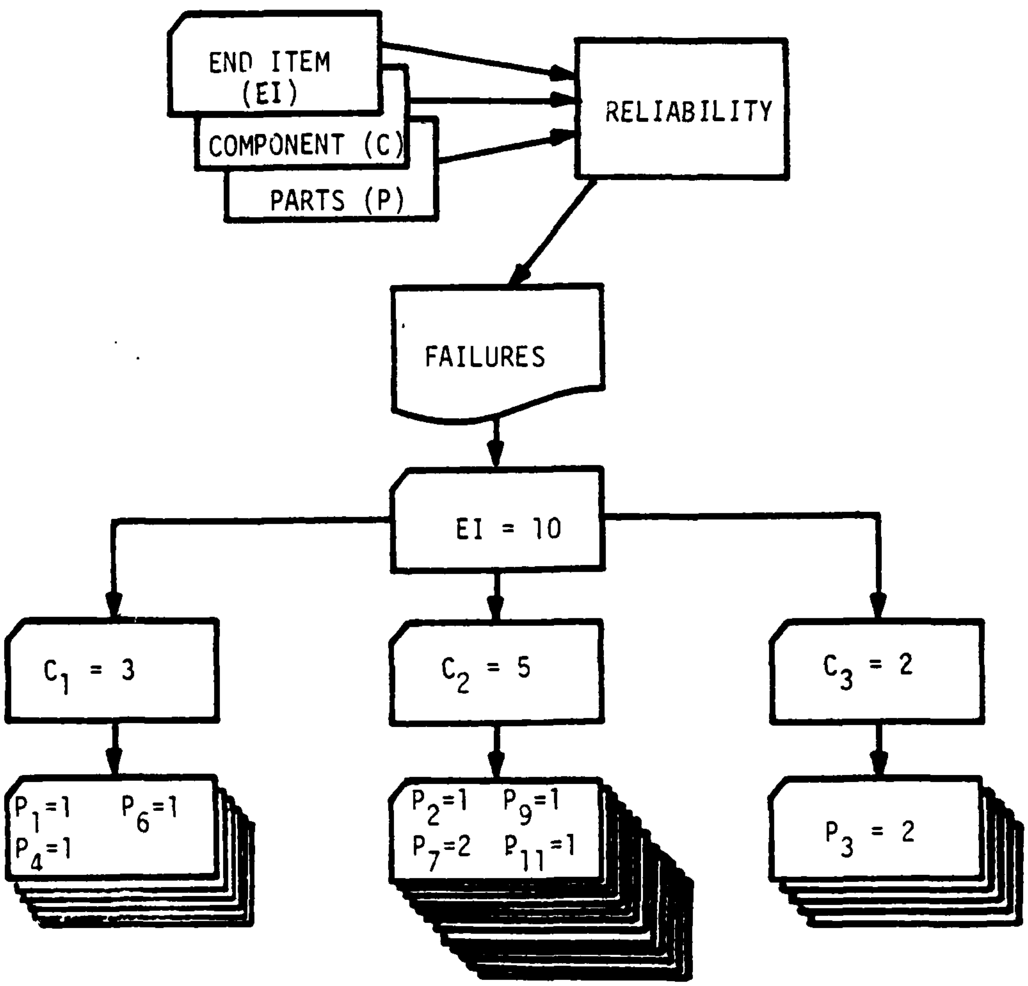

Figure 1. SIMLOG Development of Failure Data

A model of the above can be constructed as follows:

Given:

Maintenance Incident Rate (IR)
Operating Hours per year (HY)
Life Cycle in years (LC)
Number of end items fielded (IF)

The equation becomes:

IR[HY (LC) IF] = Life Cycle Failures

Establishing:

IR = 0.001
HY = 480
LC = 10
IF = 2400

The expected number of life cycle failures is:

0.001 [480 (10) 2400] = 11,520

This number of failures is meaningful in developing component and part type requirements. In a total provisioning analysis, 11,520 failures provide greater confidence in developing stockage and maintenance policy.

Figure 2 depicts the development of logistic support parameters. Based on maintenance incident rates, the failures of the end item, components, and parts are predicted. This failure data based on simulated field operations permit maintenance policies to be established; manpower for inspection, maintenance, and test determined; parts stockage quantities set; requirements for funding, facility, support and test equipment, transportation and handling estimated; and technical data and logistic management information developed.

LOGISTIC SUPPORT DEVELOPMENT

Manipulation of data collated in the three sub-systems permit direct development of the following logistic management functions:

1. The Maintenance Plan.
2. Supply Support.
3. Transportation and Handling.
4. Logistic Support Resource Funds.

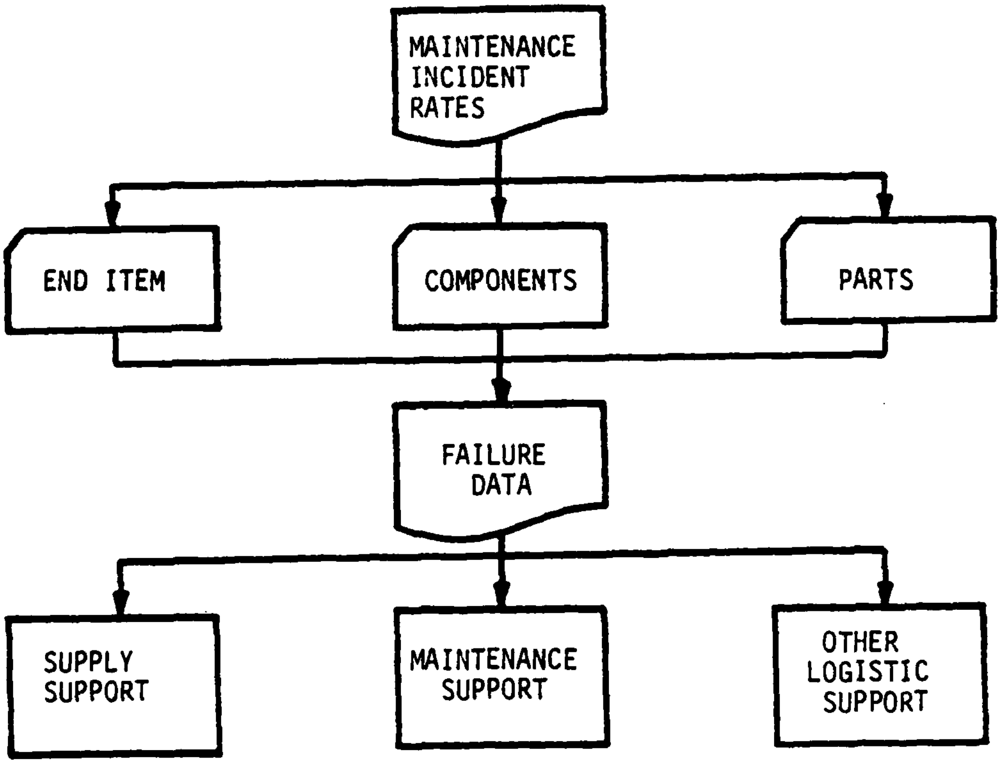

Figure 2. SIMLOG Development of Logistic Support Parameters

In addition, by analysis of the above output, the following logistic requirements may be determined:

1. Support and Test Equipment.
2. Technical Data.
3. Facilities.
4. Personnel and Training.
5. Logistic Support Management Information.

To achieve the proper balance between logistic management and performance, significant factors must be considered to establish the performance and logistic standard early in the design process. The LOCAM 3 model is an effective tool through which judgment and tradeoff analyses are performed to set the proper balance. The data developed in SIMLOG is translated into specific factors and through successive analysis and refinements a minimum cost support configuration with the required operational readiness is determined. Specification of the SIMLOG data for use in LOCAM 3 is required of the following general types of information:

1. Deployment factors: Number of systems, organizational structure, relation of groups, mobility, hierarchy and number of support installations, utilization rate of equipment, attrition rate.

2. Prime equipment factors: Equipment breakdown, failure rates, physical characteristics, construction (line replaceable units (LRU's), modules, subassemblies, circuits), cost per equipment/LRU/module, required availabilities.

3. Logistics Factors: Sparing policies (initial safety stock) supply times, production lead time, stockpile facilities, transportation factors.

4. Maintenance support factors: Test equipment characteristics/cost (manual, automatic test equipment (ATE), hybrid, built-in test equipment (BITE)), repair times, checkout times, manpower requirements/utilization/cost, test program cost, support equipment /BITE maintenance, mobility.

5. General Factors: Time period for cost analysis, escalation of manpower/equipment costs, anticipated growth, economic basis for analysis.

Through this model effort the following are answered:

1. Select a supply policy
2. Select support equipment
3. Pipeline development
4. Best transportation system and costs
5. Select optimum repair time and cost
6. Evaluate administrative costs of supply and replenishment systems
7. Establish manpower costs
8. Investigate cost effectiveness of alternative systems
9. Determine through sensitivity testing which input parameters are critical to system success.

The end item is broken down as shown in the hardware breakdown in Figure 3 and input data developed for parameters as shown in Figures 4 and 5. A flow network is then established in LOCAM 3 as shown in Figure 6 and logistic life cycle requirements and costs are derived. Through this model development emphasis is placed on integration of the support elements at a time when system engineering trade-offs can affect design and before hardware commitments. From the SIMLOG/LOCAM 3 output the following integrated logistic support (ILS) management functions can be quantified and costs derived.

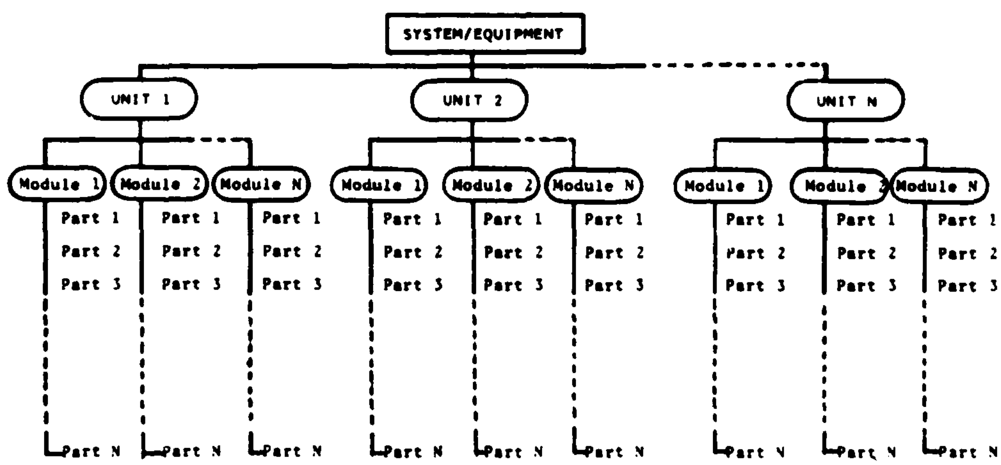

Figure 3. Hardware Breakdown

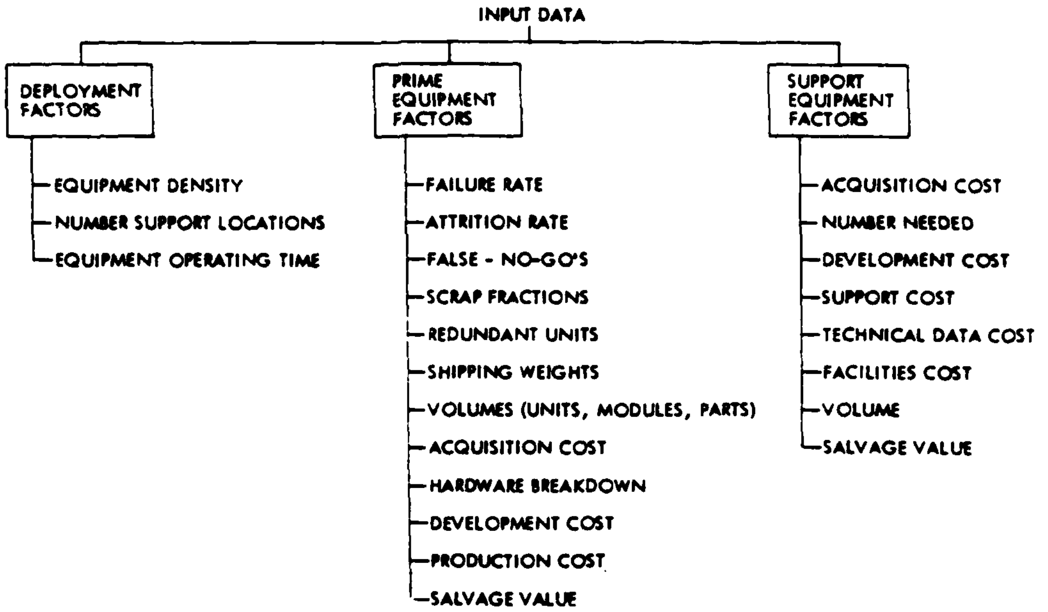

Figure 4. LOCAM 3 Input Data Equipment Factors

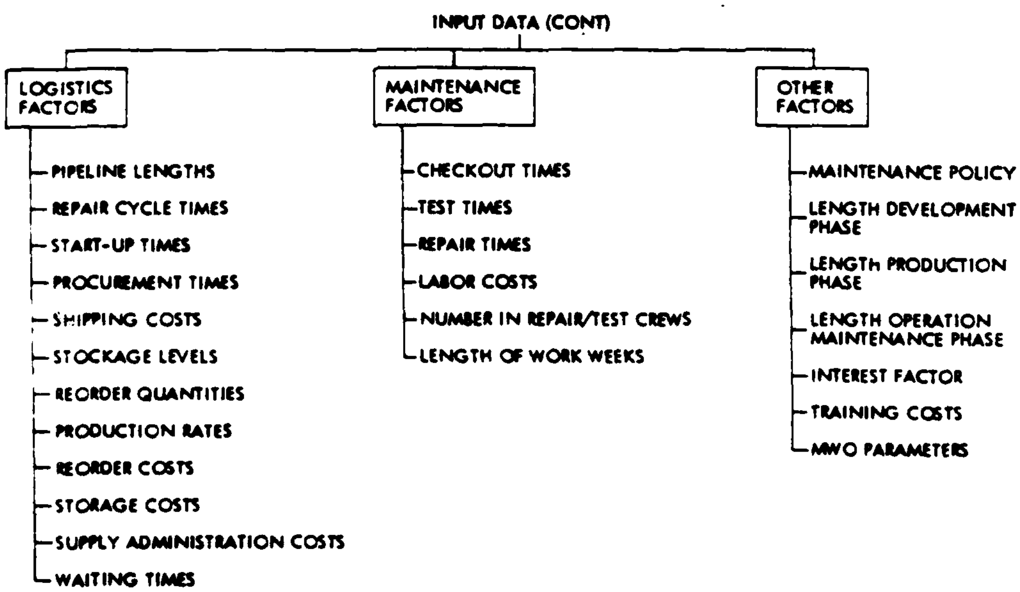

Figure 5. LOCAM 3 Input Data Support Factors

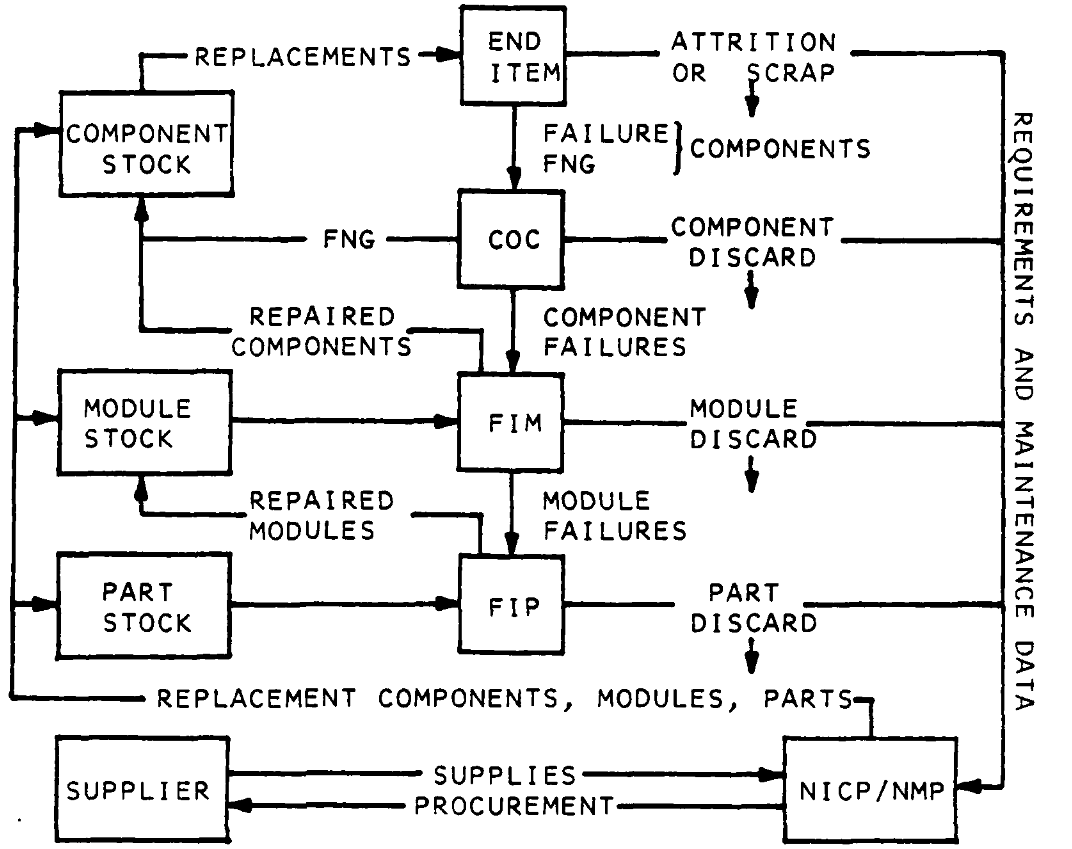

Figure 6. Basic LOCAM 3 Analysis Flow Network

MAINTENANCE PLAN

By quantifying maintenance requirements by deployment, tools and test equipment, facilities, personnel, spares and repair parts and technical data can be identified. By identifying the type maintenance required, skills can be established and facilities identified as to adequacy for utilization. Maintenance concepts and approaches can be defined and trade-offs established between support elements. By sensitivity testing, support deficiencies can be identified/analyzed to satisfy maintenance demonstration requirements.

SUPPLY SUPPORT

The projected maintenance failures down to the parts level in SIMLOG and establishment of alternative support structures in LOCAM 3 permit development of supply planning requirements. These include provisioning criteria and distribution planning. From SIMLOG, supply support assets utilization is known at any date. Changes can be made in distribution based on future procurement of end items or allowances adjusted for follow-on spares. Inventory knowledge permits control of changes with respect to records, reporting and reorder quantities.

TRANSPORTATION AND HANDLING

From the SIMLOG, development transportability and packaging criteria are developed, such as where shipment is to be made, locations shipped to, duration of shipment (air, ship, train etc.), volume, safety factors, security and fragility. Through the SIMLOG deployment the desired locations for transportation equipment and facilities can be established. The current system may be analyzed to establish availability of existing system capabilities based on quantity volume and location. Special transportation and handling procurement requirements and interface with other system design and support management functions may also be considered.

LOGISTIC SUPPORT RESOURCE FUNDS

By SIMLOG and development of cost parameters in LOCAM 3, logistic support funding requirements may be established for life cycle cost forecasting. These forecasts permit timely fiscal planning and appointment of RDT&E, PEMA and O&MA funds. Since the breakdown in the model covers program and task priorities, funds may be programmed for each logistic element based upon projected need. Through simulation of the total life cycle needs, more accuracy may be experienced in accounting of fund expenditures using work breakdown structure and measurement criteria to assure proper funds utilization and redistribution.

SUPPORT AND TEST EQUIPMENT

The support and test equipment requirements are established based upon maintenance failures presented in SIMLOG and support alternatives as proven in LOCAM 3. A development and acquisition plan may be proved for special and general purpose support and test equipment to include the following:

Adequacy and responsiveness of equipment design
Justification for each type equipment
Adequacy to accomplish maintenance functions
Cost to design, develop, procure and support.

The model permits introduction of such other features as the feasibility of automated test equipment versus manual test equipment, options for test equipment at DS, GS or Depot locations and performance of these options through sensitivity analysis.

TECHNICAL DATA

Based on the maintenance requirements and support operations simulated in the model, technical data may be developed. This includes data necessary to conduct operations, training, supply, repair and overhaul. Deficiencies in the system design can be identified and feedback to the model made to verify revisions in the simulated operational environment.

FACILITIES

Through knowledge of maintenance and supply, requirements facilities such as materials, power and communication, water access, roads and real property may be established. Support facilities planning can also be set up for personnel, training, storage, transportation and administration. The facility plan can also be defined in the following areas:

- Facility functional characteristics
- General and definitive design specifications and standards
- Detailed facility layouts for nontechnical support
- Funding, schedule, technical and management control.

PERSONNEL AND TRAINING

Requirements which may be ascertained from the model include:

- Development of manning policies and priorities
- Justification for personnel
- Interface of existing personnel and training
- New training required
- Training material preparation
- Training equipment needs
- Logistic support management information.

MANAGEMENT DATA

Information available from SIMLOG/LOCAM 3 model analysis includes:

- Maintenance engineering and analysis
- Engineering test and demonstration
- Program schedule and cost
- Maintenance management and failure data
- Requirements forecasts
- Personnel, equipment, supplies and facilities
- Configuration management
- Operational readiness support
- Supply management-effectiveness.

CONCLUSIONS

The SIMLOG/LOCAM 3 model development provides a flexible and versatile program which may be used to address all aspects of logistic support. It permits a close and dynamic working relationship between system design and support management. This relationship also permits repeated review and refinement of support requirements and their probable impact on design objectives, including operational readiness and performance characteristics. The model becomes a yardstick against which design and support can be defined in terms of assigned tasks and needs and can be evaluated in terms of finite measurements.

AD P000647

JOB SIMULATION AND PRIORITY SEQUENCING FOR DEPOT MAINTENANCE SHOP SCHEDULING

Mr. Richard Dalton

USAMC Logistic Systems Support Agency

Introduction.

The US Army operates a very large industrial complex of depots to receive, store, maintain, and issue US Army managed equipment. This is the wholesale type operations intended to supply the retail type operations servicing the troops.

This large complex consists of 11 major depots scattered at strategic locations throughout the continental US. Having been in operation for many years and with the advent of sophisticated ADP and communications equipments and techniques, a US Army Materiel Command central systems design agency has developed and is implementing a standard and integrated management system at each of the depots.

For the repair of the millions of US Army equipments and repairable piece parts which become unserviceable through extensive use or accidental damage, these depots, supplementive to commercial industry, operate large rebuild maintenance facilities, each hiring several thousand employees.

These activities are referred to as Depot Maintenance.

The Depot Maintenance Environment.

The management of vast resources of parts, materials, labor, and funds exceeds in complexity that of a comparable size manufacturing plant in industry.

A manufacturing plant must have a management system to include the ability to efficiently assemble raw materiels, piece parts, facilities, and manpower into a scheduled flow, sequenced to be procured and delivered in the time frame essential to produce the finished product as scheduled without interrupting the assembly of the finished product or unnecessarily tie up dollars in backlog inventories.

Depot maintenance management involves these same problems, but in addition, this management system must include the ability to arrange for the orderly flow of repairable equipments to be disassembled and reworked/discarded prior to the logistics problem of reassembling the raw materials, piece parts, facilities, and manpower to produce the finished product as scheduled.

The maintenance environment is one which encounters a multitude of unforeseen variables in its day to day operations.

A typical depot maintenance operation could have over a hundred work sections (centers) employing two thousand employees in support of a thousand different types of work (programs). Each work center could have available a variable number of man-hours, skills, work space, and special tools and/or test equipment. An individual work center could have the responsibility of supporting a hundred programs simultaneously requiring varying amounts of labor, skills, and test equipment. A maintenance work order could require the support of from one to nearly all of these work centers and require from one to a thousand measureable operations. In addition, there not only could exist a great variance in complexity between programs but between individual equipment (items) of the same programs. The sequence of work centers performing the repairs, the movement time between sections, the amount of parts/fabrication required, the man-hours, the types of operations, the delay times, etc., all vary with each item. Frequently the type and extent of repairs is not determined until an item has been inducted into the shops. Consequently a work center in the cost accounting network may be required to support one or many items of a program depending on the results of prior inspections and evaluations.

A maintenance Production Planning and Control (PPC) organization has the responsibility of managing, monitoring, and coordinating this highly variable operation at each depot. The US Army system designers, therefore, accepted a formidable challenge by undertaking the task to furnish depot maintenance PPC management with a tool to specifically provide both a daily work center schedule and appropriate and timely management information.

Chart A depicts the depot maintenance scheduling system as defined by the System-wide Project for Electronic Equipment at Depots Extended (SPEEDEX) and developed by the Logistic Systems Support Agency (USAMC).

Depot Maintenance Scheduling System Input Requirements.

Since depot PPC management must gather work flow and progress at the working levels, the data requirements of the Depot Maintenance Scheduling System have been kept to a minimum. Quantified descriptions of the depot's job flow constitutes a major portion of the input. Although this data is somewhat detailed, it is collected on a one time basis. Every maintenance job that is to be worked by the depot maintenance facilities must be evaluated and represented by a "PERT" type scheme. This PERT type representation depicts the flow of a job through the maintenance shops by indicating the sequence of work centers required to disassemble, repair, and rebuild a particular item. (See Chart B.) The unit man-hours, the normal cycle time, and the critical cycle time are also provided for each bubble (event). These times are based on historical averages computed for each workshop and updated on an as required basis.

The following definitions are useful in the explanation of the job route in Chart B.

- TWC - Type Work Center: Either an F, L, A, N, K, or Y in the diagrams of the PPC system designate the specific type of work center in the PERT process flow.

- UPC - Unit Production Count: A one-digit data element which provides the means by which a work center's contribution to production

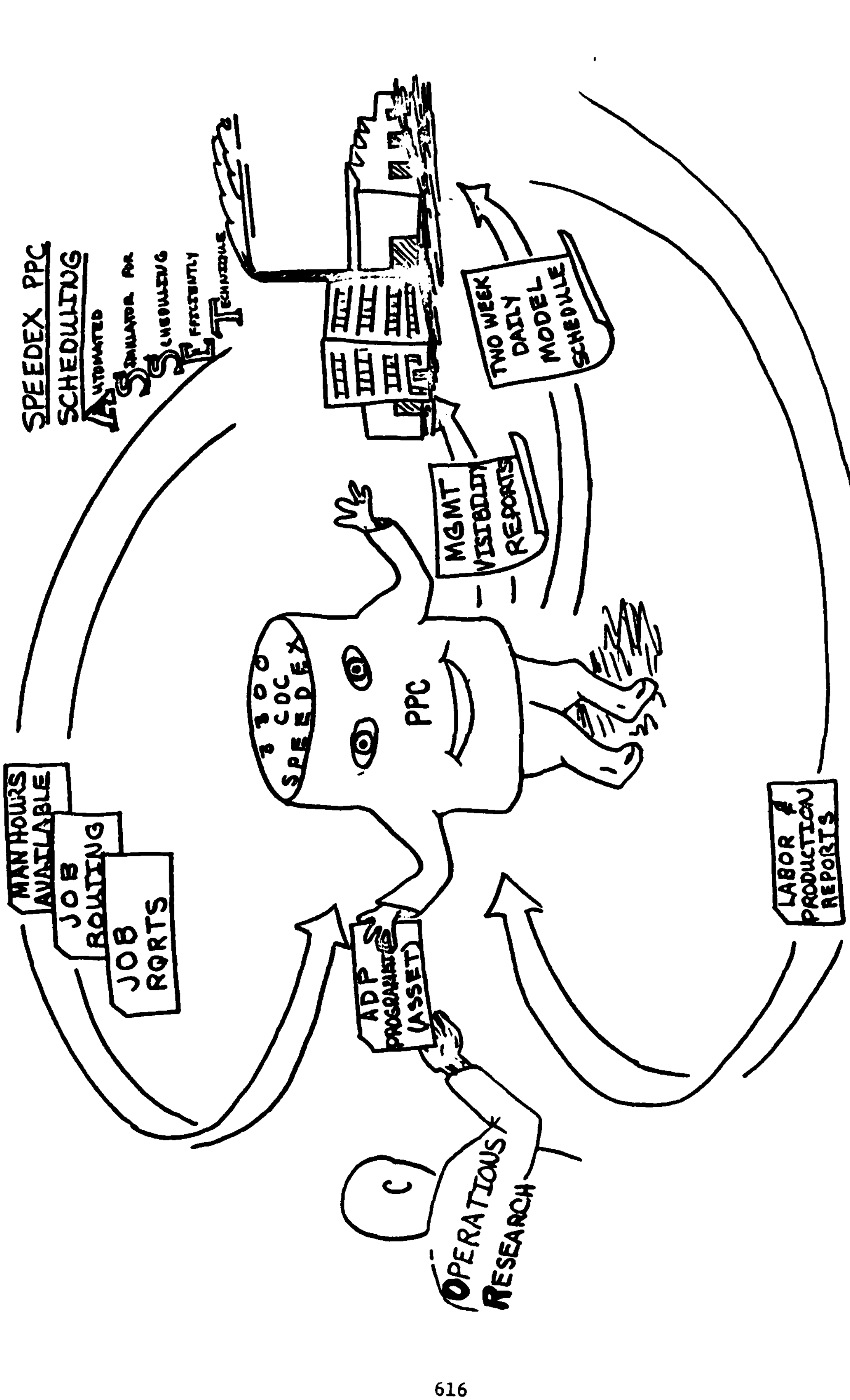
SPEEDEX PPC
SCHEDULING
AUTOMATED
SIMULATOR FOR
SCHEDULING
EFFICIENTLY
TECHNIQUE
MAN HOURS AVAILABLE
JOB ROUTING
JOB RQRTS
3300 COC SPEEDEX
PPC
MGMT VISIBILITY REPORTS
TWO WEEK DAILY MODEL SCHEDULE
ADP PROGRAMMERS (ASSET)
LABOR & PRODUCTION REPORTS
OPERATIONS RESEARCH

CHART A

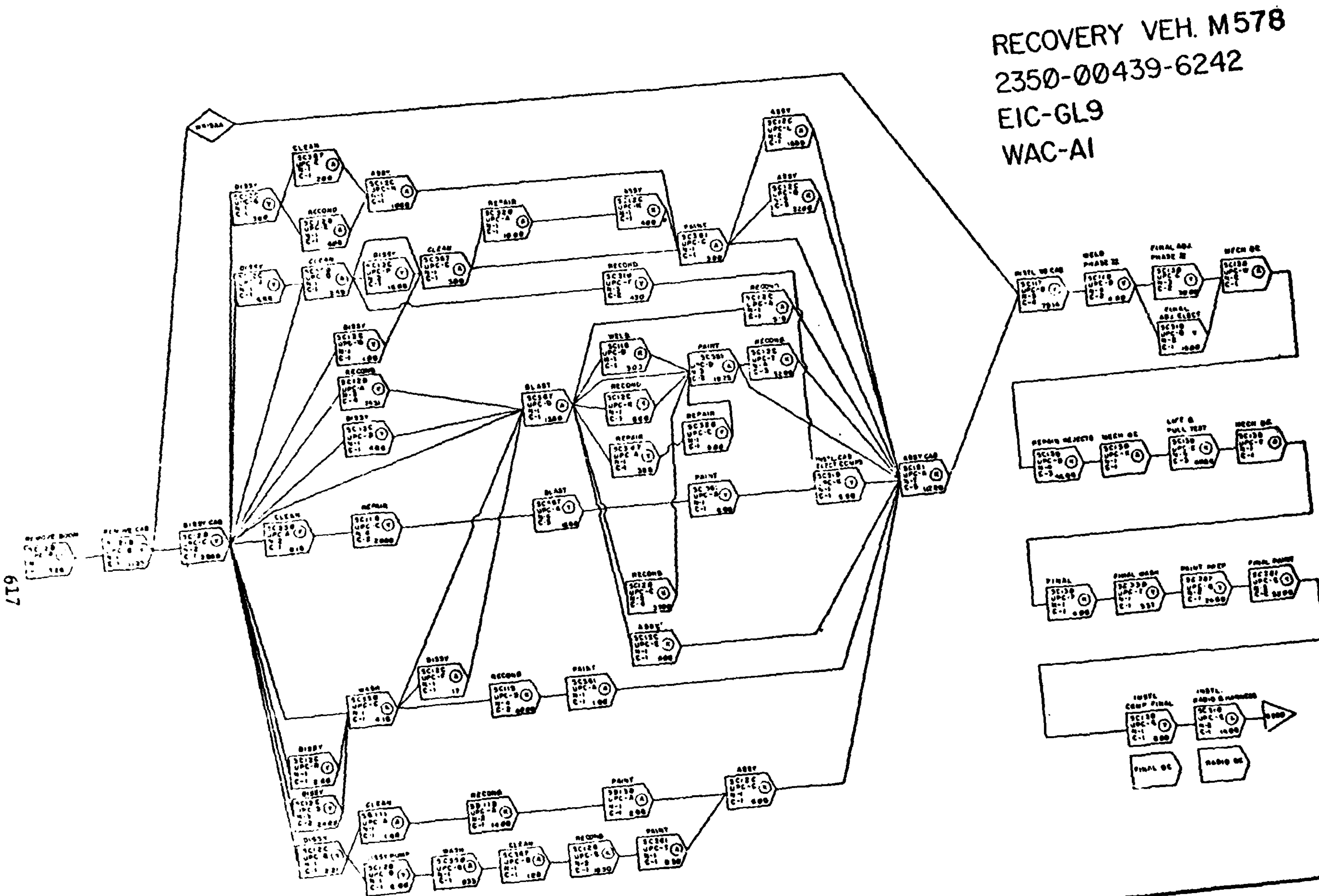

CHART B

may be broken down into individual process groups for the components and/or assemblies which the work center processes.

- N/C - Normal Cycle: The normal production time (days) required by a work center to perform a given work unit.

- C/C - Critical Cycle: The expedited production time (days) required by a work center to perform a given work unit.

- UMH - Unit Man-Hours: The man-hour standard designated to perform a defined work unit.

The different types of work centers that can be utilized in the construction of a job route are listed below.

F - First work center. Physically processes an identifiable production unit in support of each end item.

L - Last work center. Final processing of an identifiable production unit in support of each end item.

A - Work center which does not physically contribute a production unit in support of each end item or the contribution represents various insignificant efforts not economically feasible to control.

N - Area which can justify only minimum control.

K - Work center which serves as a knitting point to consolidate variable production counts.

Y - The other cost centers that physically process or contribute an identifiable production unit in support of each end item in production.

The size and number of "bubble charts" required of a particular depot varies according to its mission and work volume. A typical depot has developed over 1700 job routes ranging in size from 1 to 154 bubbles.

Monitoring work in process is accomplished by the daily collection of feedback data submitted by each workshop supervisor with labor and production (L&P) cards. The percent completion of work in a particular bubble is determined from the ratio of man-hours charged to man-hours required. The completion of each bubble is recognized when the proper operation code has been reported.

Man-hour availability data is required for each work center in the depot maintenance complex. The summation of all direct labor personnel at a cost center multiplied by an adjustment factor yields the available productive man-hours.

Gross schedules are established by month by national level management listing the job requirements priority and the scope of work to be accomplished. Based on the monthly job requirements, the specific jobs that must be in process for a work flow simulation period can be determined.

Depot Maintenance Scheduling Model.

The simulation process is developed around a FORTRAN computer program ASSET (Automated Simulator for Scheduling Efficiently Technique) and is operational on a Control Data Corporation 3300 configuration. The source deck contains approximately 1800 cards and a series of programmed overlays is required to execute the job. The FORTRAN scheduling model requires from 5-8 hours (wall time) to simulate the entire depot maintenance job flow for 20 simulated work days. Variations in the volume and complexity of the data combined with a variable mix of programs running in a multiprogramming environment causes a wide distribution in run times.

Since the computer is to prepare work flow simulations utilizing established queues and critical paths through successive and alternate work centers, the simulation model is run on the computer each week after the conclusion of Friday's business. By posting actual progress of materiel by work center to the computer schedule files prior to the simulation of upcoming work flow, the simulation process is based on actual experience at each Monday, AM and becomes increasingly theoretical towards the end of the week, Friday, PM.

Initially, the simulation event clock is set to day one and a list of jobs that should be considered on the first simulation day is compiled. The necessary data for each job are sorted and preliminary computations are made in order to reformulate certain elements of data. At this time various validation routines are initiated to purify and further refine the input. In addition, the monthly scheduled quantity, initial priority, desired job start date, rate of production, and job completion date are determined for each program.

The in-process work centers are determined by correlating the routing history data with the induction/production feedback data. The number of items in the work center queue is computed by an analysis of the production of both the work center and the ones which feed it. For example, a simple job route may exist with only two operations, represented by "F" and "L" type work centers. If the first had completed all 10 items for this month's schedule and the last hadn't completed any, it would be apparent that 10 items were in the queue of jobs to be worked at the last work center. The number of man-hours required to complete items, both waiting induction and in process is also computed for each job, by item, at all work centers.

An expected completion day based on the critical cycle times is computed for each item of every job. A comparison of the expected completion day with the desired completion day yields a positive or negative slack that indicates the status of that particular item. Therefore, several items for the same job could be in the shops in varying states of disassembly, repair, and assembly with each having a different slack. An individual item could be found simultaneously in process at several work centers following a prior disassembly and could conceivably have a different slack for each.

After all the depot maintenance job requirements have been examined, the work centers are scheduled one at a time from the queue of items determined to be waiting for completion. First the items in each work center queue are ranked according to a priority algorithym that takes into consideration initial job priority, slack, and if the job is in process. Chart C indicates the ranking of the work center queue of jobs. The job list is first divided into 3 groups based on the initial job priority assigned by higher command. The high 25% of the jobs fall into the first group and the low 25% into the last, with the remainder in the middle. These 3 groups are further segregated into 9 groups according to the slack of each item. A negative slack would indicate a slip condition while a positive slack would describe an item ahead of schedule. Each of the 9 groups are again subdivided with the items waiting to be inducted into one subdivision and those already in process in another. Therefore, the first group of items to be scheduled at a work center would be those items having the highest initial command priority, in a slip condition, and already in process. Next would be those items with a high priority, in a slip condition, and waiting to be inducted. The remaining groups would be considered in the order indicated in Chart C. The resulting 18 groups represent the ranking of the queue of jobs that would determine the priority of a work center resource allocation for a particular simulation day.

The jobs from the ranked queue are simulated to be inducted into the work center with man-hours allocated according to the man-hour standards and subject to a man-hour availability constraint. The maximum number of man-hours that can be allocated in one day for an individual item at a work center UPC level is equal to the average number of hours required per day to complete an item in the critical cycle time. As each item is scheduled, the remaining man-hours available are reduced until either no more man-hours remain or all jobs have been scheduled. At this point in time, a backlog of work or an underloaded condition can be recognized and identified for an individual work center for a particular work day in the future.

When sufficient resources (man-hours) have been allocated for a given item at a work center, it is a candidate for production. If the item has a slack equal to or greater than zero, the work center will be given a schedule to produce the item in the alloted normal cycle time. If the item has a negative slack at this particular work center, the production schedule will indicate a completion in a number of days less than the normal cycle but never less than the critical cycle. The flow of an item through the shops is, therefore, dynamically controlled with the model attempting to speed up items that are slipping while allowing items that are ahead of schedule to follow the normal time frame. After the inductions, completions, and man-hours have been calculated for all work centers in the depot maintenance complex, the schedule for day one is available.

The initial feedback information is then combined with the simulation results to obtain a revised job status representation upon which the next simulation day will be based. For example, suppose there were 10 items to be repaired by the two work centers in the simple example indicated earlier. The initial feedback indicated that all 10 items had been

RANKING OF WORK CENTER QUEUE

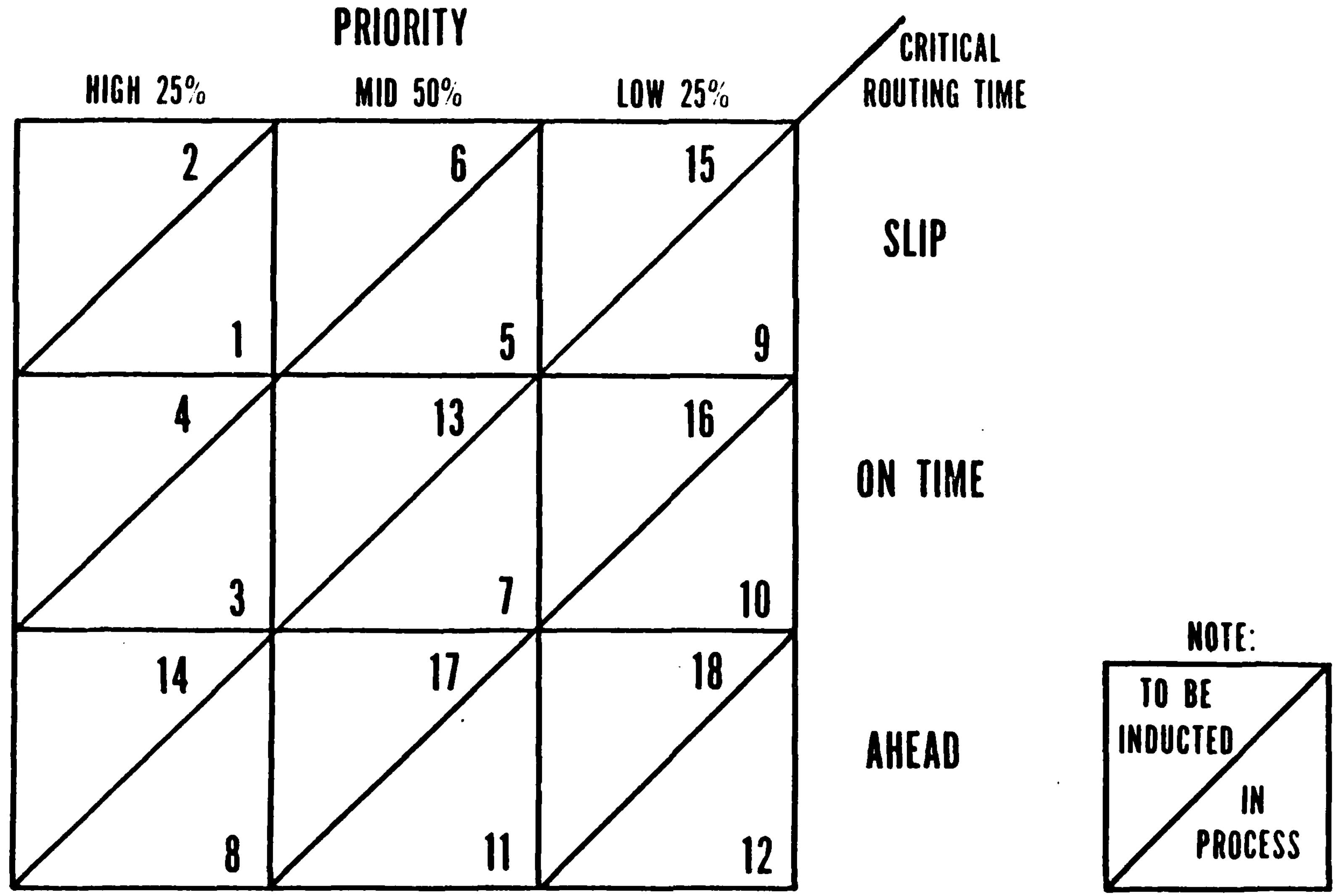

CHART C

completed in the first work center leaving 10 items in the queue of jobs to be worked at the last work center. If, however, six items were scheduled and simulated to be produced by the last work center on the first simulation day, only four items would remain in the queue of jobs for the second day. After all jobs have been updated to reflect the results of the first day's simulation, the event clock is increased and subsequent days are simulated in a similar manner until the desired time frame has been completed.

From the results of these procedures, a daily work center induction and completion schedule is formulated as depicted in Chart D. A separate listing is prepared for each work center supervisor and identifies the daily quantities of items to be inducted and completed, including the amount of man-hours to be expended during the next two weeks. In addition, many other items of data are included to aid the supervisor in the use of the report. While the listings reflect data for two weeks, it is prepared weekly with each new schedule superseding the prior product. Not only does the second week schedule indicate anticipated work, but it can in fact be utilized next week if the new schedule is delayed.

Conclusion.

Although the elimination of manual scheduling is a major goal of the PPC scheduling system, two additional reports provide management visibility of major importance in an efficient shop operation. The first identifies the jobs that appear to be in a slip condition during the simulation. The job status at each work center, the day the simulated slippage will occur, and a projected completion day is indicated. The second report is a summary of the man-hours loaded for each work center for each week of the simulation run. The man-hours available and any backlog of work is also available for each work center. Since the PPC scheduling system employes man-hours as a constraint, the effects of the reassignment of personnel can be simulated by varying the available man-hours at work center level. Therefore, if a particular job is identified as being in a slipped condition, the man-hours at the bottleneck work center can be adjusted to illustrate the effects on the next run.

Basically, the system is quite flexible and the detail of the data is left entirely up to depot management. If a requirement exists to schedule, control, and obtain management visibility at a very detailed level, the system provides the capability. The limitations, as one might surmise, are imposed by the availability of computer run time.

Presently, the scheduling system package is in the implementation stage at all eleven AMC depot maintenance facilities. The problems/lessons-learned encountered to date emphasize the importance of reliable feedback data and education of the user. Computer systems generally, and this system is no exception, can be considered only as tools. To obtain the benefits from any tool, one must fully comprehend its potential, acknowledge its limitations, and master its use. Even though depot maintenance simulation is in its infancy, the benefits and advantages are materializing as the system stabilizes through use.

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                                                                                                                     SCH-MHR
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E01Z88  A  E01Z88 A1  100037  M18D10850 0COMP       37       0   0   0   0   0   0   0   0   0   0   0   0   0   0    142
                                                                                                                     SCH-MHR
OP CODE BBAB                                    COMPL-TO-DT                                                          2ND-WK
TITLE REBUILD TUBE ASSY                              0       0   0   0   2   4   0   0   0   0   0   0   4   0   0     77


PROJ CONTR U1     STK-ITEM-NO 1025004454613     ITEM-NAME TUBE ASSY GRENADE    TYPE W-C F
                                                                                                                     SCH-MHR
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AD P000648

LOGISTIC SUPPORT PLANNING FOR THE IMPROVED COBRA ARMAMENT PROGRAM

Mr. Raymon S. Dotson
U.S. Army Missile Command

ABSTRACT

This paper is a treatise which discusses the techniques for evaluating logistic support alternatives as applied to the Improved COBRA Armament Program (ICAP). The objective is to develop methodology for generating quantitative data for cost analysis of support of the ICAP including deployment, equipment, supply, maintenance and test equipment factors. A deterministic model is described in terms of its versatility to evaluate many alternatives rapidly and inexpensively to include sensitivity testing. To this end support alternatives are tested to evaluate cost effectiveness and their worth based on quantitative results.

BACKGROUND

On 1 March 1972, the Chief of Research and Development, Department of the Army, approved contractual support and a cost-effectiveness study of adapting a Land Combat Support System (LCSS) for supporting TOW application on the AHIG (COBRA) Aerial Weapon System. The approval recommended that the study include a parametric analysis of the TOW/COBRA inventory levels.

The U.S. Army Missile Command (MICOM) Logistics Cost Analysis Model (LOCAM 2) was employed to provide visibility to support system requirements for the ICAP system line replaceable units (LRU) shown in Figure 1 which offer minimum operational cycle logistics cost and highest prime equipment availability. The major elements of support system costs include RDT&E, test equipment acquisition and development, pipeline investment, and operation and maintenance.

The application of the model in this study seeks to determine, among several alternatives, the lowest cost logistics support system for the Improved COBRA Armament Program. In addition, since it is recognized that statistical influences can be of significance and that at this point certain factors are imprecisely known, the sensitivity of support costs to variations in baseline data factors is obtained.

LOCAM 2 FORMULATION

The Logistics Cost Analysis Model used in this study is an outgrowth of several versions of the MICOM Computer Optimization and Analysis of Maintenance Policy (COAMP) Logistics Model. Acquired under contract, the model has been validated by MICOM and designated by Deputy Chief of Staff for Logistics (DCSLOG) for consideration as an Army standard for maintenance concept evaluation. It is currently in use by MICOM, Aviation Systems Command (AVSCOM) and Weapons Command (WECOM) and is included in the Department of the Army Support Model Reference List. Figure 2 illustrates the evolution of LOCAM 2.

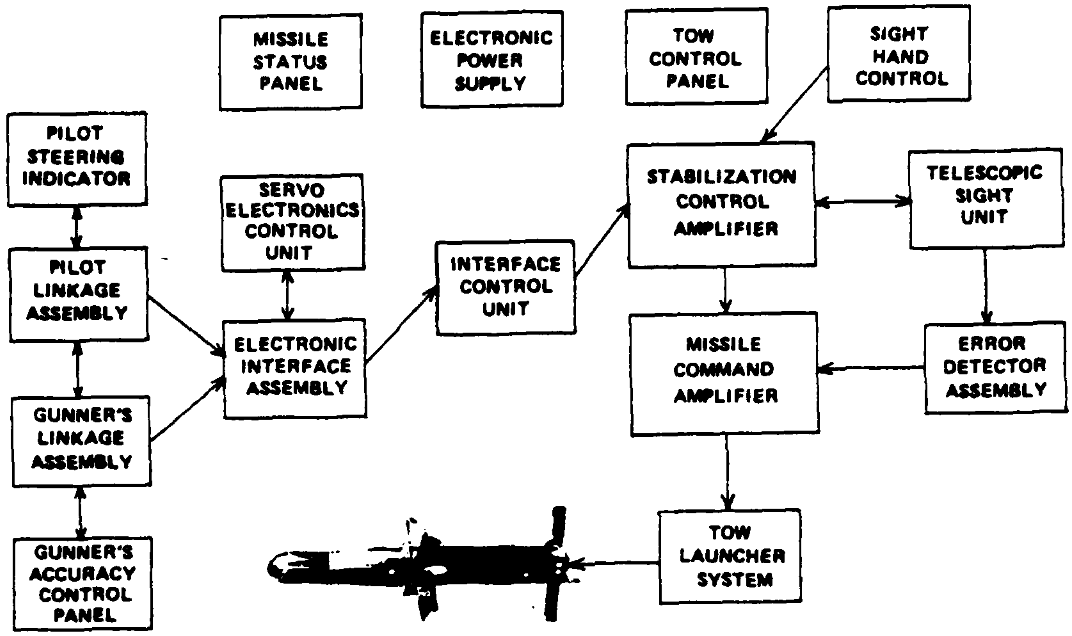

Figure 1. ICAP System Elements

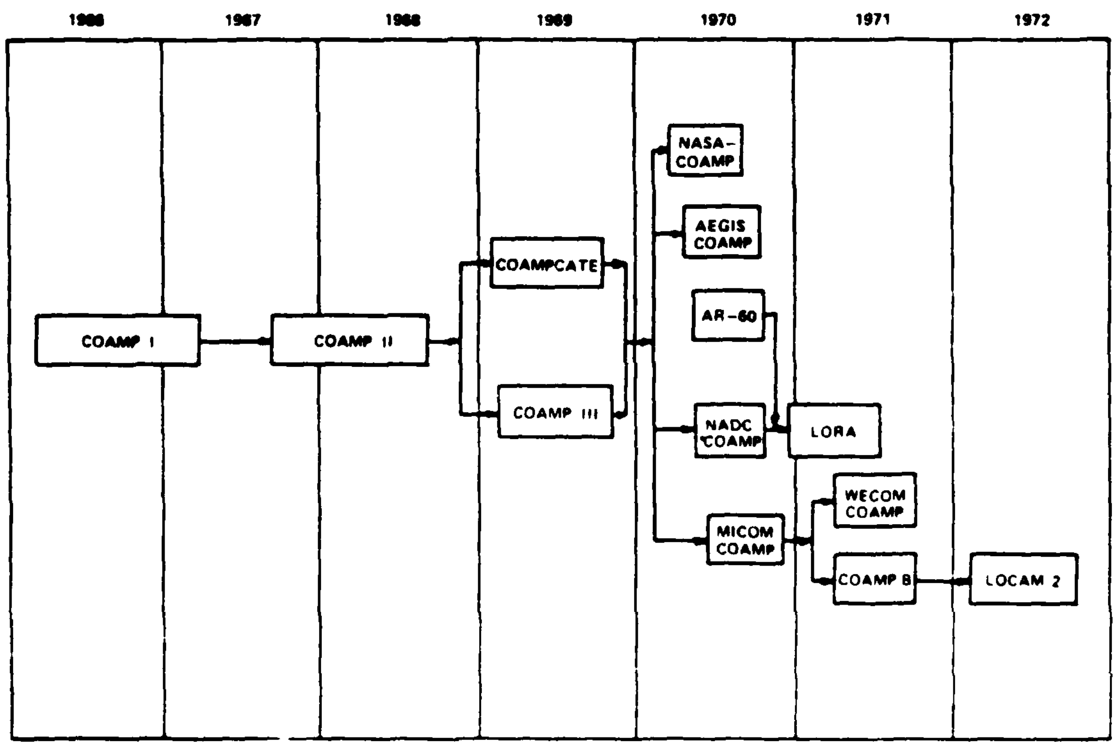

Figure 2. Development of Logistic Models Leading to LOCAM 2

In LOCAM 2 the total system is synthesized with its test equipment, personnel, support materiel, administrative functions, and such dynamics as pipeline times, repair turnaround, and maintenance incident rates. Each postulated maintenance system is asked to meet the weapon system support requirements and the response is calculated in dollar cost and impact on weapon system availability. LOCAM 2 calculates pertinent cost and operating characteristics of the support concepts. It does not evaluate or compare one policy with another. Using the information provided by the model, the study analyst can make deductions and judgments.

LOCAM 2 provides a framework for defining the maintenance concepts to be modeled. This framework is illustrated in Figure 3. The modeled maintenance flow is generic; choices must be made and specific inputs must be selected before the model can simulate a support concept. The maintenance function begins with a requirement for support, identified in the figure as failures, false No-Go's, attrition, and scrapped components associated with the prime equipment. Input data must define the maintenance incident rate, percentage of attrition, etc. Similarly, the posture being modeled must be specified as to the maintenance level (organizational, direct, general, depot) where components, modules, and parts are replaced. As these choices are made and descriptive input data assigned, the bare framework becomes a support posture.

The model operates on demand for support, that is, maintenance workload generated by the prime equipment as postulated in the model. Workload or demand is generated as a function of operating hours, expected maintenance incidents, number of operating LRU's, and false failure indications. The support equipment also generates workloads by virtue of its need for maintenance.

The demand for maintenance and for supply materiel is computed by subroutines which determine the number of operating equipments in real time as a function of the number of equipments, their operating time fraction, and their availability. Workload at a direct support (DS) test station is computed from:

The number of equipments operating in real time
Equipment maintenance incident rate
Test station testing rate for equipment, LRU's, and modules/subassemblies
Modification work order (MWO) workload.

Workload for each DS repair station is similarly and separately computed as are test/repair workloads at general support (GS) and depot. From workload calculations, LOCAM 2 determines the available time needed at each test station and where demand exceeds a set threshold, additional test stations are added, as well as personnel, and test station need for maintenance.

In calculating individual test station workloads, the flow of maintenance work throughout the postulated system is further defined by maintenance policy fractions which are designated as "G" factors. These input factors GS through GT must total unity so that all work is accounted for. These factors used for the ICAP study were as follows:

GE - LRU false No-Go screening plus repair at DS by module replacement and discard.
GG - LRU false No-Go screening plus repair at GS by module replacement and discard.
GS - LRU false No-Go screening plus LRU repair at DS, module repair at GS or Depot.
GT - LRU false No-Go screening plus LRU and module repair at GS or Depot.

The maintenance policy matrix for ICAP is shown in Figure 4.

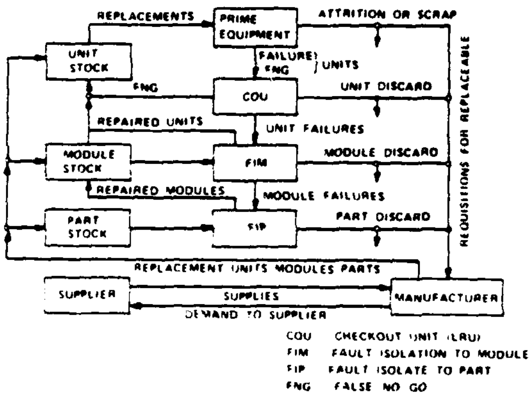

Figure 3. Basic LOCAM 2 Repair Flow Framework

FORWARDMOST LRU STOCK AT LEVEL I

SUPPORT LEVEL	POLICY DESIGNATION: GE	GG	GS	GT	
ON BOARD EQUIPMENT	x	x	x	x	LRU CHECKOUT
LEVEL I (OBM)	x	x	x	x	LRU DIRECT EXCHANGE
LEVEL II DS	x		x		LRU CHECKOUT
	x		x		FAULT ISOLATE TO MODULE
LEVEL III GS OR DEPOT		x	x	x	LRU CHECKOUT
		x	x	x	FAULT ISOLATE TO MODULE
			x	x	FAULT ISOLATE TO PART
DISCARD LEVEL	MODULE		PART		

Figure 4. ICAP Maintenance Policy Matrix

Basic apportionment of workflow is set by the inputs GE, GG, GS, or GT. Work is assigned to direct, general, and depot and provides for overflow of LRU repair to the next higher level as required. Scrap fractions, a portion of the work flow deemed not repairable, can be set for LRU's and modules at each maintenance level. Scrapped items are part of the cumulative materiel requirements for resupply stocks from higher levels.

Support alternative deployments of test equipments for the ICAP are identified as Cases I through IVA as follows:

Case I - LCSS in the field with repair by module replacement at three DS sites and overflow LRU plus module repair at a GS site.

Case IA - Special Test Equipment (STE) in the field with repair by module replacement at three DS sites and overflow LRU plus module repair at a GS site.

Case II - LCSS in the field with LRU repair by module replacement and discard at two DS sites and a GS site.

Case IIA - STE in the field with LRU repair by module replacement and discard at two DS sites and a GS site.

Case III - LCSS in the field and at CONUS depot with LRU repair by module replacement at two DS sites and overflow LRU plus module repair at a CONUS depot.

Case IIIA - STE in the field and CONUS Depot with LRU repair by module replacement at three DS sites and overflow LRU plus module repair at a CONUS Depot.

Case IV - LCSS at a CONUS depot (black box return) with all LRU and module repair at the CONUS Depot.

Case IVA - STE at a CONUS depot (black box return) with all LRU and module repair at the CONUS depot.

With workloads established and the individual support concepts defined, support costs can be calculated. Support costs are time-phased as development and production, which constitute acquisition costs, and operating costs over the projected life of the supported systems. A fourth phase is identified as the end of the program, where salvage credits can be taken. Support costs are first posted at net value. As an option in the program, these costs can be converted to present value, allowing for some expected discount rate.

Costs are computed by phase under the headings as noted below:

1. Prime Equipment Costs

Acquisition Cost = (non-recurring acquisition costs) plus (total number equipments) times (equipment unit cost)

2. Test Equipment

Test equipment comparisons for the ICAP were the Land Combat Support System (LCSS) modified for support of the ICAP LRU's and special test equipment designed by the ICAP contractor to support the program.

Test Equipment Development = (hardware development cost) plus (software development cost) plus (documentation cost).

Acquisition Costs = (number DS) times (unit LCSS or STE cost) times (number service channels per DS) times (unit LCSS or STE cost) times (number of service channels per GS) plus (depot LCSS or STE unit cost) times (number of depot service channels).

Other similar equations compute costs for the following:

Test equipment facilities at depot
Supply materiel
Reordering
Materiel storage
Supply administration
Shipping and handling

Sensitivity Testing Capability of the LOCAM 2 Program

By applying the versatility of the LOCAM 2 formulation to rapidly investigate the impact of variation of critical data factors, several tests are conducted as an adjunct to the baseline support cost output. This sensitivity testing includes variation of factors such as the following to determine the effects on logistic support costs:

- Maintenance incident rate
- False No-Go fraction
- LRU cost
- LRU plus module cost
- Mean time to repair (MTTR)
- Availability
- Length of operational cycle
- Test and repair times
- The number of LRU modifications
- Manpower productivity

The results thus obtained are of particular interest since they provide cost trend data which is indicative of the stability of support costs among the alternatives considered for investigation. The technique provides a proven method for developing maintenance and repair alternatives to arrive at lowest life-cycle costs. The methodology can significantly aid in achieving the objective of low maintenance support costs for this and other Army Programs when they are deployed for field operations.

1. Analysis of Study Results

The application of the LOCAM 2 computer model facilitated the evaluation of the impact of logistics in terms of cost and effectiveness for different support postures of the ICAP electrical/electronic LRU's. The results are presented as 10-year operational costs, equal effectiveness (availability) costs, and sensitivity of support costs to variations in critical factors. Costs are based on current fiscal year dollars without discounting. Costs already expended are considered sunk. The results for each of the eight cases previously defined are shown in Table I and reflect a breakdown of the cost elements by the following:

A. Ten year operations
B. Initial provision investment
C. Test equipment acquisition
D. Test equipment development

Comparison of the costs narrows the choice of alternatives to Cases I and III using LCSS. The increases in support costs for STE alternatives, relative to the corresponding LCSS alternatives, are principally associated with the higher test equipment development and acquisition costs and increases in test manpower requirements due to higher test times for manual equipment. A major factor contributing to higher cost for Cases II and IIA is increased materials cost for module discard.

Table I. Aggregate Baseline Cost
($ in Thousands)

		Cases							
		I	IA	II	IIA	III	IIIA	IV	IVA
(A) 10 YEAR OPERATING COSTS	MAINTENANCE MANPOWER FIELD	686	1998	686	1981	697	1938		
	MAINTENANCE MANPOWER DEPOT	833	1485	471	1015	1048	1741	2227	5536
	TEST EQUIPMENT MAINTENANCE	719	1131	687	1037	745	1160	425	842
	SUPPLY MATERIAL	14022	14017	29396	29369	13980	13865	15430	15526
	SUPPLY ADMINISTRATION	2542	2542	797	797	2542	2542	2542	2542
	ORDER, STORE, SHIP & HANDLE	374	398	501	518	349	361	763	816
	SUBTOTAL	19176	21581	32538	34717	18351	21614	21387	25265
(B) INITIAL PROVISION INVESTMENT	LINE REPLACEABLE UNITS	12826	13302	12826	13302	11697	12019	23614	24586
	MODULES/PARTS	1474	1515	2774	2833	1602	1753	720	718
	SUBTOTAL	14300	15220	15600	16136	13299	13772	24334	25303
(C) TEST EQUIPMENT ACQUISITION	LCSS FIELD AUGMENTATION KITS	825		825		825			
	DEPOT TEST STATIONS ·	528		440		748		220	
	STE FIELD AUGMENTATION KITS	1500	7206	1500	7206	1500	7206	1500	1500
	DEPOT TEST STATIONS		3052		2238		4171	138	2937
	SUBTOTAL	2853	10258	2765	9444	3070	11377	1858	4437
(D) TEST EQUIPMENT DEVELOPMENT	LCSS FIELD	1990		1990		1990			
	DEPOT & TSU	1370		430		1370		3285	
	STE FIELD	425	2625	425	2625	425	2625	425	425
	SUBTOTAL	3785	4375	2845	3175	3785	4375	3710	4597
TOTAL SUPPORT COSTS		40114	51434	53748	63472	39508	51138	51289	59602

The major factor for increased cost in Case IV and IVA is increased pipeline investment due to an increase in the number of LRU's required to support the depot pipeline and for maintenance turnaround at the depot.

2. Cost Effectiveness Comparison

In developing cost effectiveness comparison of the ICAP the model breaks out costs by the cost elements described above, and as shown in Table I, subsets of data are broken out for each element. The bar graph shown in Figure 5 gives visibility of the cost elements designated as segments A, B, C and D. Also shown in Figure 5 is the operational availability (A_o) associated with each support alternative and choice of test equipment. The LOCAM 2 model permits A_o to be input as a fraction of the inherent availability (A_I) where

$$A_I = \frac{MTBMI}{MTBMI + MTTR}$$

For the ICAP study MTTR is the integrated direct support maintenance turnaround time at the organizational level.

3. Influence of Workload on Support Costs

The principal factors which influence the workload are as follows:

Mean Time Between Maintenance Incidents (MTBMI) or its inverse, the rate at which maintenance incidents occur.

Aircraft utilization (airborne and ground time annually).

Number of systems deployed.

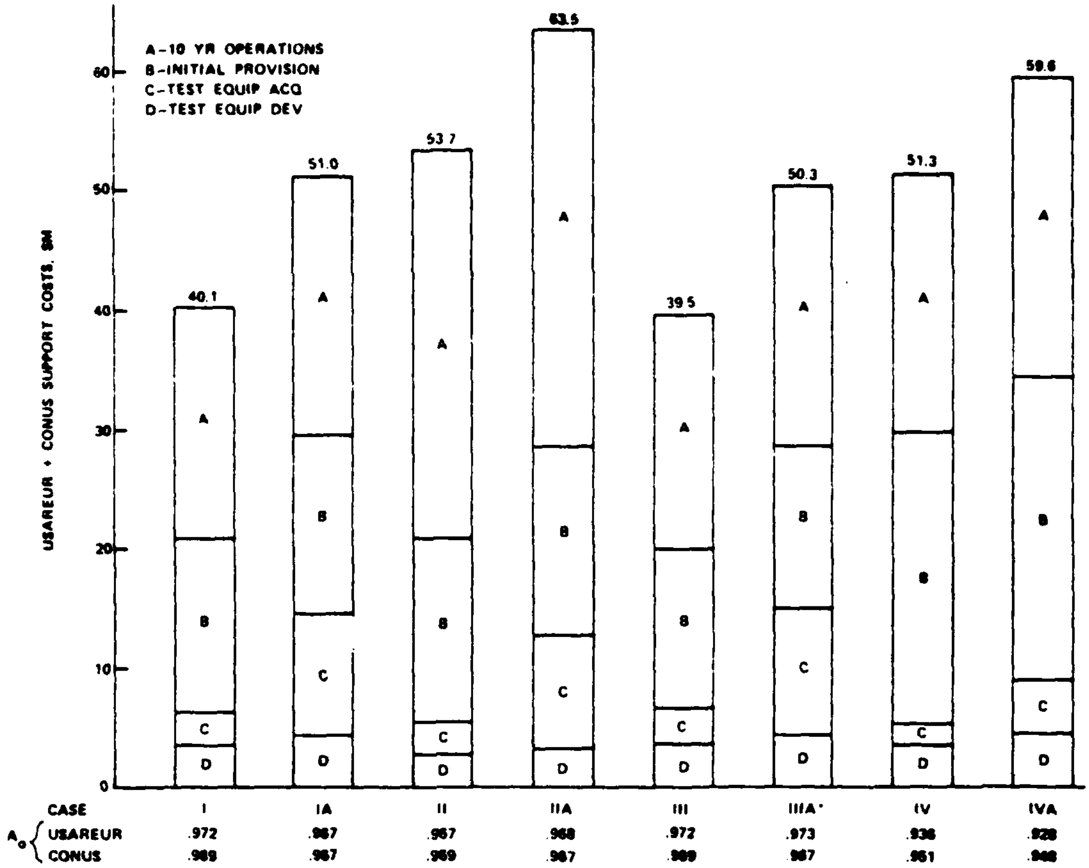

Figure 5. ICAP Support Cost Effectiveness Comparison - (Baseline Result)

MTBMI is related to prime equipment design environmental effects and to the capability of correctly diagnosing the need for maintenance at the organizational level. Built-in test equipment (BITE) for the TOW missile system and the TOW airborne system test set/TOW system evaluation missile (TASTS/TSEM) equipment facilitate detection of failures. Weapon utilization and deployment are a function of training, readiness conditions and force structure requirements. Nominal values need to be set to establish a data base; however, workload factors are likely to vary due to changes in military posture or data insufficiencies for initial estimating purposes. The MTBMI during initial military deployment tends to be lower than anticipated, sometimes by a factor of 10. As field experience and reliability growth is developed the MTBMI generally increases. By utilizing the LOCAM 2 sensitivity feature the maintenance incident rate was varied through a range of 0.5 through 3.0 and compared to the baseline. This output is shown in Figure 6. The following is significant:

Cases I and III, which reflect a support posture of repair of LRU's at the DS level and repair of modules at a higher echelon, have the lowest slope or rate of change of support cost versus incident rate. These postures show more cost stability with increased workload.

Case IIA, repair of LRU's by module replacement and throwaway of modules, and Case IVA, depot repair only, have the highest slope. Decreased cost stability with increased workload is reflected.

The curves indicate a crossover trend between Cases II and IV and Cases I and III at extremely low maintenance incident rates (about one tenth of the baseline). This reflects the practicability of a throwaway or black box turnaround policy when high enough reliability is experienced. However, the instability of these maintenance alternatives to workload increase precludes their selection.

4. Manpower Productivity.

Manhours to test and repair the ICAP LRU's and modules are based on actual times to perform the maintenance or test function. Each test or repairman will have some time which is not productive; therefore, a productivity factor is used. For instance a soldier has KP, guard duty, training, leave or other time which is non-productive. Civilian personnel likewise have non-productive time which must be considered. For purposes of this study a baseline factor of 2.0 has been used. The effects of variation of the manpower productivity factors are shown in Figure 7. It is important to note that Cases I and III reflect the greatest cost stability throughout the range of factors considered.

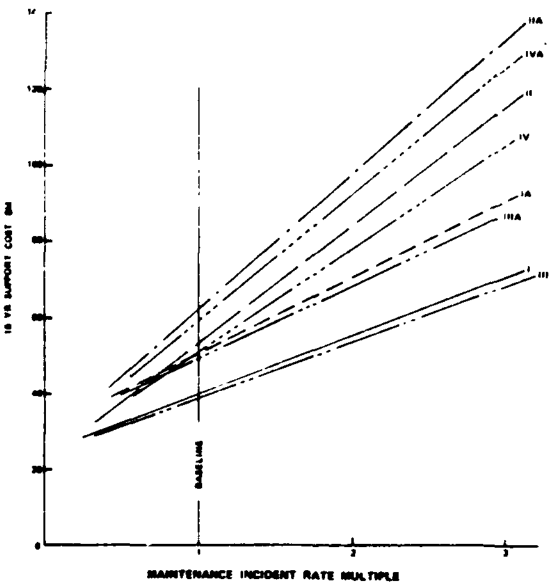

Figure 6. Effect of Maintenance Incident Rate Variation

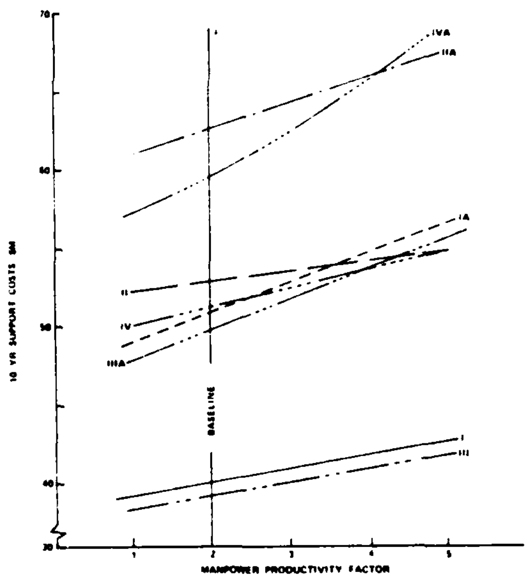

Figure 7. Effect of Variation of Manpower Productivity Factor

5. Test and Repair Time Variation

Because test and repair times for the ICAP LRU's are estimates, analysis of sensitivity to variation is essential to determine stability of cost for each support alternative. We see in Figure 8 that the effects of test and repair time variation are most notable in Cases IIIA and IA where manual equipment test time increases require additional manpower and test equipment. The sudden upsurge in costs is therefore accounted for in test equipment as well as manpower costs.

6. Effects of LRU and Module Cost Variation

The effect of variation of LRU and module costs for spares and consumed stock is shown in Figure 9. The results show that the Case I and III support costs are about equal at 0.5 of the baseline value and that the difference is only about one million dollars even at 2.5 times baseline costs. Except for Cases II and IIA the curves exhibit a decreasing slope or are reasonably linear as the LRU and module cost is increased. The module discard alternatives in Cases II and IIA exhibit the least stability showing the steepest slope with increasing LRU and module cost.

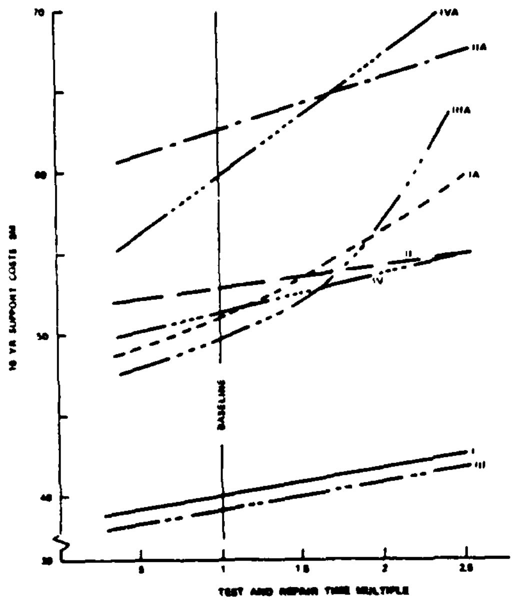

Figure 8. Effect of Test and Repair Time Variation

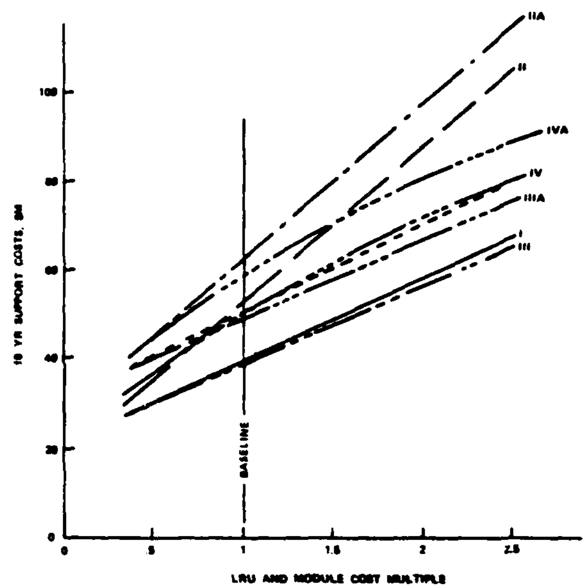

Figure 9. Effect of Variation of LRU and Module Cost

7. Effects of Increased Operational Cycle

The baseline and all other results of this study are based on a 10-year operational cycle. To evaluate the effect of changes in military posture which could result in an increase or decrease in the ICAP operational cycle, sensitivity testing was employed. Figure 10 shows the impact of increasing the operational cycle on each support posture.

The results indicate the following:

Case III costs are the lowest regardless of the length of the operational cycle.

At any point in time between 5 and 15 years the cost average of Case III over I is the same.

The field support alternatives show increased cost stability compared to depot only support.

8. <u>Inherent Availability</u>

The baseline situation assumes an MTTR of three hours after the need for maintenance of an ICAP item has been determined at an integrated direct support maintenance (IDSM) site. The inherent availability A_I of the TOW missile system is the composite (A_I product) of the functional group of LRU's comprising the TMS:

TOW Control Panel
Sight Hand Control
Stabilization Control Amplifier
Missile Command Amplifier
Electronic Power Supply
Pilot Steering Indicator
TOW Launch System
Missile Status Panel
Telescopic Sight Unit (TSU)
TSU Error Detector

Although a reasonable increase in MTTR would not significantly impact logistics costs, it does decrease the value of A_I. And since A_I is the limiting value of A_o, it is of interest to examine the relationship between A_I and MTTR due to the secondary effect on readiness. From the result shown in Figure 11 it is noted that A_I decreases from about 0.998 to about 0.991 as MTTR is increased from the baseline value of three hours to twelve hours.

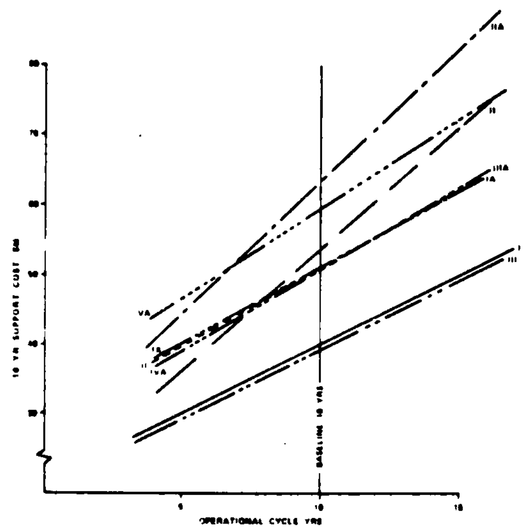

Figure 10. Variation of Support Costs with Length of Operational Cycle

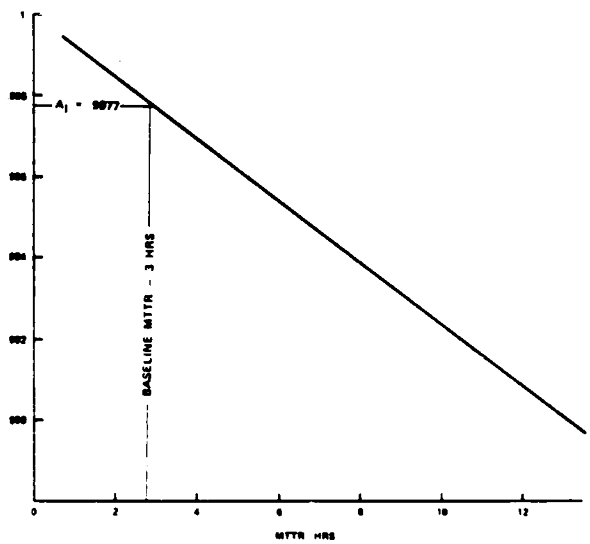

Figure 11. Effect of IDSM Turnaround Time (MTTR) on TSM System Inherent Availability, A_I

CONCLUSIONS

Analysis of the LOCAM 2 Model results leads to the following conclusions:

1. Case I and III alternatives are significantly lower in cost than others due to their lower pipeline requirements.

2. Case III is preferred to Case I for the following reasons:

a. Case III provides greater immunity to variations in the workload, length of pipeline, false No-Go's and other critical factors.

b. Costs and availabilities are more stable throughout the wide variations of parameters involved in repair of modules if the modules are repaired in the depot rather than in the semi-mobile general support site.

3. The field support alternatives are more cost effective while improving support system operational availability.

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GOAL PROGRAMMING MANPOWER MODEL

Dr. J.J. Conn

DEFENCE RESEARCH ANALYSIS ESTABLISHMENT (CANADA)

During the past 18 months the Manpower Operational Research Team of the Canadian Defence Research Analysis Establishment has successfully developed and implemented a manpower planning model based on Goal Programming techniques, which were originated by A. Charnes and W.W. Cooper. This manpower planning model, which is currently being used as a management control system to develop and evaluate officer manning plans at the Canadian National Defence Headquarters, will be described in this paper.

A common problem of manpower planning within the military type of hierarchy can be described as follows: Given budgetary limitations which restrict the total number of people who can be trained and employed; given operational requirements which fix the maximum and minimum numbers of people that can be employed in each officer classification at a given rank; given policies on promotion rates and given those other variables, such as attrition rates, that are not under direct control, what should be the manning plan for the coming three years? By manning plan is meant the recruitment quotas, the manning levels, and promotion quotas in any given year. The development of such a manning plan is a complex process which can be plagued by conflicts among the various policies and constraints.

In the recent past, the manual technique of solution of this manpower planning problem for officers in the Canadian Forces was characterized by limited responsiveness to management demands. This technique was replaced by a system based on both batch and time-sharing techniques. However, the policy conflicts were still tackled in serial fashion in isolation from other policies. The solution of one conflict often spawned other conflicts. This resulted in perpetual "musical chairs" with the gradual introduction of inconsistencies into the plans. It was also time consuming and not suitable for rapid evaluation of alternate personnel policies. What was needed was an approach which permitted the resolution of all policy conflicts at a single pass. The approach which was taken was Goal Programming.

The Goal Programming modelling technique is a modification of the usual linear programming model. Briefly, the right-hand sides of the constraints are taken as expressions of the "goals" to be attained (such as total number of majors to be promoted). The objective function to be minimized is the weighted sum of the slack variables, which are the deviations from the stated goals. These slack variables are left unrestricted in sign by splitting each slack variable into the difference between two non-negative variables. The relative importance of the constraints, or goals, is expressed in the choice of objective function weights.

PROBLEMS OF MANPOWER PLANNING

The problem becomes one of constructing a suitable objective function which will:

a. Respect organizational constraints (i.e. budgetary constraints, rank ceilings, establishment requirements, etc.),

b. permit short term organizational objectives to be attained, and

c. not prevent longer term objectives from being reached.

As indicated earlier, there will be areas of conflict among the policy constraints. For example, policies on promotion equitability prevent a disproportionate number of promotions being allocated to one classification. Policies on manning levels will constrain planners to consider courses of action that will maintain rank-to-rank ratios required for organizational effectiveness but which will sometimes be counter-productive to career opportunity. Both policies are constrained by budgetary consideration. Thus it will be necessary to indicate if one policy is to be adhered to strictly and the other violated, or whether both policies can be relaxed and to what degree.

Our problem reduces to one of determining the promotion quotas and recruitment quotas for each rank level and for each of the officer classifications for a given planning horizon. Note that by fixing promotion and recruiting quotas one is also determining the manning level in each rank-classification state, the total number of officers, the total number of promotions, and so on.

PLANNING GOALS

These promotion and recruiting quotas are not derived in isolation but in consideration with a number of objectives or goals. These objectives are:

<u>Budgetary</u>: The budget available for salaries is limited and so therefore is the total number of officers in each rank level. Given the total end-strengths and an estimated attrition, the total number of officer promotions can be calculated.

<u>Military Effectiveness</u>: It is possible to determine, for each rank and classification, a minimum number of officers below which military effectiveness is impaired. It is equally possible to determine a maximum or preferred number for each rank-classification state.

<u>Promotion Equitability</u>: In the lower ranks, i.e. CAPT/LT to COL, it is desired to have as small variation in promotion rate among the classifications as possible.

Stability of Rank Structure: It is desirable not to have large and rapid fluctuations from year to year in promotion rates and year-end strengths, both within rank-classification states and overall.

GLOBAL GOALS

Initially, therefore the budgetary constraints must be given prime consideration. The budget can be translated into desired total strengths, by rank, for each year of the planning period. Knowing the current strengths and estimated attrition, the total number of promotions necessary to attain the desired end strengths can be calculated. Typical strengths and promotion quotas are shown in Table 1. These represent the global constraints of the model.

TABLE 1: TYPICAL GLOBAL CONSTRAINTS
(RANK CEILINGS & PROMOTION QUOTAS)

RANK	RANK CEILING	PROMOTION QUOTA
GEN	1	———
LGEN	6	0
MGEN	21	1
BGEN	63	6
COL	189	18
LCOL	567	55
MAJ	1901	201
CAPT/LIEUT	7604	563
RECRUIT INTAKE	----	1200

STRENGTH GOALS

While the total strengths in a given rank must be fixed, the rank strengths in the individual classifications can be permitted to vary. There is a minimum number in each classification below which effectiveness is impaired. There is also a maximum or preferred number which is desired to maintain a career structure. The rank strength of any given classification should lie somewhere between these limits.

PROMOTION GOALS

In order to provide a measure of equitability to personnel, it is desirable to maintain approximately equal promotion rates in all classifications. Since attrition rates vary from classification to classification, this is not always possible. However, maxima and minima are set as goals on the numbers who may be promoted from one rank of a classification to the next higher rank. This has the effect of narrowing the range of variations in promotion rates.

DETERMINATION OF GOALS

There are the global goals, as shown in Table 1, namely the 8 desired rank strengths and the 8 rank promotion quotas. Considering only the 4 rank levels from captain to colonel, the planners must further suballocate these global strengths among 29 officer occupational classifications, i.e. divide them into 116 smaller packets or rank/classification states. There is now, however, a greater degree of flexibility available to the planner. He need not be constrained to a single, fixed strength figure. Operational requirements will dictate a minimum strength below which the operational effectiveness of a rank/classification state will be impaired (called the minimum manning level). There is also a maximum manning level, which may be desired for operational reasons as well as from the career opportunity viewpoint. The planner should attempt to keep his year end strength forecast for each rank/classification state between these bounds. It should be noted that if all rank/classification states were manned near the maximum manning levels it is quite probable that the total required strength constraints would be violated. Therefore, some will be manned near the maximum level and others near the minimum level. It is this flexibility that enables the planner to develop suitable plans. Thus there will be 116 minimum manning level goals and 116 maximum manning level goals.

Again considering only the 116 rank/classification states from captain to colonel, the total permitted promotions must be allocated in a fair manner in order to compensate for scheduled or unscheduled attrition from each state as well as for promotions out of any particular state. The term "fairness" implies that there should be as small a variation in promotion rates among classifications as it is possible to attain. It is also desirable to avoid large and rapid fluctuations in promotion rates and in end strengths, both within rank/classification states and overall, because of the effect on morale and hence upon effectiveness. Therefore, for each rank/classification state a required minimum number of promotions is calculated, using a rule that roughly 1% of the end strength should be the minimum promotion goal. A second number is determined for each rank/classification state as an upper limit on promotions. This is initially set high enough to prevent an inordinate number of promotions being assigned to any one classification. Thus there will be a total of 116 minimum promotion goals and 116 maximum promotion goals determined. These values are subsequently adjusted in the "fine tuning" of the solution. In fact they are the control knobs of the model.

The task of the manpower planner is therefore not an enviable one. In addition to meeting his total strength and promotion requirements in the 8 ranks levels, he must also take into account the 232 manning levels and the 232 promotion flows. When the 33 manning levels and promotion flows for the general officer ranks are included, the planner has 513 factors to consider in his plan for each year of his planning horizon. These factors become constraints within our model. An additional 116 manpower constraints are added for bookkeeping purposes - to prevent people from being 'created' or 'destroyed' at rank boundaries. This results in a total of 629 goals or constraints which must be considered by the model. A simple goal programming model could now produce a solution in terms of recommended manning levels, promotion quotas and recruitment quotas which would minimize the total deviation from the stated goals.

This would be adequate if all goals were of equal priority. But obviously it is far more serious to exceed the budgetary strength goal than to be overmanned in one of the 116 rank/classification states. Therefore, a system of weights must be assigned to deviations from the goals to reflect the order of priority of the goals and the penalties which would accrue if the goal is violated. In addition, the direction of deviation is a critical factor. It is a more serious matter to exceed a maximum manning level than to just fail to reach it.

With these considerations in mind, a weighting factor is assigned to deviations from the stated goals, depending on the direction of the deviation and the priority of the goal. There will be a total of 1258 weights generated (2 x 629). The model then will produce a solution in terms of recommended manning levels, promotion flows, and recruitment quotas which will minimize the sum of the weighted deviations from the 629 stated goals.

Since some of the policy objectives will be in conflict, it is necessary to rank the policy goals. Each policy goal is assigned by the model a numerical weight representing the importance of the goal and the degree to which it can be violated in case of conflict. Typical weights are shown in Table 2.

TABLE 2: TYPICAL WEIGHTS FOR DEVIATIONS FROM GOALS

(↑ Increasing weight)

Penalties for not satisfying financial constraints on total strengths and total promotions (9900)	(9300)
Penalties for not exceeding minimum promotion flow (875)	Penalties for exceeding maximum promotion flow (875)
Penalties for not exceeding minimum strengths (750)	
Penalties for exceeding "preferred" or maximum strengths (525)	
Low penalty for not reaching maximum promotion flow, and for being below maximum strength (70)	
No penalty is assigned for exceeding minimum strength or minimum promotion flow (0)	

The penalties (weights) are very high for violation of the budgetary goals. The penalties for violation of promotion goals are the next highest, and ar used as controls for the model. The penalties for not exceeding minimum manning levels are higher than the penalties for exceeding maximum strength for several reasons. The minimum manning level is determined by operationa considerations and should be met at all costs. The maximum manning level c be exceeded through no fault of the planners. Organizational or equipment changes can readily reduce the maximum required strengths to the point where normal attrition cannot handle the problem, resulting in an overmanne status in one or more rank/classification states.

In addition there is priority of weights by rank and by occupational classification, with higher weights for deviation at the colonel rank than for deviations at the captain rank. The various occupational classificatio also can be ranked in any desired order of priority.

THE GOAL PROGRAMMING MANPOWER MODEL

The model is a series of three computer programs which are run on an IBM 360/85 computer and require the use of a Mathematical Programming Syste Extended (MPSX) package. It is a cascaded one-period model with a three year horizon. The model is run for the first year of the planning period until the planner is satisfied with the output. The model is then run for the second year, based upon the results for year 1, until the planner is satisfied. Then the model is run for the third year, based upon year 2 results.

The first program basically organizes the input data. It validates and edits the input data formats, updates the data bases, translates the user policies into the goal programming weights, presents reports on the data base and summarizes the user policies.

There are two data bases maintained on two disc files. The first, called the Integer Data Base, contains the actual numerical manpower data variables which the planner has determined for each year of the three year planning period. These include, for each rank/classification state, the beginning strengths, scheduled and unscheduled attrition, the minimum and maximum manning level goals, anticipated transfers in and out, and the minimum and maximum promotion goals. Also in this data base are the data elements for actual promotions recommended by the model and the year end strength. Initially these data elements are set at zero.

The second data base, called the Real Data Base, contains the numerical statements of preferences (weights) regarding the global rank ceilings and promotion goals as well as those for each of the local goals, i.e. those of each rank/classification state. Also included are the data elements for the weights for the different classifications and for the commissioning policies which govern the distribution of the officer recruits.

When the planner is satisfied with his data base for year 1, the second program is run. This program translates the problem data stored in the two data bases into the format required by the MPSX package and produces a manning plan solution which is optimal in the linear programming sense and transfers the solution data back into the two data bases. The solution data consists of the recommended promotion flows from each rank/classification state and the recommended commissioning pattern into the lowest level of the officer system.

The third program is a report generator program which permits the planner to print any combination of analytical output reports in a single execution. These reports are for internal analysis or external circulation.

The Force Summary Report is a simple basic report which compares the recommended rank strengths and promotion allocations against the desired goals.

The Exception Report is a concise highlight of the constraints or goals which were violated, the nature of the violations and the values of the relevant goal variables.

The Rank to Rank Ratio Report provides a comparison of the manning strengths and the establishment requirements. The ratio of each rank to the next highest rank is calculated using the manning strengths and using the maximum manning level. The goodness of fit between the ratios is measured in two ways: First as a difference relative to the requirement for each ratio and secondly as a non-parametric deviation index for the classification as a whole and ranked in descending order of importance.

The Production Requirement Report is a tabular summary of recommended recruitment for each of the officer entry plans for intake into the officer recruit level.

The Promotion Report contains the total promotion picture in terms of absolute promotion numbers and relative percentage for all rank/classification states. There is also a statistical summary (average, standard deviation and coefficient of variation) to present the planner with a measure of the "goodness of fit" to promotion equitability.

The Classification Status Report is a concise summary of the recommended manning plan for each classification for each of the three years under study.

The Working Report is just that - a loosely formatted report of the data bases for any special purpose.

The planner selects the required reports, analyses the solution, identifies inconsistencies, alters goals and priorities and runs the model again until an acceptable solution is produced for the planning year under study. This solution serves as the beginning position for the next planning year. In this manner a three year manning plan, which is consistent with current or proposed policy, can quickly be produced.

In summary, the application of goal programming techniques to the solution of the manpower planning problem has been very successful. The model has been implemented within the Personnel Branch of the Department of National Defence for the development of officer manpower plans since April, 1972. Many benefits and improvements have been realized, namely:

a. All considered policies are formalized and clearly stated,

b. The rapid response time of the automated model permits the evaluation of a large number of alternative policies,

c. All conflicts are resolved simultaneously rather than serially,

d. There are extensive data checking, diagnostics, and report generation capabilities in the model,

with the result that a flexible and responsive tool has been developed for the analysis and evaluation of manning and promotion policies within DND.

THE STUDENT INSTRUCTOR LOAD MODEL: A SIMULATION OF THE US ARMY INDIVIDUAL TRAINING SYSTEM

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BACKGROUND DISCUSSION

The US Army individual training mission is a complex function undertaken by more than 40 schools and training centers, and responsible for training in excess of 100,000 students annually. A possible training program consists of several hundred courses, all of which contribute to the ultimate goal of meeting a constantly changing trained end-strength of the Army. The end-strength is a Congressionally established figure, and must be well defined and justified before a number of committees, both in the Department of Defense and in Congress. Thus, it is necessary to provide the best analytical support possible to substantiate a specific training program.

The Army individual training mission is a series of interrelated activities directed by DCSPER within HQ DA, and functionally related as shown in Fig. 1. The direction of the activities is assigned from HQ DA to the US Army TRADOC for the most part, although special training functions such as the Surgeon General do not fall under this chain of command.

With increased attention from both Congress and the Department of Defense on training, there has been a recent attempt, and one which is meeting with success, to handle training as a system. Thus, training must be costed and justified in budget exercises much as weapon systems are costed and justified.

This systemization of training poses some problems for the Army, for a number of reasons. Although training is largely under TRADOC, the reporting procedures are not through TRADOC but are through a number of diverse Army agencies. The establishment of requirements and priorities is not a part of the TRADOC function but a higher headquarters (DA, ACSFOR) responsibility. Similarly, the budgeting of manpower and dollars is to a large extent not part of the TRADOC function. Thus, TRADOC serves as the implementer, with many of the controls being external to TRADOC. This situation presents a problem, although manageable, insofar as representing the Army individual training activity as a system.

Historically, the primary means of developing the Army training program has been the White Book Conference, a DCSPER-sponsored activity convened quarterly (or as required) to develop the Army enlisted training program. The White Book has been in use for approximately 15 years as a key document on which the Army bases and develops enlisted MOS training, plans, programs, and schedules. The other means of programming training is through solicitation of training requirements from the various branches, commands, and agencies requiring trained personnel

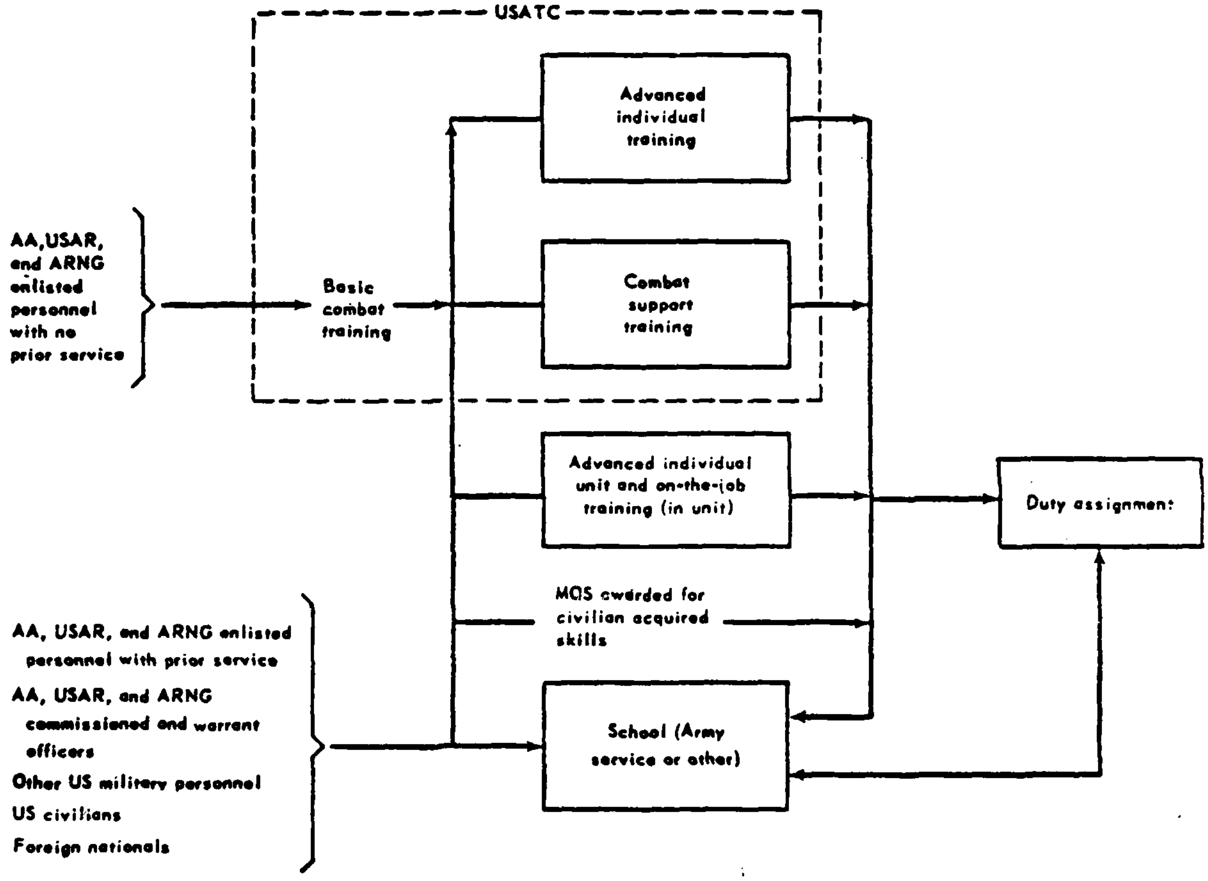

Fig. 1—US Army Individual Training Mission

that are not scheduled through the White Book Proceedings. Since its adoption, the White Book and the solicitation processes have been continually modified and improved to meet changing situations. Training programs established through these means have generally resulted in the availability of the trained personnel assets the Army needs to perform its mission. The validity and usefulness of these programs depend, however, on the accuracy and timeliness of initial data and the stability of parameters and authorizations used in the various computations made to produce them, as well as the responsiveness of decision makers to rapidly changing situations. These decision makers must be able to investigate the alternatives open to them as rapidly as possible so they can make more informative decisions with respect to funding and allocating personnel to the required training mission.

The large volume of information required to develop a training program precludes an extensive investigation of alternative training programs when done manually. In fact, the amount of data that must be considered in a short time at one White Book Conference is frequently so great that a complete training program cannot be fully developed for more than 12 to 24 months thereafter. Therefore, means have been sought from time to time that would reduce the burden of data handling for the Conference attendees and would also forecast the needs for training resulting from solicitations. The current SIL-II Model is the latest in a series of such attempts. With SIL-II, the Army will be able to schedule the man in the month that he is required, that is, schedule on a monthly rather than a yearly basis. The resultant efficiency in the training system as well as the improvement in management and control of the training base should prove of considerable benefit in the future. The goal of obtaining better performance of the training system has been a key factor in directing the Student Instructor Load model development.

Thus, in response to a request from the Assistant Secretary of the Army (Manpower and Reserve Affairs) that new ways be explored to facilitate estimates of future training requirements, ODCSPER initiated a study of the problem in 1970. This study led to the development of a historical data base, which was designed to record the number of students assigned to and graduating from Army Service Schools.

The SIL-I data base was fully defined in 1971. It maintains data for students by school and by category—such as permanent change of station (PCS), temporary duty (TDY), a Reserve Active Duty for Training, and non-US military and civilians—on a monthly basis. The SIL-I data base became operational in early 1972 and is producing output data for use by the Army.

The Army Staff recognized the need to extend the Student Instructor Load Model concept to an integrated system for tying SIL-I together with many of the other inputs to the training process, such as the PIA System and the Army Training Center Historical Data System. The idea of a new integrating system (later termed SIL-II) was conceived to support the White Book Conference deliberations and to provide the capability to investigate alternative training configurations.

In 1971 the Army (ODCSPER) requested RAC to extend its involvement in the study of Army personnel management problems to the development of a computer model and an associated data base that would permit systematic analysis of training programs on a monthly basis for 36 months for all courses of instruction at all Army training establishments and show costs in training funds and in trainer and ISOH personnel. In an alternative mode, with specified ISOH and trainer manpower constraints and training fund constraints, the model was to display resultant training shortfalls. The SIL-II Model was developed to meet these design specifications.

APPLICATION OF SIL-II

The SIL-II Model is intended to provide a systematized approach to the analysis of training problems. It presents a means of conducting rapid analyses of constrained training conditions, investigating changes in parameters of the training establishment, and costing training programs.

The model is, in effect, a manpower accounting system which distributes current and projected accessions to meet current and projected needs. The model is designed to operate under constraints of manpower and/or budget, and to generate the training capability with such restrictions imposed. There are reports generated which show schedules by class and course, by overage and underage in meeting the demands, and, ultimately, by manpower category for the entire Army. SIL-II is an integration of a number of training reporting systems in use elsewhere in the Army. Figure 2 illustrates this integration.

Here, the basic files in use by Army personnel managers for current reporting, for planning, and for projecting are indicated across the top of the figure. The raw data files are input to a preprocessor where editing and combining of data are performed. The combined file is passed from the preprocessor to the major processing module, the Training Simulator Program, where all current and projected scheduling is performed. From this program, data is passed to the report writing portion of SIL, where the various reports are generated.

The following four-figure (Figs. 3.1, 3.2, 3.3, and 3.4) set of data presents an array (of hypothetical data) at the course level, showing the following information:

Page 1: The FY73 Active Army and National Guard Enlisted Schedule, with a Total Enlisted summary for this course (800-94B20).

Page 2: The FY73 Total Officer Grand Total, and Course Related Factor summary for this course.

Pages 3 and 4: Similar data, FY74.

Figure 4 represents a partial recapitulation of additional hypothetical data for the total array, which is the final report available at the highest level of aggregation.

These figures illustrate how the SIL-II Model serves as the integrator of the diverse sources of data which describe current and projected

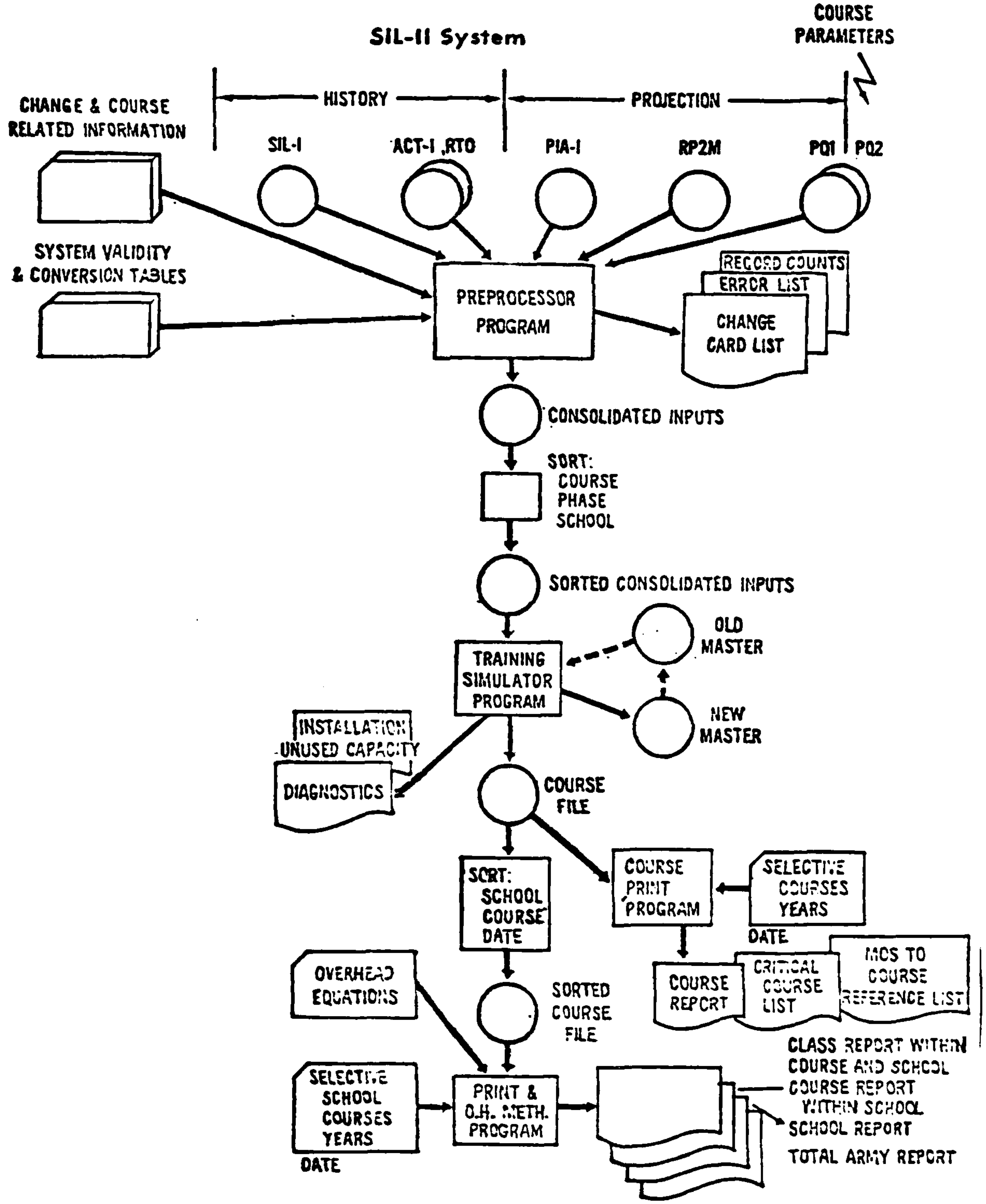

Fig. 2—The Student Instructor Load Model, Overview

UNCLASSIFIED

TRAINING SCHEDULE BY COURSE

DATE - 11-2-72

COURSE NUMBER - 800-94B20 COURSE PHASE - COURSE NAME -
MOS - MOS NAME -

	FY73 JUL	FY73 AUG	FY73 SEP	FY73 OCT	FY73 NOV	FY73 DEC	FY73 JAN	FY73 FEB	FY73 MAR	FY73 APR	FY73 MAY	FY73 JUN	FY73 TOTAL	FY73 MAN-YR
ENLISTED ACTIVE ARMY														
FORECASTED TRAINING REQ.	100	100	100	50	10	100	90	80	80	80	80	80	940	78
TRAINED ASSETS	40	40	40	40	40	40	28	52	40	40	40	40	480	40
NPS GAINS (ACCESSIONS)	30	30	30	30	30	30	30	30	30	30	30	30	360	30
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	0	0	0	0	0	12	0	0	0	0	0	0	12	1
ATTRITION BEFORE TRAIN.	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	10	10	120	10
ENTERED TRAINING	40	40	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	40	40	480	40
IN TRAINING	40	40	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	40	40	480	40
ATTRITION DURING TRAIN.	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0
COMPLETED TRAINING	40	40	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	40	40	480	40
ENLISTED ARNG														
FORECASTED TRAINING REQ.	3	3	3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	9	1
TRAINED ASSETS	3	3	3	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	9	1
NPS GAINS (ACCESSIONS)	10	10	10	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	10	10	120	10
OJT TRAINING	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0
AWAITING TRAINING	14	21	31	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	101	111	121	795	66
ATTRITION BEFORE TRAIN.	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENTERED TRAINING	3	3	0	0	0	0	0	0	0	0	0	0	6	1
IN TRAINING	3	3	0	0	0	0	0	0	0	0	0	0	6	1
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	3	3	3	0	0	0	0	0	0	0	0	0	9	1
TOTAL - ENLISTED														
FORECASTED TRAINING REQ.	103	103	103	50	10	100	80	80	80	80	80	80	949	79
TRAINED ASSETS	43	43	43	40	40	40	28	52	40	40	40	40	489	41
NPS GAINS (ACCESSIONS)	40	40	40	40	40	40	40	40	40	40	40	40	480	40
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	14	21	31	41	51	73	71	81	91	101	111	121	807	67
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	10	10	10	10	10	10	10	10	120	10
ENTERED TRAINING	43	43	40	40	40	28	52	40	40	40	40	40	486	41
IN TRAINING	43	43	40	40	40	28	52	40	40	40	40	40	486	41
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	43	43	43	40	40	40	28	52	40	40	40	40	489	41

TRAINING REQUIREMENT OF 3 IS FULFILLED BY 3 OF 10 ACCESSIONS. THIS BECOMES 3 ENTERED AND IN TRAINING FOR MONTH OF AUGUST WITH 3 GRADUATING IN SEPTEMBER. THE EXCESS ACCESSIONS OF 7 ARE ADDED TO THE PRIOR AWAITING OF 14 TO BECOME A CURRENT AWAITING OF 21.

UNCLASSIFIED

TRAINING SCHEDULE BY COURSE

COURSE NUMBER - 800-94B20 COURSE PHASE - COURSE NAME - DATE - 11-2-72

MOS - MOS NAME -

	FY73 JUL	FY73 AUG	FY73 SEP	FY73 OCT	FY73 NOV	FY73 DEC	FY73 JAN	FY73 FEB	FY73 MAR	FY73 APR	FY73 MAY	FY73 JUN	FY73 TOTAL	FY73 MAN-YR
TOTAL - OFFICER														
FORECASTED TRAINING REQ.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRAINED ASSETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPS GAINS (ACCESSIONS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENTERED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAND TOTAL														
FORECASTED TRAINING REQ.	103	103	103	50	10	100	80	80	80	80	80	80	949	79
TRAINED ASSETS	43	43	43	40	40	40	28	52	40	40	40	40	489	41
NPS GAINS (ACCESSIONS)	40	40	40	40	40	40	40	40	40	40	40	40	480	40
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	14	21	31	41	51	73	71	81	91	101	111	121	807	67
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	10	10	10	10	10	10	10	10	120	10
ENTERED TRAINING	43	43	40	40	40	28	52	40	40	40	40	40	486	41
IN TRAINING	43	43	40	40	40	28	52	40	40	40	40	40	486	41
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	43	43	43	40	40	40	28	52	40	40	40	40	489	41
COURSE RELATED FACTORS														
TRAINERS	0	0	0	0	0	0	0	0	0	0	0	0		
TRAINERS/STUDENT	.050	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		
INDIRECT COSTS														
OMA	8600	8600	8000	8000	8000	5600	10600	8000	8000	8000	8000	8000	97400	8117
MPA	90300	90300	84000	84000	84000	58800	11300	84000	84000	84000	84000	84000	22700	1892
PEMA	2150	2150	2000	2000	2000	1400	2650	2000	2000	2000	2000	2000	24350	2029
DIRECT COSTS														
OMA	344	344	320	320	320	224	424	320	320	320	320	320	3896	325
MPA	1290	1290	1200	1200	1200	840	1590	1200	1200	1200	1200	1200	14610	1218
PEMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL COSTS	2684	2684	95520	95520	95520	66864	26564	95520	95520	95520	95520	95520	62956	13581

COURSE SIZE -- MIN= 10 MAX= 14 OPT= 12 COURSE LENGTH = 4 WEEKS MAX COURSE WAITING TIME = 4 MONTHS

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Fig. 3.2—SIL-II Output: Officer, Totals, and Course Factors for FY73 (hypothetical)

UNCLASSIFIED

TRAINING SCHEDULE BY COURSE

COURSE NUMBER - 800-94B20   COURSE PHASE -   COURSE NAME -   DATE - 11-2-72

MOS -   MOS NAME -

	FY74 JUL	FY74 AUG	FY74 SEP	FY74 OCT	FY74 NOV	FY74 DEC	FY74 JAN	FY74 FEB	FY74 MAR	FY74 APR	FY74 MAY	FY74 JUN	FY74 TOTAL	FY74 MAN-YR
ENLISTED ACTIVE ARMY														
FORECASTED TRAINING REQ.	80	80	80	80	0	80	50	80	70	40	40	70	750	63
TRAINED ASSETS	40	40	40	40	40	40	40	40	40	40	40	40	480	40
NPS GAINS (ACCESSIONS)	30	30	30	30	30	30	30	30	30	30	30	30	360	30
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	10	10	10	10	10	10	10	10	120	10
ENTERED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
IN TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
ENLISTED ARNG														
FORECASTED TRAINING REQ.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRAINED ASSETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPS GAINS (ACCESSIONS)	10	10	10	10	10	10	10	10	10	10	10	10	120	10
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	131	141	151	161	171	181	191	201	211	221	231	241	2232	186
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENTERED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL - ENLISTED														
FORECASTED TRAINING REQ.	80	80	80	80	0	80	50	80	70	40	40	70	750	63
TRAINED ASSETS	40	40	40	40	40	40	40	40	40	40	40	40	480	40
NPS GAINS (ACCESSIONS)	40	40	40	40	40	40	40	40	40	40	40	40	480	40
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	131	141	151	161	171	181	191	201	211	221	231	241	2232	186
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	10	10	10	10	10	10	10	10	120	10
ENTERED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
IN TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40

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Fig. 3.3—SIL-II Output, Partial, for FY74

UNCLASSIFIED

TRAINING SCHEDULE BY COURSE

DATE - 11-2-72

COURSE NUMBER - 800-94920 COURSE PHASE - COURSE NAME -
MOS - MOS NAME -

	FY74 JUL	FY74 AUG	FY74 SEP	FY74 OCT	FY74 NOV	FY74 DEC	FY74 JAN	FY74 FEB	FY74 MAR	FY74 APR	FY74 MAY	FY74 JUN	FY74 TOTAL	FY74 MAN-YR
TOTAL - OFFICER														
FORECASTED TRAINING REQ.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRAINEE ASSETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPS GAINS (ACCESSIONS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENTERED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAND TOTAL														
FORECASTED TRAINING REQ.	80	80	80	80	0	80	50	80	70	40	40	70	750	63
TRAINEE ASSETS	40	40	40	40	40	40	40	40	40	40	40	40	480	40
NPS GAINS (ACCESSIONS)	40	40	40	40	40	40	40	40	40	40	40	40	480	40
OJT TRAINING	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIVILIAN ACQUIRED SKILLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AWAITING TRAINING	131	141	151	161	171	181	191	201	211	221	231	241	2232	186
ATTRITION BEFORE TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRIOR SERV ENTERED TRAIN	10	10	10	10	10	10	10	10	10	10	10	10	120	10
ENTERED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
IN TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
ATTRITION DURING TRAIN.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMPLETED TRAINING	40	40	40	40	40	40	40	40	40	40	40	40	480	40
COURSE RELATED FACTORS														
TRAINERS	0	0	0	0	0	0	0	0	0	0	0	0		
TRAINERS/STUDENT	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		
INDIRECT COSTS														
OMA	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	96000	8000
MPA	84000	84000	84000	84000	84000	84000	84000	84000	84000	84000	84000	84000	8000	667
PEMA	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	24000	2000
DIRECT COSTS														
OMA	320	320	320	320	320	320	320	320	320	320	320	320	3840	320
MPA	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	14400	1200
PEMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL COSTS	95520	95520	95520	95520	95520	95520	95520	95520	95520	95520	95520	95520	46240	12187

COURSE SIZE -- MIN= 10 MAX= 14 OPT= 12 COURSE LENGTH = 4 WEEKS MAX COURSE WAITING TIME = 4 MONTHS

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Fig. 3.4—SIL-II Output, Course Factors, FY74

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TOTAL ARMY TRAINING SCHEDULE

	FY-75 JUL	FY-75 AUG	FY-75 SEP	FY-75 OCT	FY-75 NOV	FY-75 DEC	FY-75 JAN	FY-75 FEB	FY-75 MAR	FY-75 APL	FY-75 MAY	FY-75 JUN	FY-75 TOTAL	FY-75 MN-YR
ENLISTED ACTIVE ARMY													AL	MN-YR
AWAITING TRAINING	0	0	0	0	0	385	259	179	58	0	0	0	881	73
ATTRITION BEFORE TRAINING	0	0	0	0	0	0	10	4	3	1	0	0	18	2
ENTERED TRAINING	550	390	480	680	680	295	822	787	840	788	746	750	7802	650
IN TRAINING	937	793	754	923	1166	872	1287	1243	1370	1339	1302	1292	13158	1097
ATTRITION DURING TRAINING	126	104	99	124	155	115	154	159	180	177	175	174	1742	145
COMPLETED TRAINING	372	408	415	412	319	474	332	597	554	639	606	585	5761	475
ENLISTED USAR + ARNG													81	475
AWAITING TRAINING	0	0	0	0	0	9	0	0	0	0	0	0	0	0
ATTRITION BEFORE			0	0	0	0	0	0						
ENTERED TR					0	0	0							
IN TRAINING	948	796	757	928	1171	837	1241	1276	1403	1372	1335	1325	13381	1115
ATTRITION DURING TRAINING	126	104	99	124	155	115	156	161	182	179	177	176	1754	146
COMPLETED TRAINING	372	411	418	415	318	479	337	629	585	670	631	616	5881	490
OFFICER ACTIVE ARMY													81	490
AWAITING TRAINING	0	0	0	0	0	0	0	9	8	7	6	5	35	3
ATTRITION BEFORE TRAINING	0	0	0	0	0	0	0	0	1	1	1	1	4	0
ENTERED TRAINING	100	100	0	0	50	100	0	140	0	0	0	0	490	41
IN TRAINING	340	440	320	320	250	350	248	286	284	283	232	140	3493	291
ATTRITION DURING TRAINING	0	0	0	0	0	2	2	2	1	1	1	0	9	1
COMPLETED TRAINING	100	0	120	0	120	0	100	100	0	0	50	91	681	57
OFFICER USAR + ARNG													81	57
AWAITING TRAINING	0	0	0	0	0				0	0	0	0	0	0
...BEFORE TRAINING	0	0	0									0	0	0
GRAND TOTAL														
AWAITING TRAINING				0	0	385	259	188	66	7	6			
ATTRITION BEFORE TRAINING	0	0	0	0	0	0	10	4	4	2	1	1	22	2
ENTERED TRAINING	673	553	483	735	735	400	956	1020	873	821	773	783	8705	725
IN TRAINING	1370	1336	1177	1378	1551	1317	1599	1672	1797	1715	1627	1525	18014	1501
ATTRITION DURING TRAINING	126	104	99	124	155	117	158	163	183	180	178	176	1763	147
COMPLETED TRAINING	512	411	538	435	435	479	457	789	585	720	681	707	6752	563
													52	563
TOTAL ARMY FACTORS													52	563
TRAINERS	385	326	309	323	413	448	448	462	543	543	543	483	5223	435
INSTRUCTORS	188	228	192	204	212	186	238	242	242	218	194	160	2488	207
TRAINERS/STUDENTS (IN TRAINING)	1	1	1	1	1	2	2	2	2	3	3	1	20	2
INSTRUCTORS/STUDENTS (IN TRAIN)	3	3	3	3	3	3	3	3	3	3	3	3	36	3
INDIRECT COSTS													36	3
OMA	293	228	212	284	336	308	308	325	384	377	385	383	3813	318
MPA	435	403	356	452	503	508	479	508	573	553	550	523	5844	487
PEMA	271	210	198	269	324	293	297	313	372	367	376	377	3667	306
DIRECT COST													67	306
OMA	97	77	72	97	116	109	109	116	135	131	135	133	1327	111
MPA	129	112	101	130	149	146	142	149	171	165	167	161	1721	143
PEMA	13	18	10	13	16	18	19	19	26	20	20	19	197	16
TOTAL COST	1229	1043	949	1245	1444	1382	1354	1430	1655	1613	1633	1596	16569	1381
OVERHEAD MANPOWER (OH) ATCS	268	268	268	268	268	268	268	268	268	268	268	268	3216	268
OVERHEAD MANPOWER (OH) SCHOOLS	1093	1083	1083	1043	1089	1073	1094	1094	1094	1093	1090	1090	13056	1088
TRAINERS+OH ATCS	653	594	577	591	679	716	716	730	811	811	811	751	8439	703

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Army training into one coherent set of information for management and planning purposes.

The actual use of the model in analyzing training programs, the effects of cost and manpower constraints, the effects of modifications to course structure, and a number of other applications of the model are currently planned, and will be described as these are performed and available. Results will be presented with the presentation of this description of the SIL-II Model.

AD-A125 990 PROCEEDINGS OF THE ANNUAL US ARMY OPERATIONS RESEARCH SYMPOSIUM (12TH) 2-5 OCTOBER 1973 VOLUME II(U) ASSISTANT CHIEF OF STAFF FOR FORCE DEVELOPMENT (ARMY) WASHING .. 1973 4/5

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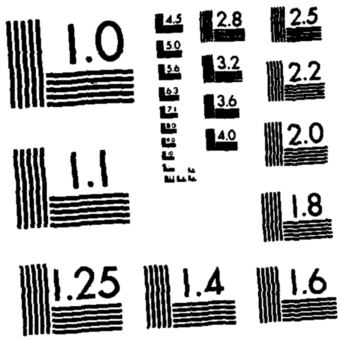

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD P000651

HEAVY EQUIPMENT TRACTOR (DECISION RISK ANALYSIS)

John H. Kenley III
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WARREN, MICHIGAN

INTRODUCTION

A study was conducted to evaluate the procurement of 725 heavy equipment tractors (22½-ton) to meet the Army's requirement for the 1975-80 time frame. The initial purpose of this study was to conduct a cost-effectiveness comparison of the XM746 and appropriate commercial truck tractors. The specific objectives then were, (1) a qualitative QMR review, (2) a life cycle cost estimate, (3) a cost-effectiveness study, and (4) finally as warranted to determine an optimum mix of vehicles.

Historically, this effort was initiated at the request of DA on 3 March 1972. The essential reason for this request was the growing concern for the increased costs of the HET. A 44% increase in hardware cost had occurred during the last five years. A HET system cost of $144,000 per unit was indicated by DA cost estimates. Cutbacks in the military budget mandated close scrutiny of high cost military features/requirements in all systems.

This study effort was organized into three (3) major phases (Table 1). Underlying these phases was the theme or philosophy of the study. The philosophy was that, although the HET QMR specified certain factors as essential (with required levels for all relevant factors), not all the using units required the same levels nor placed the same importance on the factors. Thus, a less costly vehicle could be very cost-effective in a unit that did not exhibit the same degree of need for the HET QMR specified levels. The first phase (establishment of basic methodology) includes the identification of the alternative truck tractors, determining which using units belong to what usage category. (The basis for this categorization was the mission statement for all the authorized units), and the identification of the evaluation factors indicative of vehicle effectiveness. The initial review yielded 139 factors. This was condensed to 26. Secondarily weights were established for the 26 factors together with the requirement levels of these factors for each of the three usage categories.

Phase 2 determined the life cycle cost for each alternative as well as the effectiveness value for each alternative as applied to each usage unit category. Phase 3 related the life cycle cost to effectiveness of the alternatives for each usage category.

PHASE 1
(a.) Alternative truck tractor analysis
(b.) Usage category classification
(c.) QMR review
(d.) Evaluating Factor analysis
(e.) Requirement level determination
PHASE 2
(a.) LCCE for each alternative
(b.) Effectiveness analysis
PHASE 3
Cost-effectiveness summary analysis

Table 1.
STUDY PHASE EFFORT

METHODOLOGY

The following assumptions are considered relevant to the scope and limitations of the study.

* XM746 is available for procurement in FY73, 74,75 and 76.

* An Austere XM746 and commercial truck tractor are available in FY74, 75 and 76.

* Procure schedule is:

FY73	FY74	FY75	FY76
125	-	300	300

* First 125 HET's will be XM746.

* The vehicle mix should not include more than two types of vehicles. The XM746 is preferred for combat usage.

* The Austere XM746 is a theoretical paper vehicle.

* Vehicles will be procurred under multi-year competitive contracts.

* Costs are in 1972 dollars.

* Costs are based on CONUS deployment.

* Cost estimates in the study are for decision-making and not budgetary purposes.

Proceeding then to the model detailing the three phases of the study, the three vehicles under consideration are the XM746, the XM746 Austere and a commercial truck tractor. The XM746 Austere would be a downgraded XM746 incorporating:

a. Reduced engine power (eliminate turbocharger)
b. One winch (rather than two)
c. Reduced drive axles (8 x 6 in lieu of 8 x 8)
d. Special tires
e. 60 amp electrical system rather than 80
f. Tacograph
g. Night loading flood lights

The various TO&E and TDA organizational units having heavy equipment truck tractors were reviewed regarding vehicles mission and task requirements. Viewing approximately fifty user units, three mission categories were established: (I) COMBAT, (II) COMBAT SUPPORT, and (III) TRANSPORTATION. The descriptions of these categories are seen in Table 2.

	CATEGORY		
	I	II	III
MISSION	COMBAT	COMBAT SUPPORT	TRANSPORTATION
TERRAIN	5% off road 50% secondary 45% highway	3% off road 52% secondary 45% highway	0% off road 30% secondary 70% highway
LOADING	60 ton max	60 ton max	30-60 ton
PRIMARY SERVICE	Disabled tanks under combat	Special purpose vehicles: Communication equip. artillery, supplies	Engineer construction equipment. Equip. for maint. company
UTILIZATION PROFILE	12K miles/year for 20K miles	12K miles/year for 30K miles	20K miles/year for 50K miles

Table 2.
CATEGORIZATION OF USING UNITS

The HET Qualitative Materiel Requirement (QMR) was analyzed and a list of 139 requirements were (under seven sub-categories) determined. This list was reduced to 26 key factors that capture the essence of the critical requirements. The seven sub-categories are:

(1) Performance
(2) Mobility
(3) Environmental suitability
(4) Human Engineering
(5) Physical characteristics
(6) Maintenance support/RAM-D
(7) Associated considerations

Performance and mobility are the most important.

In examining the vehicle utilization profile and duty cycle for each of the three categories indicates that requirements differ. As a means of rating the effectiveness of the various candidate vehicles in each category of usage, a numerical system was developed by assigning weights to the evaluation factors for each category of usage. The weights for all three units of categories were based upon the priority of characteristics as defined in paragraph eleven of the HET QMR. the 26 evaluation factors, their "weightings" and "requirements" (by category) are seen in Tables 3 and 4. The summed total weights of all 26 factors were evaluated as to how well it met the requirements of each of the three vehicle categories; it was given a rating value of 0 to 1.0. Therefore, when the weight of each factor for a vehicle category was multiplied by the rating value for that factor an effectiveness number (in percent) was obtained. Summing these values yielded an effectiveness by category.

The life cycle cost estimates were developed for each of the considered vehicles. The major cost categories are:

1. Non-Recurring Investment
   a. RDT&E
   b. APE
2. Recurring Investment
   a. Hardware Procurement
   b. Hardware Support
3. Total Operating Cost

This estimate is a function of the quantity procured. Since each usage category is distinctly different, a procurement mixture analysis seemed a valid approach. It should be noted that a condition of this study is that the first 125 vehicles procurred would be the XM746's. This then left 600 to be procurred. The vehicle mix alternatives that were considered are:

	ALTERNATIVE						
	1	2	3	4	5	6	7
XM746	725	450	450	250	250	125	125
XM746 Ams	0	275	0	475	0	0	0
Commercial	0	0	275	0	475	600	600

ITEM NO.	EVALUATION FACTORS DESCRIPTION	UNIT REQUIREMENT PROFILE "WEIGHT" W 1	W 2	W 3	UNIT REQUIREMENT PROFILE "LEVEL" R 1	R 2	R 3
	<u>PERFORMANCE</u>	<u>17</u>	<u>16</u>	<u>15</u>			
1	Transport Full Rated Payload (Lbs.)	8	8	8	137,000	137,000	137,000
2	Max. Axle Load (Lbs.)	6	6	7	25,000	25,000	25,000
3	Max. Fording Capability (In)	3	2	0	48	30	0
	<u>MOBILITY</u>	<u>38</u>	<u>37</u>	<u>37</u>			
4	Max. Range (Miles/mph)	6	5	5	300 /20	300 /20	200 /30
5	Max. Sustained Speed (mph)	5	6	9	30	30	45
6	Min. Sustained Speed (mph)	5	5	3	2½	2½	2½
7	Min. Speed on 2-1/2% Grade (mph)	4	4	7	25	25	25
8	Min. Speed on 15% Grade (mph)	4	4	3	1	1	1
9	Max. Turning Circle	6	6	8	60 Ft Intersection	60 Ft Intersection	60 Ft Intersection
10	Min. Side Slope w/RP	3	2	0	20% Moving 30% Stationary	20% Moving 30% Stationary	20% Moving 30% Stationary
11	Bridge Crossing Capability	5	5	2	Class #60	Class #60	Class #60
	<u>ENVIRONMENTAL SUITABILITY</u>						
12	Environmental Suitability	<u>1</u>	<u>1</u>	<u>1</u>	AR70-38 Cat 1-7	AR70-38 Cat 1-7	AR 70-38 Cat 1-7

Table 3.

ITEM NO.	EVALUATION FACTORS DESCRIPTION	UNIT REQUIREMENT PROFILE "WEIGHT" W 1	W 2	W 3	UNIT REQUIREMENT PROFILE "LEVEL" R 1	R 2	R 3
13	HUMAN ENGINEERING	1	1	1	HEL S-6-66	HEL S-6-66	HEL S-6-66
	PHYSICAL	30	30	32			
14	Crew	3	3	2	3	3	2
15	Power Service Brakes w/Fail Safe System to Halt Veh if Brakes Fail	4	4	7	YES	YES	YES
16	Power Steering (w/Auxil, Power Steering Unit)	4	4	7	YES	YES	YES
17	Full Power or Auto Shift	2	2	0	YES	YES	NO
18	Fully Suppressed/Water Proofed 24-V Elec. Sys.	2	2	2	YES	YES	YES
19	Tractor must mate with M747 Trailer	8	8	6	YES	YES	YES
20	Winch Requirements	7	7	8	2-30 TON	1-30 TON	1-30 TON
	MAINTENANCE SUPPORT AND RAM-D	9	11	10			
21	Min. Preventive & In-Storage Maintenance	2	2	3	MSI-25% @12.7mph	MSI-25% @12.7mph	MSI-25% @12.7mph
22	Miles between failures	4	6	5	1200/20,000	1200/30,000	1200/50,000
23	Standardization/Interchangeability	3	3	2	MAX	MAX	AS MUCH AS POSSIBLE
	ASSOCIATED CONSIDERATIONS	4	4	4			
24	Testing	2	2	2	SEVERE	SEVERE	SEVERE
25	Training	0	0	0	MIN PHASE III	MIN PHASE III	MIN SEA/LAND
26	Transportability	2	2	2	AIR	AIR	
	TOTAL	100	100	100			

Table 4.

The tentative stratification of vehicles by categories of usage for vehicle mix alternatives is seen in Table 5. An overall effectiveness then was obtained for each of the vehicle mix alternatives (Table 6). Also, because explicit quantities were specified, LCCE's were ascertained per alternative.

RESULTS

Tables 7 and 8 indicate the comparative results of hardware and LCCE costs, and hardware (or LCCE)/effectiveness ratios by alternative respectively. The rank is also shown. Table 9 yields a summary of the result rankings by alternative. The life cycle cost estimates of the vehicles as a function of quantity are seen in Table 10.

CONCLUSIONS

* 250 XM746's are required to meet combat requirements.

* The comparative evaluation of the seven vehicle mixes indicates that alternative 5 (250 XM746's and 475 commercials) is the best. It will:

a. Meet the demands required of at category I vehicle.
b. Verify the 50K to 60K unit hardware cost for commercial HET's.
c. Be the most cost-effective alternative having 250 XM746's as a minimum.

This paper is taken from the August 1972 study by Mr. Irwin Goodman of USATACOM entitled Heavy Equipment Transporter (HET) Study (Cost-Effectiveness Comparison of Appropriate Commercial and Tactical Truck Tractors).

		1	2	3	4	5	6	7
XM746		725	450	450	250	250	125	125
Austere		---	275	---	475	---	600	---
Commercial		---	---	275	---	475	---	600
CAT I	250	250	250	250	250	250	125	125
		---	---	---	---	---	125	---
		---	---	---	---	---	---	125
CAT II	200	200	200	200	---	---	---	---
		---	---	---	200	---	200	---
		---	---	---	---	200	---	200
CAT III	275	275	---	---	---	---	---	---
		---	275	---	275	---	275	---
		---	---	275	---	275	---	275

Table 5.
Tentative Stratification

ALTERNATIVE	CATEGORY - MEASURE	
1	ALL	98.6
	I	99.2
	II	99.2
	III	97.6
2	ALL	98.3
	I	99.2
	II	99.2
	III	96.9
3	ALL	96.3
	I	99.2
	II	99.2
	III	91.5
4	ALL	98.1
	I	99.2
	II	98.6
	III	96.9
5	ALL	93.2
	I	99.2
	II	88.3
	III	91.5
6	ALL	97.4
	I	97.0
	II	98.6
	III	96.9
7	ALL	90.4
	I	90.8
	II	88.3
	III	91.5

Table 6.
EFFECTIVENESS

ALTERNATIVE	HARDWARE COST (RANK)	LCCE (RANK)
1	64.8 (7)	161.7 (7)
2	64.0 (6)	157.1 (5)
3	54.6 (3)	159.8 (6)
4	62.0 (5)	15[illegible].4 (4)
5	47.0 (2)	[illegible].2 (2)
6	60.4 (4)	1[illegible] (3)
7	41.5 (1)	1[illegible] (1)

Table 7.
Comparative Data Results: Costs

ALTERNATIVE	HARDWARE COST-EFFECTIVENESS (RANK)	LCCE COST-EFFECTIVENESS (RANK)
1	65.7 (7)	164.0 (6)
2	65.1 (6)	159.8 (5)
3	56.7 (3)	165.9 (7)
4	63.2 (5)	155.4 (4)
5	50.4 (2)	154.7 (3)
6	62.0 (4)	153.0 (2)
7	45.9 (1)	148.0 (1)

Table 8.
Comparative Data Results: Costs/Effectiveness

RANK ON BASIS OF: *

Alternative	Acq. Cost	Life Cycle Cost	C/E Acq. Cost	C/E Life Cycle Cost
1	7	7	7	6
2	6	5	6	5
3	3	6	3	7
4	5	4	5	4
5	2	2	2	3
6	4	3	4	2
7	1	1	1	1

* Ranked numerically with "1" being the most desirable.

Table 9.
Comparative Results: Rankings

QUANTITY	XM746		XM746A		COMMERCIAL	
	UNIT	TOTAL	UNIT	TOTAL	UNIT	TOTAL
1	$30,018.2		$12,283.6		$19,391.7	
10	3,192.9	31,929	1,391.6	13,916	2,046.2	20,462
100	491.1	49,110	290.3	29,030	302.0	30,200
125	428.7	53,588	264.5	33,059	262.9	32,864
200	337.1	67,420	226.6	45,320	202.4	40,480
250	306.2	76,550	213.4	53,340	182.0	45,495
275	275.7	81,000	208.8	57,300	175.0	47,900
300	285.2	85,560	204.2	61,260	168.0	50,400
425	252.6	107,355	188.1	79,960	147.9	62,860
450	248.7	111,920	186.5	83,914	144.8	65,138
475	245.3	116,500	185.1	87,900	142.4	67,600
500	242.0	121,000	183.7	91,850	140.1	70,050
600	231.8	139,080	179.1	107,460	133.7	80,220
725	223.0	161,680	175.1	126,947	127.6	92,510

* ALL COSTS IN THOUSANDS

Table 10.
LCCE (QUANTITY)

Evaluation of Automatic Transmissions For Use In Military Wheeled Vehicles

(Decision Risk Analysis)

Mr. Daniel L. Palmer

US Army Tank-Automotive Command
Warren, Michigan

The use of automatic transmissions has penetrated deeper into the commercial environment in the last few years and applications now include not only passenger vehicles, but heavy trucks and off-road type vehicles as well. Military experience with automatic transmissions has been concentrated on tracked vehicles with only limited use in wheeled vehicles (such as the 44-passenger bus, the 2-1/2-ton truck and, more recently, the GOER vehicle, the M656 truck and the Heavy Equipment Transporter). Military experience with automatic transmissions in wheeled vehicles is much less than the 30-plus years of commercial experience. Recognizing the potential of automatic transmissions from the widening field of commercial applications, the US Army Tank-Automotive Command initiated a study in December 1971 to explore the use of automatic transmissions in the tactical wheeled vehicles procured and used by the United States Army. The purpose of the study was to facilitate policy decisions and materiel selection concerning the use of automatic transmissions in these vehicles. It was designed to consider Army wheeled vehicles in the 1/4, 1-1/4, 2-1/2, 5 and 10 ton weight classes (all body types within these weight classes were regarded collectively) for the 1972-1980 time-frame. New vehicle procurements and approved product improvement programs for that period were included. While it was felt that the military environment more closely resembled the commercial off-road application, the adoption of automatic transmissions to all categories of military wheeled vehicles was examined.

Criteria were established for selection of automatic transmissions for the study. They had to (1) meet military requirements (ratio, torque input, speed, etc.) and (2) be commercially available by January 1973. Several types of automatic transmissions were considered; the torque converter fully automatic, the torque converter power shift, and the hydromechanical. Another type, the positive synchronizing automatic transmission, was not considered because it was still in the developmental stages at the time the study was performed and no firm production dates had been established. Such factors as total cost of ownership, physical fit, operation, effects on vehicle performance, durability, reliability, maintainability and human engineering were also considered, as well as existing and proposed regulations of the Environmental Protection Agency and the Department of Transportation. These will be discussed later.

Study Methodology

The study was accomplished by a study team chaired by a member of the Systems Analysis Division, Plans and Analysis Directorate, US Army Tank-Automotive Command. Members from engineering, quality assurance, procurement and supply activities were included in the study team. The study data base consisted of, on the commercial side, field reports, market studies, and sales literature. On the military side, 25-years experience with automatic transmissions in tracked vehicles, experience gained with the 2-1/2 ton truck in the Korean War, limited data from the aforementioned recent application in the M656 (5-ton), the GOER family and the Heavy Equipment Transporter, and limited data from test rigs using automatics in 1/2, 2-1/2, 5 and 10 ton vehicles were considered.

A number of factors which could enter into a decision regarding the type of transmission best suited to the job were developed. These factors were broken down into five major groups and were individually assigned a value of relative importance to the decision maker (based on a value of 100). The weights were assigned after careful consideration of all factors in each of the groups.

	Factor Groups	Weight
1.	Cost of Ownership	30
2.	Engineering/Product Assurance	20
3.	Suitability for Military Application	20
4.	Maintenance and Logistics Support	25
5.	State-of-the-Art	5
	TOTAL	100

A complete list of factors and their weights are presented in Figure 1.

Because cost is a prime decision in any decision concerning military hardware and because there is intense competition from other government agencies for tax dollars this item was assigned the highest value of the five groups. The sub-factors in this group were assigned weights according to their relative importance in the life cycle cost for wheeled vehicles.

The second factor group, Engineering/Product Assurance, is concerned with the engineering problems which may arise during conversion from manual automatic transmissions and the impact on product assurance. Warranty provisions were also considered.

The third factor group, Suitability for Military Application, reflects the fact that unless a vehicle is able to perform its assigned mission when required, it is of questionable value to the user, regardless of the cost.

The fourth group, Maintenance and Logistics Support, can have a great impact in making any decision on selection between alternatives. Equipment which is difficult to maintain and support will result in many problems in the field.

The fifth group, State-of-the-Art, is of lesser importance because all of the items considered in the study are basically commercial items and no development program is anticipated.

After all of the factor weights were assigned, a narrative was developed for each of the individual factors to explore the relative "pro's" and "con's" of automatic transmission applications. To develop this comparative narrative, the current manual transmission equipped vehicles in each weight class were used as a basis for comparison.

When the narrative analysis for each of the factors was complete, a rating system was used to summarize all of the information contained in the narratives in terms of an overall "pro" or "con" position. The rating scale ranged from -5 to +5; where -5 represents "con" automatic, +5 represents "pro" automatic and a value of 0 indicates indifference. For each factor a rating value was determined on the basis of the narrative. To associate a risk with the rating system a pessimistic and optimistic value were also determined for each factor. An example of the rating procedure is shown in Figure 2. By making use of the pessimistic, most likely, and optimistic rating values for each factor, and the usual assumptions of the normal BETA distribution of the PERT process, an average rating value and standard deviations were obtained for each factor. From this information a statement for each vehicle weight class could be made regarding the "pro" or "con" value for automatic transmissions and the probability of the decision maker erroring if he chose to use automatic instead of manual transmissions.

Study Conclusions

In summary, automatic transmissions represent a higher initial acquisition cost, but these costs are expected to be offset by lower operational cost and the overall improvement in vehicle performance and life characteristics. The results of the factor evaluation indicates that the probability of automatic transmissions having a "pro" rating range from .964 for the 2-1/2 ton truck to .995 for the 1/4 ton truck. On a "rating" scale of -5 to +5 the weighted average ratings of automatic transmissions versus manual transmissions in the 1/4 ton to 10 ton weight class ranged from +.6 to +.8. (These results are tabulated in Figure 3.) From a total system and life cycle view adoption of the automatic transmission over the manual is favored for introduction into the military tactical wheeled vehicle fleet in the 1972-1980 time period.

Specific results for each factor group are discussed below:

1. Cost of ownership.

In most cases acquisition cost for automatic transmission is greater than that of a manual transmission as reflected in the following table:

Vehicle Application	Current Manual*	Proposed Automatics**
1/4 ton trk, M151 Ser	$315	$425 to $450
1 1/4 ton trk, M151 Ser	$310	$600 to $750
2 1/2 ton trk, M44A2 Ser	$980	$850 to $2100

Vehicle Application	Current Manual*	Proposed Automatics**
5 ton trk, M809 Ser	$1,510	$1,775 to $4,025
10 ton trk, M123A1C	$2,600	$4,200 to $4,500

* Includes transmission, transfer assembly, and clutch assembly.

** Includes equivalent drive-line components at the current manual listing.

The type of transmission does not have any significant impact on operating (POL) costs. These costs are considered to be insignificant in making a selection of the type of transmission for military application.

Maintenance costs are the most important consideration in comparing manual and automatic transmissions. Maintenance cost data on commercial truck fleets indicates substantial savings with automatic transmissions. Figure 4 indicates the time to recover the automatic transmission overcost assuming a 10% savings in maintenance cost. This 10% is considered to be very conservative. An analysis of the sensitivity of the ratings to changes in assumed maintenance savings was performed with the following results

Overall Most Likely Weighted Ratings
(-5 to +5 scale)

Wt Class (Ton)	Assumed Maintenance Savings		
	10%	5%	0%
1/4	+.77	+.61	+.13
1 1/4	+.74	+.58	+.10
2 1/2	+.66	+.50	+.02
5	+.84	+.68	+.20
10	+.83	+.67	+.19

If there were no savings in maintenance costs by using automatic transmissions, naturally the overcost could not be recovered. However, due to the improved performance with automatics, numerous other favorable evaluation factors, and the weighting factors used, the total ratings for the automatic transmissions would still be on the "pro" side.

2. Engineering/Product Assurance.

Vehicle performance is a major consideration in military vehicles. The highest "pro" automatic rating values were realized in this area due to the potentials of increased performance resulting from projected "ease of use" and longer life attributes. The study group felt that the favorable experience in the commercial world would carry over in military applications and affect performance favorably.

4. Maintenance and Logistics Support

Overall ratings in this area reflected a "con" value for automatics. This was due to an increase in labor and parts support required, new manuals, initial provisioning and special tools. The study group emphasized that although the overall rating was "con" automatic, "pro" values were realized for such items as overhaul and drive-line component replacement.

5. State-of-the-Art

All of the automatic transmissions considered in this study are commercially availabe and in most cases their technical feasibility has been established.

Study Recommendations

That the top Army management regard with favor the application of automatic type transmissions to the military wheeled vehicle fleet.

Additional hardware evaluation be pursued in conjunction with approved product improvement programs to verify the correlation between the commercial off-the-road environment and the military environment.

The study shows a cost advantage for the automatic transmission on the total cost of ownership basis. This advantage principally reflects the expected increase in durability and reliability, and reduced maintenance of the total automatic drive line. Since cost is an important part in the study, it is recommended that considerable emphasis be placed on evaluating reliability and durability in pursuit of the PIP programs.

Continue surveillance of on-going investigations and developments in the commercial automatic transmission field in the interest of future military application.

Post Study Actions

The principal theme of most of the recommendations concerns whether the expected maintenance savings and other benefits are sufficient to offset the initial overcost of the automatic transmission equipped drive line. Product improvement programs (PIP's) initiated for all vehicles considered in this study, and automatic transmissions were included in these PIP's. The PIP test programs were to provide the additional data required in order to determine the future application of automatic transmissions in the Army wheeled vehicle fleet. With the advent of the WHEELS Study, however, these PIP's were cancelled. Additional PIP's have not been approved as of this writing.

FACTOR WEIGHTS

		WT
1.	Cost of Ownership	30.0
	(1) Acquisition cost	10.0
	(2) Operating cost	3.0
	(3) Maintenance cost	16.0
	(4) Salvage value	1.0
2.	Engineering/Product Assurance	20.0
	Vehicle Systems Considerations	13.0
	(1) Power take-off provisions	3.0
	(2) Seals	2.0
	(3) Transfer cases	3.0
	(4) Drive-line compatibility	3.0
	(5) Vehicle design changes	2.0
	Weight and Size Suitability	1.0
	(6) Weight	0.5
	(7) Dimensions	0.5
	Testing	6.0
	(8) Engrg tests	1.5
	(9) Quality Assurance tests	1.5
	(10) Warranty provisions	0.0
	(11) Exhaust emission control	3.0
3.	Suitability for Military Application	20.0
	Vehicle Performance	4.5
	(1) Fuel comsumption and economy	0.5
	(2) Drawbar pull	0.5
	(3) Braking ability	0.5
	(4) Acceleration	1.0
	(5) Maximum min speed	0.5
	(6) Productivity	1.0
	(7) Oil pick-up on slope	0.5

Figure 1a

FACTOR WEIGHTS (Cont'd)

	WT
Vehicle Effectiveness	3.5
(8) Reliability	
Replacement rates	1.0
Modes of failure	0.5
(9) Maintainability	1.0
(10) Availability	1.0
Vehicle Mobility	4.0
(11) Push-tow starts	0.5
(12) Initiation of vehicle movement	0.5
(13) Gear selection	0.5
(14) Power effect	0.5
(15) Weight effect	0.5
(16) Gradeability	0.5
(17) Rocking out	0.5
(18) On-road and off-road	0.5
Environmental Suitability	2.5
(19) Ease of start at low temp	0.5
(20) Cooling rqmt	0.5
(21) Submerged operation	0.5
(22) Temp range (-65 to +125° F.)	0.5
(23) Preservation and storage	0.5
Human Engineering	5.5
(24) Operator use	1.0
(25) Driver fatigue	0.5
(26) Safety	0.5
(27) User attitude (acceptance)	1.0
(28) Abuse to drive-line	1.0
(29) Driver training	1.0
(30) Noise	0.5

Figure 1b

FACTOR WEIGHTS (Cont'd)

		WT
4.	Maintenance and Logistics Support	2.5
	(1) Modular maintenance	1.0
	(2) Diagnostic testing	0.5
	(3) Maintenance allocation	1.0
	(4) Training requirements	3.0
	(5) Initial, follow-on provisioning	3.0
	(6) Publications	1.0
	(7) Mod. work orders	1.5
	(8) Scheduled maintenance	3.0
	(9) Overhaul	3.0
	(10) Unscheduled maintenance	3.0
	(11) Drive-line compl. repl.	3.0
	(12) Line item management	1.0
	(13) Special tools	0.5
5.	State-of-the-Art	5.0
	(1) Military experience	2.5
	(2) Commercial experience	1.5
	(3) State of technology	1.0

Figure 1c

Example of Rating Procedure

Factor Weights and Rating

Rating Value (-5 to +5) For Each Vehicle Type

		1/4 TON			1-1/4 TON			2-1/2 TON		
FACTOR	WT	PES	ML	OPT	PES	ML	OPT	PES	ML	OPT
COST OF OWNERSHIP	30	-2	+2	+6	-2	+2	+6	-4	+1	+6
(1) ACQUISITION COST	10.0	-3	-2	-1	-3	-2	-1	-5	-3	-1
(2) OPERATING COST	3.0	-1	0	+1	-1	0	+1	-1	0	+1
(3) MAINTENANCE COST	16.0	+3	+4	+5	+3	+4	+5	+3	+4	+5
(4) SALVAGE VALUE	1.0	-1	0	+1	-1	0	+1	-1	0	+1

Figure 2

Summary of Rating Values
By Vehicle Weight Class
On A -5 ("Con") to +5 ("Pro) Scale

VEHICLE WEIGHT CLASS	RATING VALUES			WEIGHTED RATING VALUES			AVERAGE RATING VALUE	"RISK"* PROBABILITY RATING
	PES	ML	OPT	PES	ML	OPT		
1/4-Ton	-.2	.3	.7	-.1	.8	1.5	.7 (.27)**	0.5%
1-1/4-Ton	-.2	.3	.7	-.2	.7	1.5	.7 (.29)	0.8%
2-1/2-Ton	-.3	.3	.7	-.4	.7	1.6	.6 (.33)	3.6%
5-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%
10-Ton	-.2	.3	.8	-.2	.8	1.8	.8 (.33)	0.8%

NOTE:

PES - Pessimistic
ML - Most Likely
OPT - Optimistic

* Risk probability that the rating is actually "CON" when the decision maker reached a "PRO" automatic decision.

** Figures in perentheses are standard deviations.

Figure 3

Maintenance Savings Costs for Vehicles With Automatic Transmissions

VEHICLE	MAINT COST	10% OF ANNUAL MAINT COST	12 YR MAINT COST	10% OF 12 YR MAINT COST	APPROX AUTOMATIC TRANS OVERCOST	YEARS FOR MAINT SAVINGS* TO RECOVER TRANS OVERCOST
1/4 Ton Trk, M151 Ser	$ 980	$ 98	$11,760	$1,176	$110 to $135	1.1 to 1.4
1-1/4 Ton Trk, M715 Ser	$2,325	$233	$27,900	$2,790	$290 to $440	1.2 to 1.9
2-1/2 Ton Trk, M44A2 Ser	$1,855	$186	$22.260	$2.226	-$130 to $1,120	0 to 6
5-Ton Trk, M809 Ser	$2,440	$244	$29,280	$2,928	$265 to $2,515	1.1 to 10.3
10-Ton Trk, M123A1C	$2,530	$253	$30,360	$3,036	$1,600 to $1,900	6.3 to 7.5

*Annual maintenance savings assumed as 10% of annual maintenance cost with manual transmission.

Figure 4

Acknowledgement

The author wishes to acknowledge the efforts of Mr. Irwin Goodman, under whose leadership the study was conducted.

AD P000653

DECISION RISK ANALYSIS OF THE RUN-FLAT FOLDING SIDEWALL TIRE

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1. INTRODUCTION & DESCRIPTION:

The purpose of the study was to raise the main issues and risks associated with the "Run-Flat Folding Sidewall" Tire.

The basic principle for the Folding Sidewall Tire was independently developed by the B. F. Goodrich Company and has been funded by the U. S. Army Tank-Automotive Command (TACOM) since July 1967. Development has been tried on various size tires, but to date only the 7.00 X 16 size has been successfully accomplished.

When loss of inflation occurs, the tire is fabricated to allow the sidewall to fold inward providing a triple layer for support. The characteristics and cost of both the current and development tire are shown in Table 1. All other characteristics, including ply rating, tread depth, wheel size and diameter are basically equal.

TABLE 1

CHARACTERISTICS

	STD	RUN FLAT
Type	Tube	Tubeless
Weight (lbs.)	27	41
Run-Flat Dia. (in.)	N/A	24.25
Production Cost (dollars)	14.69	49.00 (Contractor Estimate) (for up to 5000 Tires)

2. DISCUSSION:

Two major tests have been performed on the 7.00 X 16 Folding Sidewall Tire. One test of 15,000 miles was conducted by B. F. Goodrich in October 1968 and the second was run for 3,150 miles at the Yuma Proving Grounds. The reports did not provide an evaluation of vehicle component wear rates with respect to operating in a run flat condition or sufficient data to evaluate mobility or tread wear in varied geographical areas.

B. F. Goodrich tested the tires on a M151A1 operating 70% of the time on highway and 30% on gravel roads. Although the standard tire operates for 8000 miles in the field, based on the B. F. Goodrich test, they estimated the life of the Folding Sidewall Tires at 34,700 miles while the standard tire was estimated to last 17,400 miles. Vehicle handling was stated to be good, allowing near normal operation even with flat tires. The total test included operation for 300 miles with individual front tires flat and 175 miles with rear tires flat.

Yuma Proving Grounds tests identified a potential life of 12,000 miles for the Folding Sidewall Tire. Vehicle handling was basically identical for both types of tires, but some pulling was noted when a single tire was deflated. The test included 50 miles of operation of each tire in the deflated mode. Sand mobility tests were also conducted at Yuma. These showed that under normal pressures the tire showed increased mobility due to the spread of the tire.

Speed tests were run at Quantico, Virginia with the tires in both inflated and deflated modes. Speed varied from 23 MPH inflated to 16 MPH deflated.

One hundred tires were furnished to the Marine Corps for a six month troop test in early 1972. No reports have been received covering that operation. In addition, forty-two tires were furnished to the Vietnam Laboratory Assistance Program for a four month troop test which was not conducted due to the phase-down.

Additional testing would be required to determine items shown in Table 2 while major problems and questions related to logistics and procurement are shown in Table 3.

TABLE 2

ADDITIONAL TEST REQUIREMENTS

(1) Performance under Arctic conditions.

(2) Performance of tubeless Folding Sidewall tires on rims dented by cross-country operation.

(3) Tire chain effect.

(4) Retreaded tire operation (retreading accomplished but not tested.

(5) Cross-country operation in deflated mode with a loss of 3-1/8" ground clearance.

(6) Effects of deterioration or "memory" loss of the pre-stressed side wall during storage.

TABLE 3

(1) Mounting of the Folding Sidewall Tire can only be accomplished with a special Mounter-Demounter. The prototype unit costs $750 with no production estimate available.

(2) Proprietary rights for the tire belong to the B. F. Goodrich Company, therefore restricting the Government to a sole source procurement.

(3) Should the Folding Sidewall Tire be used for general or special purpose application?

(4) Could spare tires be eliminated on vehicles using Folding Sidewall Tires, and if so, what echelons would stock, transport, and repair?

(5) If the prime mover used Folding Sidewall Tires, what tires would the trailer mount and would spares have to be added to the trailer?

3. COST EFFECTIVENESS:

In a direct comparison of the tire systems, incorporation of a tube for the standard tire and the proportionate share of the Mounter-Demounter to the Folding Sidewall Tire establishes a tentative comparison cost of $17.05 versus $50.00 (Table 4).

TABLE 4

COSTS

	STD	RUN FLAT
Tire Procurement	$14.69	$49.00
Tube	$ 2.36	-
Mounter-Demounter		$ 1.00
	$17.05	$50.00

Using the estimated mileages given in both the Goodrich and Yuma Test Reports, cost per mile as an index of Cost Effectiveness is shown in Table 5.

TABLE 5

	B. F. GOODRICH TEST REPORT		YUMA TEST REPORT	
	STD	RUN FLAT	STD	RUN FLAT
Est. Tread Life (Mi)	17400	34700	8000	12000
Total Cost (dollars)	17.05	50.00	17.05	50.00
Cost Per Mile (cents)	.098	.144	.213	.417

Since the data in Table 5 only reviews potential tire mileage and ignores all other aspects of safety and combat effectiveness, two versions of utilization were reviewed - General Purpose and Special Purpose Application. In the actual study, both foam-filled and "combat" tires (12 ply sidewall) were considered but high procurement costs resulted in their being dropped from consideration.

In the General Purpose Application, the assumptions shown in Table 6-8 were made.

TABLE 6

PROBABILITY ASSUMPTIONS

GENERAL APPLICATION

- Probability of conflict - 75-85 - 50%
- Probability of specific truck in combat - 50%
- Probability of being exposed to hostile fire - 40%
- Probability of combat loss due to tires - 2%

.50 X .50 X .40 X .02 = .002

TABLE 7

TIRE ASSUMPTIONS

	STD	RUN FLAT
Average Life (Miles)	8000	12000
Tires Per Set	5	4
Mileage Per Set	10000	12000
Tires Per 60000 Miles	30	20
Cost	$511.50	$1000.00

TABLE 8

COMBAT LOSS ASSUMPTIONS

- Given that a combat loss occurs solely due to a flat tire completely incapacitating the vehicle, a cost penalty of $50,000 is assessed against the standard tire to represent personnel and material cost.

- Given that a tire is punctured during combat operations, a cost penalty of $2000 is assessed against the Folding Side-wall Tire to represent some loss in mobility.

The decision matrix for the General Purpose Application is shown in Table 9 and shows a total preference for the standard tire.

TABLE 9

DECISION MATRIX

TIRE	SYSTEM COST	COMBAT LOSS	NO LOSS .998	LOSS .002	TOTAL
Standard	$ 511.50	$50000.00	$510.48	$101.62	$ 611.50
Run Flat	$1000.00	$ 2000.00	$998.00	$ 6.00	$1004.00

For the Special Purpose Application, 1/4 ton vehicles mounting the 106 Recoiless Rifle were considered. The probabilities were changed to reflect a 90% probability of being assigned to a Combat Area and 90% probability of exposure to enemy fire. With these changes, the probability of loss due to tires changed to .008. With these changes, the decision matrix is as shown in Table 10 with again the standard tires showing a slight edge from a cost-effective standpoint.

TABLE 10

DECISION MATRIX

TIRE	SYSTEM COST	COMBAT LOSS	NO LOSS .992	LOSS .008	TOTAL
Standard	$ 511.50	$50000.00	$507.41	$404.09	$ 911.50
Run Flat	$1000.00	$ 2000.00	$992.00	$ 24.00	$1016.00

4. SENSITIVITY ANALYSIS:

Because the difference between tires in the Special Purpose Application was about ten percent, it was determined that a sensitivity analysis should be conducted on each of the parameters including tire mileage, unit cost, and combat loss probability. Each of these parameters were reviewed individually and combined one step variation was performed for the Folding Sidewall Tire. The individual parameters sensitivity analyses are shown in Tables 11-13. It can be readily seen that the standard tire consistantly reflects a lower total cost regardless of the sensitivity tested, except where the run-flat total cost is less than $44.78.

TABLE 11

EXPECTED TIRE COST - 60000 MILES

MILEAGE	RUN FLAT	STD
6000	$2,016.00	$1,082.00
6642	$1,882.00	$1,016.00
8000	$1,516.00	$ 911.50
10000	$1,216.00	$ 809.20
12000	$1,016.00	$ 741.00
13393	$ 911.50	$ 706.90
14000	$ 871.00	$ 691.56
16000	$ 766.00	$ 655.75

TABLE 12

UNIT COST SENSITIVITY

EXPECTED TIRE COST - 60000 MILES

RUN FLAT	STD ($17.50)	RUN FLAT
$38.00		$ 776.00
$41.00		$ 836.00
$44.78		$ 911.50
$47.00		$ 956.00
$50.00	$911.50	$1,016.00
$53.00		$1,076.00
$56.00		$1,136.00

TABLE 13

COMBAT LOSS PROBABILITY SENSITIVITY

NO LOSS	COMBAT LOSS	EXPECED TIRE COST - 60000 MILES STD	RUN FLAT
.996	.004	$ 711.50	$1,008.00
.995	.005	$ 761.50	$1,010.00
.994	.006	$ 811.50	$1,012.00
.993	.007	$ 861.50	$1,014.00
.992	.008	$ 911.50	$1,016.00
.991	.009	$ 961.50	$1,018.00
.990	.010	$1,011.50	$1,020.00
.989	.011	$1,061.50	$1,022.00
.988	.012	$1,111.50	$1,024.00

Combat loss sensitivity is a direct relationship of $8.00 for each $1000 increment of cost applied. Therefore, the allowable combat loss cost for the standand tire could increase to $63,000 before the Folding Sidewall Tire cost could result in an equal increase in the standard tire cost.

Since the unit cost and mileage for the standard tire are relatively firm based on historical data, a one step matrix in favor of the Folding Sidewall Tire was accomplished and is shown in Table 14. The average mileage was increased to 14,000 miles and the unit cost was reduced to $47.

TABLE 14

DECISION MATRIX - SENSITIVITY

TIRE	SYSTEM COST	COMBAT LOSS	NO LOSS .991	COMBAT LOSS .009	TOTAL
Std	$511.50	$50000	$506.90	$454.60	$961.50
Run Flat	$803.70	$ 2000	$796.47	$ 25.23	$821.70

5. CONCLUSIONS:

In the final evaluation, it was found that the standard tire was always more cost effective. If we held the standard tire mileage and unit cost at their current established figures of 8000 miles and $17.05, by varying the values for the Folding Sidewall Tire it can be made more cost effective. Variations in the conditions shown in Table 15 will reverse the original decision.

TABLE 15

VARIATION IN DATA

• Probability of Combat Loss	.010
• Average Combat Loss Cost - Standard Tire (with Folding Sidewall held at $2000)	$63,000
• Average Mileage - Folding Sidewall Tire	13,400
• Unit Cost - Folding Sidewall Tire	$ 44.78

If further testing and a more definitive unit production cost should revise the current data to show that the Folding Sidewall Tire is more cost effective, logistics costs associated with introduction of the new items into the supply system and revised shipping and storage costs should be reviewed prior to final acceptance.

AD P000654

Platoon Early Warning Device (PEWD) Decision Risk Analysis (DRA)

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1. Problem

a. The objective of this study was to perform a cost, schedule and technical Decision Risk Analysis (DRA) on the Platoon Early Warning Device (PEWD) to determine the Engineering Development alternative(s) that present the lowest risk to the government.

b. The PEWD program is about to enter into Engineering Development. A Decision Risk Analysis (DRA) is required before that milestone can be reached. Therefore, PM REMBASS requested that Systems Analysis Office, USAECOM, perform the DRA.

c. Presently there are a number of personnel and/or vehicle sensor programs, including the Army MISER[1] and PSID[2]/PEMID[3] and the Navy SURSS[4] programs. All of these programs have different requirements and applications. This DRA evaluates the schedule, cost and performance risks of meeting the PEWD specifications for each of those programs, and also for new development programs.

2. Methodology

a. Approach

The approach utilized for this PEWD system DRA was as follows:

(1) The alternatives were generated during a meeting held by PM REMBASS to discuss PEWD development. After the meeting, REMBASS personnel were contacted so all the events (activities) necessary for a complete and successful PEWD engineering development program could be determined.

(2) The RISCA networking model was selected to assist in assessing the risk of the individual programs.

(3) The required cost and scheduling information for each event (activity) of each alternative, along with technical data on development effort and overall program approach, were requested from seven of the key sensor personnel.

(4) After the cost, schedule and technical information was received from the above mentioned personnel, the inputs were analyzed with PM REMBASS

1. MISER - Mini Sensor Relay
2. PSID - Patrol Seismic Intrusion Detector
3. PEMID - Patrol Electromagnetic Intrusion Detector
4. SURSS - Small Unit Remote Sensor System

personnel to assure that they were credible and responsive to what was requested.

(5) The event cost, schedule and technical probability data were then converted to activity data for risk analysis network model, RISCA. RISCA output provided the probability and cumulative density functions of cost and schedule for each of the alternatives considered.

(6) Cost and schedule outputs of RISCA were plotted versus the cumulative density function to determine the relationships among alternatives. The alternatives were then ranked with respect to cost and schedule independently.

(7) Technical data were then analyzed so that the alternatives could be ranked with respect to technical performance.

(8) The cost, schedule and technical risk data for each alternative were then combined to order the alternatives according to overall risk. The level of significance between groups of alternatives was established.

(9) Then a sensitivity analysis was performed and it was determined that the ranking (ordering) did not change and the level of significance was not affected.

2. RISCA

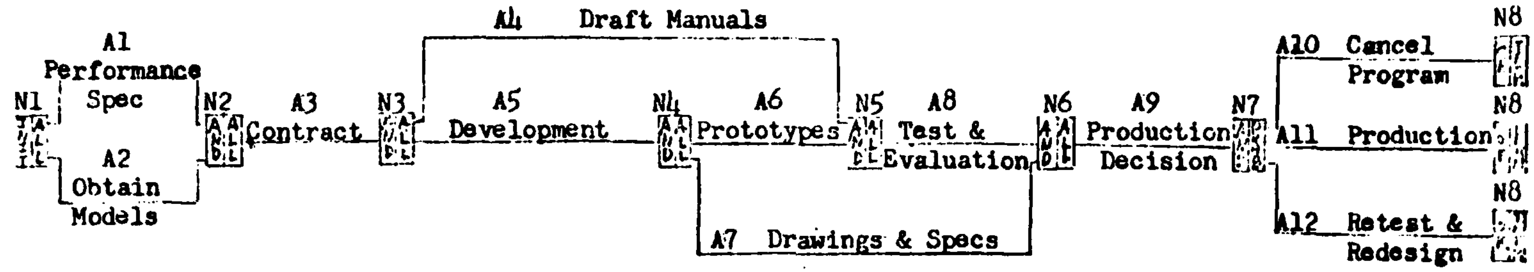
a. RISCA, an acronym for Risk In Schedule and Cost Analysis, is a mathematically oriented simulation networking technique. It is used to assist management in the decision-making process involving risk assessment on on-going or new projects. RISCA enables the user to integrate time and cost into a common measure of risk. It has an extensive array of logical and mathematical features which make it possible to analyze complex systems and problems in a less inductive manner than traditional methods.

b. RISCA consists basically of two parts. Part one consists of constructing a graphical network that is representative of the project. Figure 1 is an example of the PERT like network used by RISCA.

c. Project activities are represented by arcs, and events or milestones are represented by nodes. The arcs and especially the nodes are used to create real time decision capability. The flexibility and array of capabilities structured in nodes and arcs permit modeling of unusual decision situations. Input to RISCA model consists of time, which is the independent variable with a number of input distributions possible, and cost which is dependent upon time plus a constant value.

d. Part two of RISCA procedure consists of analyzing the network through the use of computer program. Networks are constructed so that various combinations of alternative activities could occur to make a project successful. The computer program explores alternative ways of completing the project through the technique of simulation. Upon simulating the network a sufficient number of times, the computer program prints out terminal node time and cost data by the use of probability density functions, cumulative density functions, mean values and standard deviation.

I. Network for Alternatives AI, AII, BI, BII, DIa, DIb (Contractor Development)



II. Network for Alternatives AIII, BIII & DII (Laboratory Development)

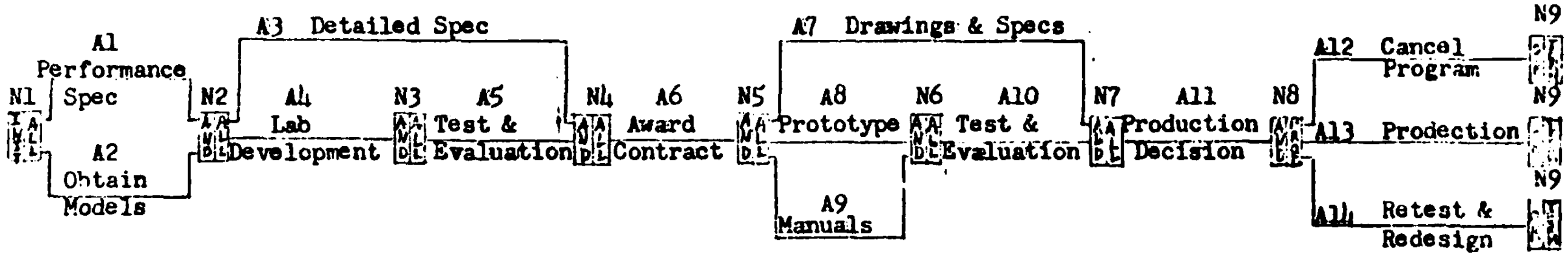


Figure 1

3. Assumptions

To perform a Decision Risk Analysis a number of basic assumptions are required. The following assumptions were used to perform this DRA on the PEWD:

a. The PEWD development program can build upon existing technology of the Army MISER or PSID/PEMID programs, or the Navy SURSS program, or upon new development, each having different risks and risk areas.

b. PEWD development can be performed by qualified contractors, including Dorsett, and by the Combat Surveillance and Target Acquisition Laboratory; however, the associated risks will vary dependent upon the developer.

c. This DRA has considered the complete Life Cycle cost of the PEWD, however, the difference if costs for each alternative for prototype unit cost, production unit cost and Logistic and Maintenance cost is not available. Thus, this DRA will only address development program effort.

4. Alternatives

The results of the PEWD meeting at REMBASS provided the following PEWD development and procurement options that were available:

a. Development options for PEWD were:

(1) Take advantage of the Navy SURSS effort by modifying the hardware being developed to meet the PEWD SDR. Some of the aspects that were considered are: add wire transmission mode, modify data transmission, add transducers, add decision logic, and modify readout display.

(2) Take advantage of the MISER effort by modifying the hardware being developed to meet the PEWD SDR. The following aspects were considered: add wire transmission mode, modify data transmission bit rate, add transducers, add decision logic, and modify readout display.

(3) Take advantage of both the Navy and MISER efforts by modifying specific items of hardware being developed to meet the PEWD SDR.

(4) Go for a new design based on a performance specification. This effort involves engineering development including human engineering and software.

(5) Go for a government design based on detailed specifications which reflect in-house government development effort. This effort involves engineering and software.

(6) Take advantage of PSID/PEMID by modifying the hardware to meet the PEWD SDR. The following aspects were considered: add wire transmission mode, modify data transmission, add transducers, add decision logic, and modify readout display.

b. Procurement options for PEWD were:

(1) Modify existing contract(s) for contractor to modify hardware under development in accordance with a performance specification (this will constitute a sole-source contract to Dorsett).

(2) Modify existing contract(s) for contractor to provide models which would be used to award a new contract for contractor to modify hardware in accordance with a performance specification (multi-source).

(3) Modify existing contract(s) for contractor to provide models which would be used for the laboratory to modify to meet PEWD requirements and develop detailed specifications, drawings and models which would be used to award a contract for hardware (prototypes).

(4) Award a contract based on a performance specification where the level of specification would be:

(a) Broad (Basically the SDR)

(b) Narrow (Preliminary Design)

c. A review of the foregoing development and procurement options resulted in the formulation of the following alternatives for the PEWD SDR:

<u>ALTERNATIVE</u>

A Add to the Navy Program

I Navy contractor modify hardware in accordance with PEWD performance specification.

II Obtain SURSS models and award contract for development in accordance with PEWD performance specification.

III Obtain SURSS models and have CSTA Laboratory modify models to meet PEWD requirements, and award contract for hardware (prototypes).

B Add on to the MISER Program

I MISER contractor modify hardware in accordance with PEWD performance specification.

II Obtain MISER models and award contract for development in accordance with PEWD performance specification.

III Obtain MISER models and have CSTA Laboratory modify models to meet PEWD requirements, and award contract for hardware (prototypes).

C Add on the Navy and MISER Programs

I Have Navy & MISER contractor modify hardware in accordance with PEWD performance specification.

II Obtain Navy & MISER models and award contract for development in accordance with PEWD performance specification.

III Obtain Navy & MISER models and have CSTA Laboratory modify models to meet PEWD requirements, and award contract for hardware (prototypes).

D New Design

Ia Award independent development contract based on "broad" performance specifications (PEWD SDR).

Ib Award independent development contract based on "narrow" performance specifications (preliminary technical design).

II Award independent development contract based on a government design identified in a detailed specification.

E Modify PSID/PEMID hardware
(NOTE: Since this approach would entail a major redesign effor it is considered essentially a new design).

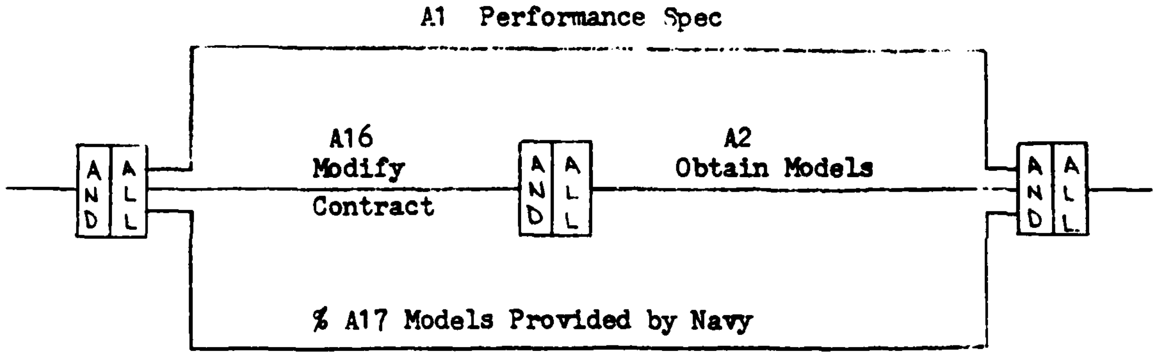
d. Alternatives CI, CII, and CIII each had a sub-alternative associated with them because these alternatives were a combination of both Navy and MISER Programs. These sub-alternatives and alternatives upon analysis were considered subsets of A&B alternatives and were not evaluated because of this and due to lack of resources. Also technically, C alternatives were considered at least as difficult to accomplish as A and B individually.

e. Alternative E, Modification of the PSID/PEMID hardware, was initially considered but later eliminated due to the fact that PSID/PEMID presents a radical departure from the PEWD spec. The PSID/PEMID design cannot be readily modified and is essentially a new design.

f. Alternatives AI, AII, BI, BII, DIa and DIb all have the same basic Network I of Figure 1, however the activity A2 for obtaining models is deleted for Alternatives AI and BI.

g. Network II of Figure 1 is utilized by Alternatives AIII, BIII and DII. Alternative DII, however, doesn't require activity A2 for obtaining models but after Development test and evaluation (A5), the activities A20, A21 and A22 must be added for Contract Decision and probability of Retest and Redesign.

h. A further modification of Networks I and II, Figure 1 is required in activity for obtaining models for Alternatives AII and AIII as shown below because of the uncertainty of obtaining models from the Navy.



Note: A-15 and A-18 are Dummy Variables required by RISCA.

5. Schedule & Cost Risk

a. The RISCA networking model was used to evaluate cost and schedule risks for the alternatives considered. Figure 1 contains the networks employed for this analysis which are the activities provided by REMBASS personnel for the development of PEWD for Contractor Development (Network I) and Laboratory Development (Network II). These networks were used to obtain distribution of time and cost for the development of the PEWD depending upon the alternative.

b. A matrix was generated to obtain estimates of time and cost for the events and milestones for each alternative that was considered. Estimates of time and cost of the PEWD are based on inputs from key sensor personnel. Each person was requested to provide the optimistic, most likely, and pessimistic time and cost for each alternative. Figure 2 shows a sample of the matrix and the data received. These data were then converted into activity times and costs as required by RISCA as shown in Figure 3.

c. The RISCA networking model provided for the terminal nodes, time and cost data by probability density function, cumulative density function, mean (expected) value and standard deviation for each alternative considered. The mean and 95% probability of completion for each alternative were extracted and displayed on Figure 4. The mean value is that value that is expected to occur and the 95% level indicates there is a 95% probability that the development time/cost will not exceed that particular value.

d. The cumulative density functions for all alternatives were graphically displayed on a single page so the level of significance could be determined for both time and cost independently. The level of significance established during this analysis is shown under column entitled "Risk Value" in Figure 4.

6. Technical Risk

a. The seven key sensor personnel were also requested to provide the technical (performance) information on each of the PEWD alternatives. A matrix was again generated and the two main areas were: (1) assessment of technical risk associated with the development effort and overall program approach and (2) identify which approach is considered best. Any potential problem areas and supporting rational were also requested. In order to evaluate each of the two areas, a scoring criteria was provided to the personnel with the matrix. A value of 1 was given for very poor and 10 for excellent with poor, good, very good in between.

b. The technical (performance) inputs from each of the evaluators were combined to generate a numerical score for each PEWD development alternative regarding development effort and overall program areas. The results are shown in Figure 4. Upon analysis of the technical scores, it was determined that they could be grouped as shown under column entitled "Risk Value."

7. Results Obtained

To obtain the recommended PEWD Development alternatives the following procedure was used:

a. Determine the alternatives that are significantly better than the other alternatives for time, cost and performance independently and then rank the risk of each alternative. A risk value of 1 thru 4 was assigned where 1 was the worst alternative and 4 was the best.

b. Weighted the alternatives as follows:

	Time	Cost	Performance
a	2	4	4
b	3	5	2

This provides a method by which a sensitivity analysis can be performed.

c. Multiply the risk value of each alternative of (a) above by the applicable weight of (b) above to obtain a numerical score.

d. Numerically ranked each score of (c) above to show least to highest risk alternatives in descending order as shown:

DIb	New Design, Narrow Performance Spec
BI	MISER Program, Sole Source Dorsett from Performance Spec
DII	Government Development, Procure Prototypes
DIa	New Design, Broad Performance Spec
BII	MISER Program, Obtain Models, Multi-Source Development
BIII	MISER Program, Obtain Models, Lab Development
AI	Navy Program, Sole Source Dorsett from Performance Spec
AII	Navy Program, Obtain Models, Multi-Source Development
AIII	Navy Program, Obtain Models, Lab Development

The ranking of the alternatives are listed with a line between those alternatives that are significantly worse than the group above. It was determined from the sensitivity analysis that the ranking did not change and the level of significance was not affected.

8. <u>Results Impact</u>:

a. This Decision Risk Analysis then provided the decision maker, PM, REMBASS, with three alternatives out of the original nine on which his decision could be based as to the best alternative for PEWD engineering development program. These three alternatives were DIb, BI and DII (i.e. New Development based on Narrow Specifications, Sole Source Development to Dorsett based on MISER design, and ECOM Laboratory Development, respectively).

b. The PM, REMBASS selected DIb as the best alternative because it was a multiple-source solicitation, not sole source as BI alternative. Alternative DII was also eliminated because it was an in-house project requiring an increase in the number of Laboratory personnel which was not considered advantageous at this time.

D New Design

Ib Narrow Performance Spec

	TIME			COST		
	Optimistic	Most Likely	Pessimistic	Optimistic	Most Likely	Pessimistic
1. Performance Specification	3	4	6	24	32	48
2. Provided Models	--	--	--	--	--	--
3. Obtain Models	--	--	--	--	--	--
4. Contract Award	4	5	6	16	20	24
5. Detailed Specification	--	--	--	--	--	--
6. Development	7	8	9	90	130	170
7. Test	--	--	--	--	--	--
8. Probability Retest/Redesign	--	--	--	--	--	--
9. Retest and/or Redesign	--	--	--	--	--	--
10. Prototype	2	3	4	100	120	140
11. Test & Eval by Lab, Contractor, TECOM	5	7	10	40	56	[illegible]
12. Manuals	7	10	13	45	52.5	58
13. Drawings & Specifications	4	6	8	25	32.5	40
14. Production Decision	2	3	5	25	25	25
15. Probability Cancelling Program	--	8%	--	--	--	--
16. Probability Entering Production	--	57%	--	--	--	--
17. Probability of Retest/Redesign	--	35%	--	--	--	--
18. Retest and/or Redesign	3	4	5	45	60	75

Sample Data Collection Sheet

Figure 2

ALTERNATIVES

DIB NEW DESIGN NARROW PERFORMANCE SPEC

ACTIVITY	DISTRIBUTION	TIME: OPTIMISTIC	MOST LIKELY	PESSIMISTIC	COST: FIXED	VARIABLE
A1	TRI	3.00	4.00	6.00	.00 +	8.00 T
A3	TRI	4.00	5.00	6.00	.00 +	4.00 T
A5	TRI	7.00	8.00	9.00	-205.00 +	45.00 T
A6	TRI	2.00	3.00	4.00	60.00 +	20.00 T
A4	TRI	7.00	10.00	13.00	27.50 +	2.50 T
A7	TRI	4.00	6.00	8.00	10.00 +	3.75 T
A8	TRI	5.00	7.00	10.00	.00 +	8.00 T
A9	TRI	2.00	3.00	5.00	25.00 +	.00 T
A10	CON	.00	.00	.00	.00 +	.00 T
A11	CON	.00	.00	.00	.00 +	.00 T
A12	TRI	3.00	4.00	5.00	.00 +	15.00 T

NODE	INPUT RULE	OUTPUT RULE
N1	INIT	ALL
N2	AND	ALL
N3	AND	ALL
N4	AND	ALL
N5	AND	ALL
N6	AND	ALL
N7	AND	PROB
N8	OR	TERM

Sample Input Data in RISCA Form

Figure 3

Mean & 95% Values for Time, Cost & Performance vs PEWD Development Alternatives

	TIME (Months)			COST (Thousands)			PERFORMANCE (Units)		
	Mean	95%	Risk Value	Mean	95%	Risk Value	Develop	Program	Risk Value
AI	33.4	38.4	2	572	664	2	320	30.5	1
AII	37.0	42.0	3	602	674	2	29.0	25.0	1
AIII	41.4	47.0	1	600	676	2	31.0	30.0	1
BI	29.5	33.3	4	512	575	4	42.0	42.5	2
BII	34.4	38.0	2	562	628	3	35.0	28.0	3
BIII	38.5	42.4	3	558	620	3	35.0	34.0	3
DIa	31.6	36.6	4	514	598	4	32.5	33.0	1
DIb	31.2	33.8	4	501	538	4	45.5	43.5	4
DII	35.6	39.1	2	492	545	4	46.0	43.0	4

Figure 4

DECISION RISK ANALYSIS FOR THE DIGITAL DATA LINK (DDL) PROGRAM

Mr. Edwin M. Goldberg

US Army Electronics Command

1. Discussion of the Problem

The problem is to determine the best approach (schedule, cost, performance) for accomplishing the DDL mission of the Air Traffic Management System (ATMS). The impetus for this effort is the requirement that the Operational Test-II (OT-II) date for the DDL program coincide with the OT-II date for the Air Traffic Management Automated Center (ATMAC) development program. This effort commences with the consideration of the current status of two preliminary study contracts and terminates with the consideration of all viable alternatives for arriving at an OT-II date for the DDL system.

2. Preliminary Study Contracts

A UHF Preliminary Design and Test Contract has been awarded to Contractor A and an HF/VHF Preliminary Design and Test Contract has been awarded to Contractor B. The objectives of these study efforts are to formulate a recommended approach and preliminary design for the DDL program. Outputs of these study contracts may be characterized by the terms Fully Compliant System (FCS) and Austere System (AS). The fully compliant system is one which meets all of the specification requirements; the austere system is an alternate approach, based on reduced system requirements, which utilizes existing equipment to the maximum extent possible.

Three levels of compliance to the specification are considered for both the UHF and VHF portions of the electromagnetic spectrum. The austere and fully compliant systems are described above, a third level of compliance is introduced, and is referred to as the Most Likely Compromise System (MLCS). It is expected that the most likely compromise system could relax the specification requirements in addition to utilizing existing equipments less than the maximum extent possible. In short, the MLCS represents the current assessment, based on engineering judgement, of the type of DDL system that would eventually be produced. For the HF portion of the spectrum, the austere system only is considered.

3. Alternative Solutions

Two categories of alternatives are addressed. The first relates to the three viable levels of compliance to the preliminary DDL study specification (FCS, MLCS, AS) for either the UHF or VHF DDL system. The second relates to the viable alternative Advanced Development-Engineering Development (AD-ED) program development plans.

a. Design Levels of Compliance - For the UHF and VHF portions of the electromagnetic spectrum we have:

Compliance Alternative I - Develop the fully compliant system

Compliance Alternative II - Develop the most likely compromise system

Compliance Alternative III - Develop DDL system emphasizing austerity.

For the HF portion of the spectrum, only Compliance Alternative III is applicable.

b. Program Development Plan Options - Nine viable AD-ED alternative program development plans are:

Alternative 1 - One AD contract and one ED contract

Alternative 2 - One AD contract and two ED contracts

Alternative 3 - Two AD contracts and one ED contract

Alternative 4 - Two AD contracts and two ED contracts

Alternative 5 - One combined AD/ED contract

Alternative 6 - Two combined AD/ED contracts

Alternative 7 - One ED contract (by-pass AD contract)

Alternative 8 - Two ED contracts (by-pass AD contract)

Alternative 9 - One ED contract (by-pass AD contract with assumption of input from other systems being developed)

4. Methodology

The methodology used for this analysis was to create a complexity ordered sequence of decision networks for each of the alternatives. The simplest network is referred to as the Macro Configuration. This configuration is the construct by which high level management presents a problem to the analyst. The analyst expands, bounds and, in general, defines the problem on a level comparable to the manner in which it was initially presented. The analyst then presents his interpretation and approach to the program manager for a validity check. Figure 1 is the Macro Flowchart for Alternate Program Development Plan #1. The Micro Configuration is a detailed flow diagram which is evolved from the macro configuration. Figure 2 is the Micro Flowchart for Alternate Program Development Plan #1. Finally, the micro flowcharts are utilized to develop the RISCA Network. In essence, the transition from the micro flowchart to the RISCA network involves translating the micro configuration into a format compatible to the RISCA computer model.

RISCA is a computer network analysis program that uses a Monte Carlo simulation of a given network to provide frequency distributions of time and cost for the activities of the network analyzed.

5. Input Considerations

Schedule, performance and cost data were predicated on the combined best engineering judgment of the Comm/ADP Lab and Systems Analysis Division personnel. Inputs to the RISCA Program included the most optimistic, the most likely, and the most pessimistic dates for each activity of the RISCA network as well as probabilities of passing each of the pertinent tests.

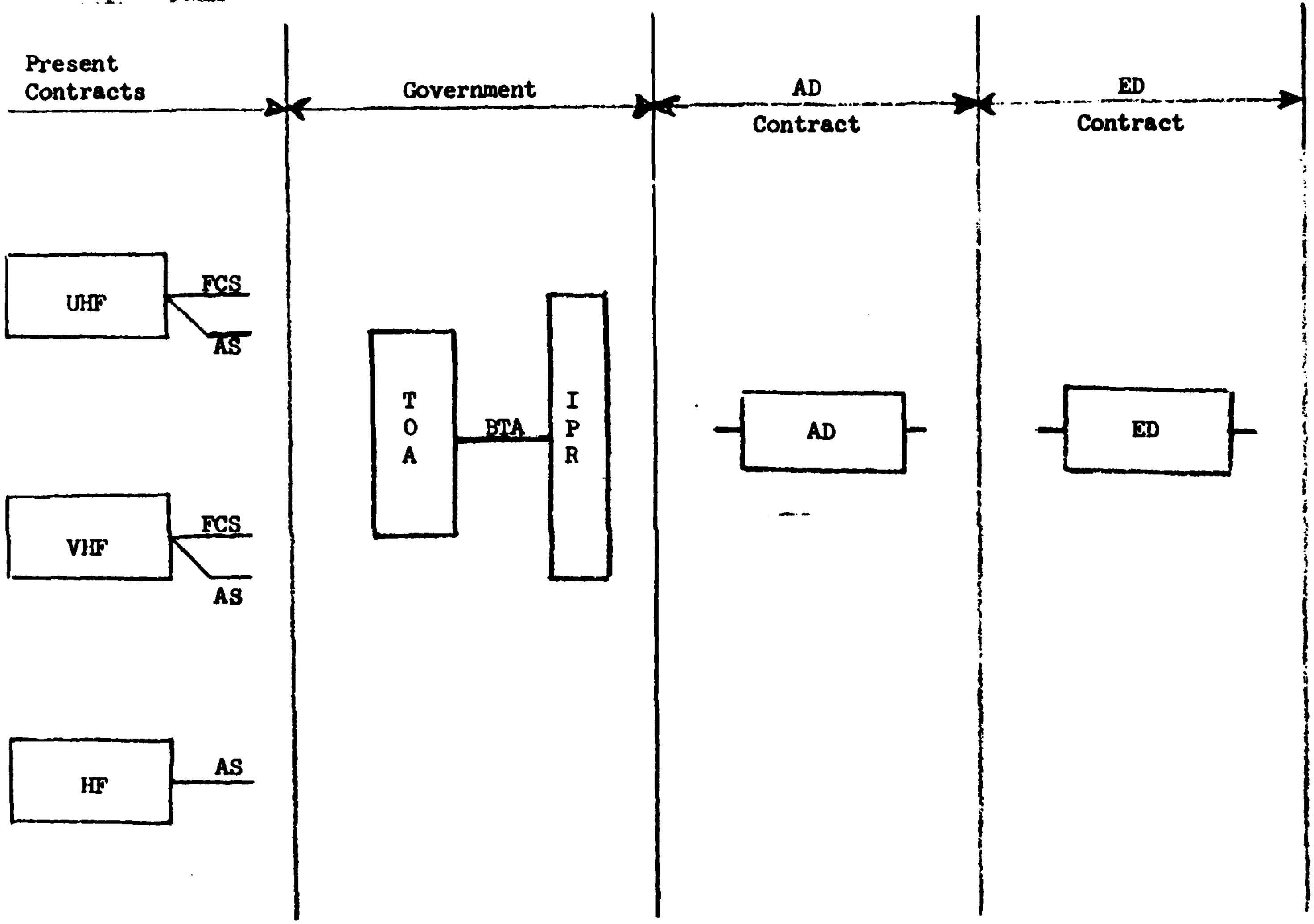


Figure 1 Macro Flow Chart
Alternative Program Development Plan #1

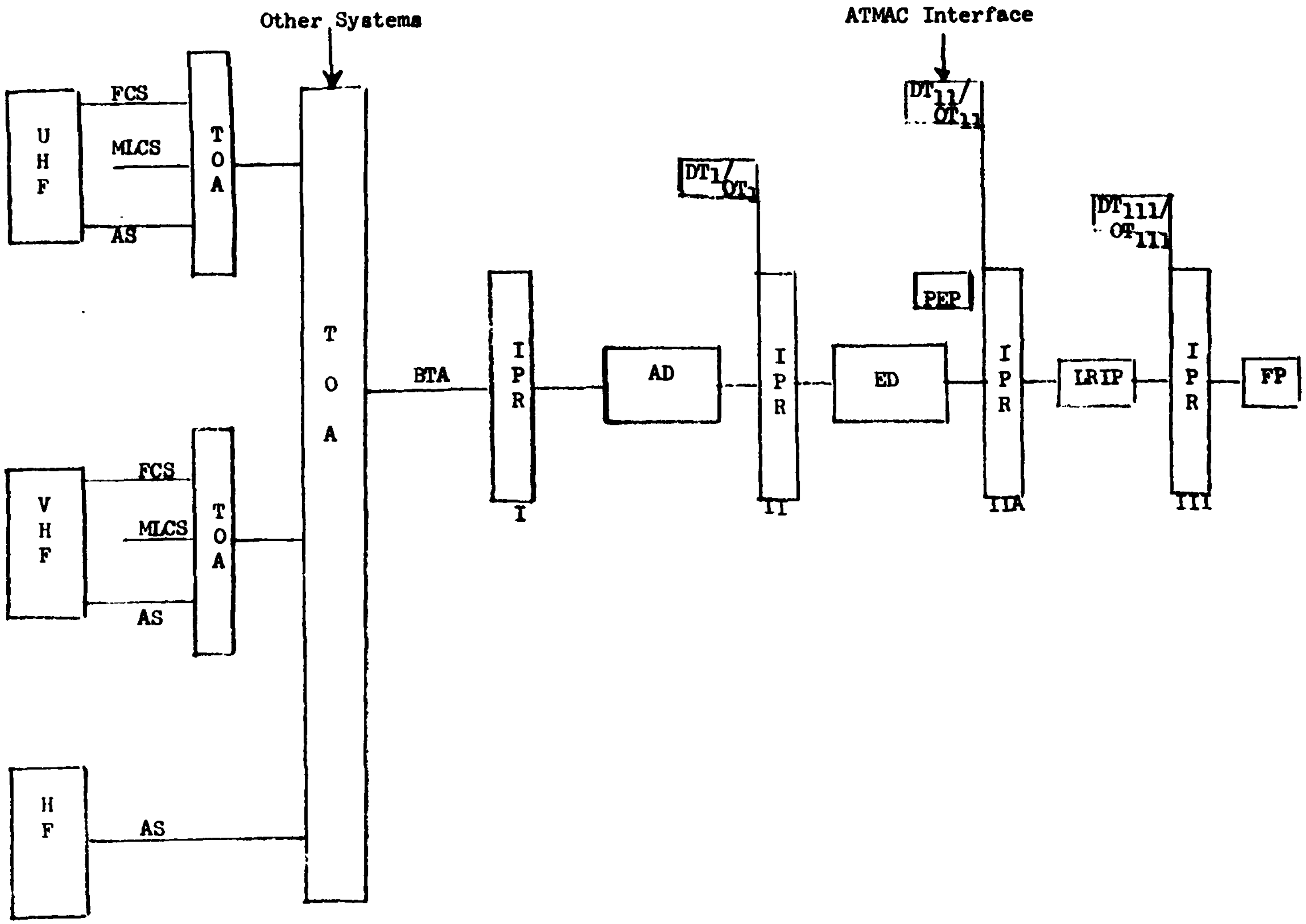


Figure 2. Micro Flow Chart

6. Results

The results of this decision risk analysis may be condensed into three schedule overview figures and one ranking summary table.

a. Schedule Overview Figures - The most likely and pessimistic completion dates for each of the program development plan options associated with the fully compliant system, the most likely compromise system and the austere system are shown in Figures 3, 4 and 5, respectively. For each alternative development plan, the date on the left of a rectangular block represents an estimate of the most likely completion date and the date on the right of the rectanble is indicative of the projected pessimistic completion time. The most likely completion date is the date on which the cumulative probability of completion reaches 0.5. The pessimistic completion date is the date on which the cumulative probability of completion reaches 0.95.

b. Ranking Summary (Table I) is a machanism employed to determine the recommended program development plan. All alternative program development plans have been ranked (Rank 1 = best, Rank 2 = second best, ...) with respect to each of the following categories:

Schedule
- Fully Compliant System (FCS)
- Most Likely Compromise System (MLCS)
- Austere System (AS)

Technical Risk

Cost

It is noted that the ranking process, per se, provides only a realtive measure of the alternatives within each category. The quantitative notion of degree (e.g., that one alternative is so much better than another) is afforded via the use of horizontal lines separating the alternatives. Double horizontal lines are indicative of significant quantitative diffferences between separated alternatives. In regard to contractual costs, the numbers in parentheses are ratios of the cost of a particular alternative to the cost to the lowest cost alternative. The cost estimate for the lowest cost development plan is $2,898,000.

7. Ranking Summary Discussion

The Schedule Rank Order, for each level of compliance was obtained from the output of the RISCA model. Also, in regard to schedule, it is noted that the alternative development options have been ranked on the basis of their expected (most likely) completion dates. Cost data were based on the best engineering judgement of Comm/ADP personnel. Finally, the technical risk order was predicated on the combined best engineering judgement of Comm/ADP and Systems Analysis Division personnel.

8. Conclusions

The following two paragraphs are predicated on the consideration of the summarized results shown in Table 1.

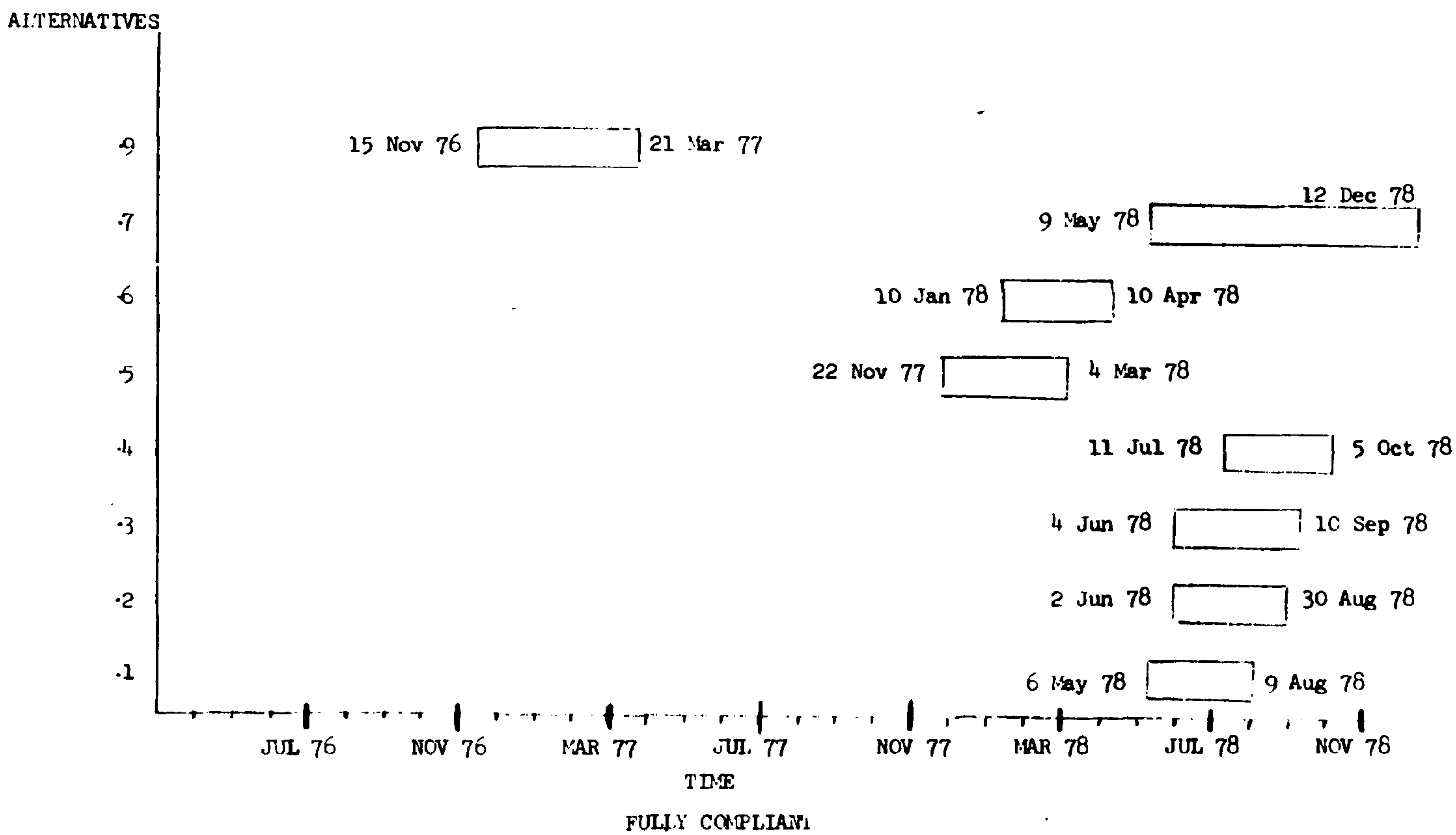
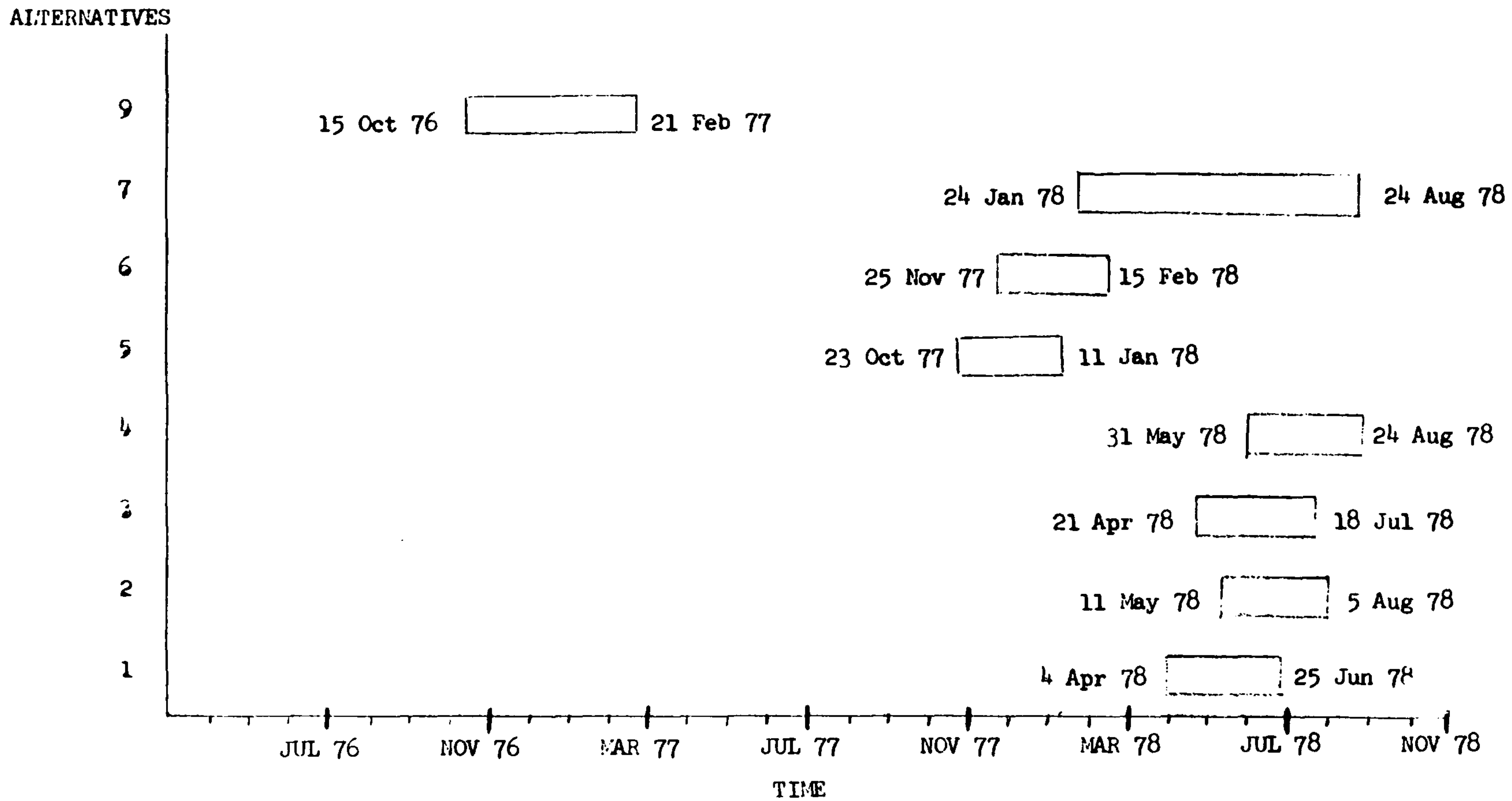
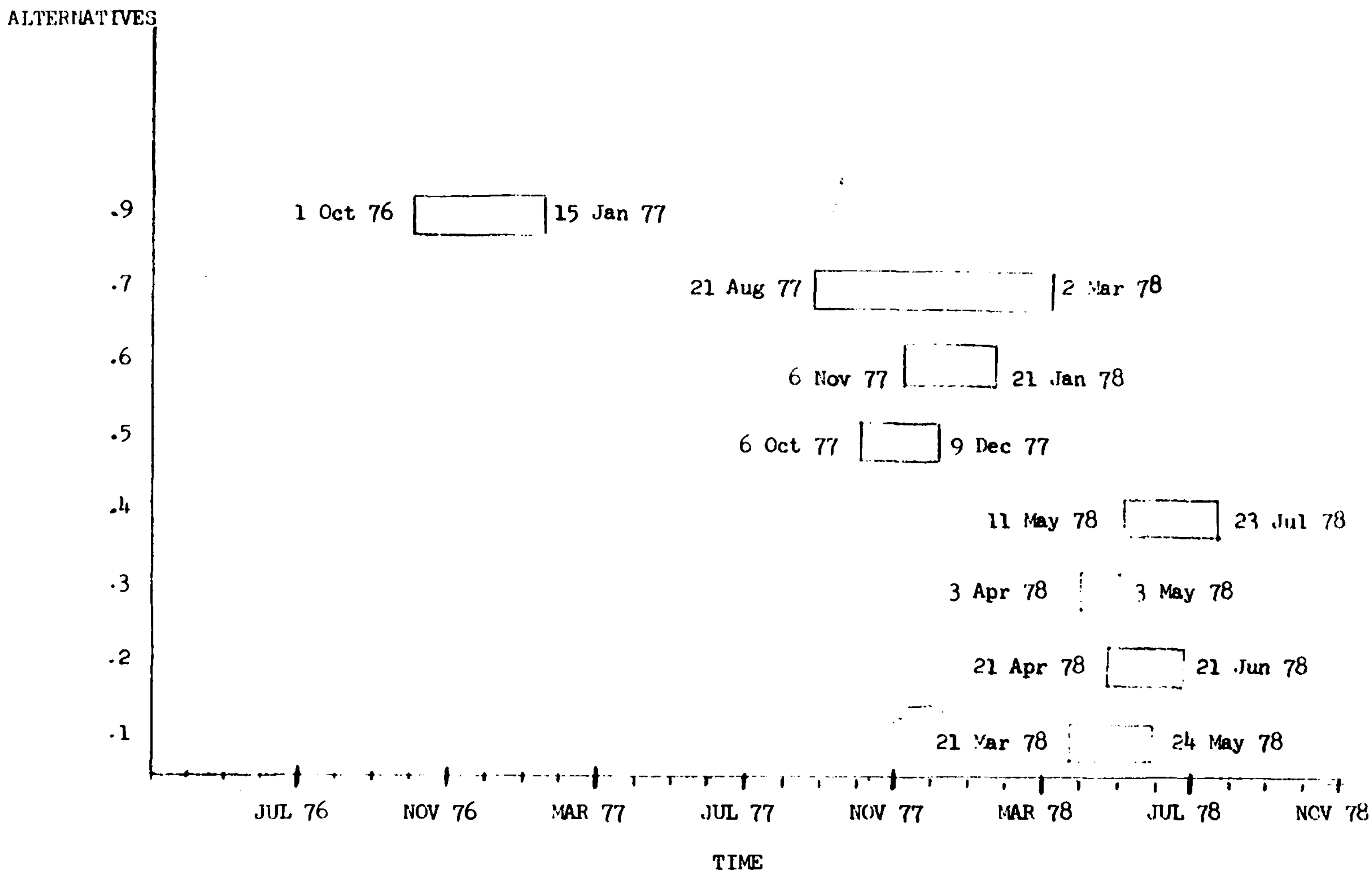


Figure 3 Most Likely and Pessimistic Completion Dates



MOST LIKELY COMPROMISE SYSTEM

Figure 4 Most Likely and Pessimistic Completion Dates



AUSTERE SYSTEM

Figure 5 Most Likely and Pessimistic Completion Dates

a. Based on the joint consideration of schedule, technical risk and cost, Alternative Development Plan #9 is the recommended appraoch. However, it is noted that the success of this plan is conditioned on the possibility of writing a good ED specification without benefit of direct AD experience. In the event that the assumption on which Alternative 9 is predicated (i.e., having enough data from other services to write a good ED specification) may not prove valid, then the following rationale is pursued in order to select a preferred alternative from among the remaining eight.

b. The rationale for selecting a second recommended approach is presented. In regard to schedule, Table 1 indicates that Alternative Development Plans #5 (for all levels of compliance), #6 (for all levels of compliance), #7 (austere) and #8 (austere) are the top contenders for the second preferred alternative. In regard to the consideration of technical risk, alternative #6 is preferred over alternative #5 (primarily because alternative #6 has two competitive AD efforts as opposed to one for alternative #5). Also, alternative plans #7 and #8 are eliminated because of the high technical risk associated with by-passing the AD phase (i.e., in going directly from the current preliminary study efforts into an ED phase). These alternatives are distinguished from alternative #9 by the fact that information pertinent to DDL developments of other services is not a major consideration. In regard to cost, alternative #5 is preferred over alternative #6. Finally, via the joint consideration of schedule, technical risk and cost, alternative #5 is selected as the second recommended approach.

In conclusion, it is noted that any final decision on the DDL effort should take into account the risks associated with ATMAC meeting its projected schedule as well as the monetary allocation for the overall ATMS project.

TABLE I

RANKING SUMMARY

	RANK ORDER	SCHEDULE AS	SCHEDULE MLCS	SCHEDULE FCS	SUBJECTIVE TECHNICAL RISK	COST		
BEST	1	9	9	9	4	7,9	(1)	$2.898M
	2	7	5	5	3	5	(1.40)	
	3	8	6	6	6	1	(1.41)	
	4	5	7	7,1	2	3	(1.85)	
	5	6	8	2,3,8	1	8	(1.89)	
	6	1	1	4	5	2	(2.30)	
	7	3	3		9	6	(2.72)	
	8	2	2,4		8	4	(2.73)	
WORST	9	4			7			

KEY:

Alt. 1 AD-ED

Alt. 2 AD < ED / ED

Alt. 3 AD / AD > ED

Alt. 4 AD / AD >< ED / ED

Alt. 5 AD/ED

Alt. 6 AD/ED
AD/ED

Alt. 7 ED

Alt. 8 ED
ED

Alt. 9 Other Systems → ED

REMOTELY MONITORED BATTLEFIELD SENSOR SYSTEM (REMBASS) PROGRAM DECISION RISK ANALYSIS

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1. System Description

a. REMBASS is a system of unattended ground sensors with associated communications, processing and display equipment. The sensors can be hand, air or ballistically emplaced depending on the specific situation. Also, several different sensor technologies are available so the user can select the best sensor for his specific situation. The sensors will detect, classify and locate targets within their range.

b. The information developed by the sensor is sent to a monitoring station through a transmission network composed of relays. The monitoring station contains processing and display equipment so the operator can readily interpret the information and send it elsewhere, if required.

c. The system consists of many small parts which can be put together in many combinations to form a REMBASS system. This flexibility allows the user to adapt REMBASS to his specific mission requirements so that he can always gain maximum benefit from the system.

2. Problem

a. The REMBASS program was in the Advanced Development (AD) phase in February 1973. At that time, the current plan projected that the REMBASS would enter Engineering Development (ED) in July 1973. The system was encountering problems in certain critical technical areas which were essential to the ultimate success of the REMBASS. Examples of these critical areas are target position location and target classification.

b. The Project Manager (PM) and personnel in the Office of the Chief, Research and Development (OCRD), Department of the Army, were concerned that these technical difficulties would not be overcome prior to the ED decision date of July 1973. In mid-February 1973 OCRD directed the PM not to enter ED in July 1973, but to remain in the AD phase. The PM was to revise his program to postpone the ED decision date to such time that all critical technical problems would be overcome. This revised program was to be presented to LTG Gribble (CRD) for review and approval.

c. The PM's approach to developing a revised program was to formulate as many reasonable alternative programs as possible. These programs would be examined and a coarse evaluation made to eliminate any alternatives which were obviously unacceptable. The remaining alternatives would then be subjected to a thorough analysis to determine the best approach available.

d. The PM's staff developed four distinct alternative programs which would comply with the OCRD guidance. The staff's coarse analysis eliminated two alternatives as being significantly more costly and having unacceptably long schedules. The PM then requested that the Systems Analysis Office, USAECOM, review his staff's analysis and perform a Decision Risk Analysis (DRA) on the remaining two alternatives.

3. Alternatives

a. A review was made of all four alternatives generated by the REMBASS office. A comparison of key information on the alternatives verified that the REMBASS staff's elimination of the two alternatives was correct. The two alternatives remaining under consideration are described in the following paragraphs.

b. The first alternative is a program utilizing Southeast Asia Operational Sensor System (SEAOPSS) equipment. The SEAOPSS is an unattended ground sensor system similar to REMBASS except that it lacks the most important REMBASS features. These features that SEAOPSS does not contain are automatic target classification and automatic target position location to name just two. The SEAOPSS would be used as the foundation for an AD program. The added functions included in REMBASS would be fabricated as separate units and attached to the SEAOPSS equipment by umbilical cords. This unsophisticated system would be tested in Development Test/Operational Test I (DT/OT I). The system would demonstrate all Materiel Need (MN) required functions which would lead to a favorable decision to enter ED. The main effort during ED would be to refine the components and to package them in a readily usable form which would eliminate umbilicals.

c. Alternative 2 is a concurrent AD/ED program. Under this program, brassboard models are to be built under the AD portion to satisfy "high risk" MN required functions. These "high risk" items include automatic target classification and automatic target position location. "Low risk" items such as detecting sensors and the data transmission network would be fabricated under a concurrent ED program. The hardware developed under these concurrent programs would be tested in DT/OT I and would demonstrate all MN required functions. A system ED decision would be obtained. The effort required in the ED phase would include refining the AD hardware and combining it, where necessary, with the previously available ED hardware.

d. Important cost and schedule data for the two alternatives is shown in Table 1. It should be noted that Alternative 1 requires a shorter AD phase than Alternative 2, but that the ED phase for Alternative 1 is longer than Alternative 2. This results in the Initial Operational Capability (IOC) and Full Capability dates being the same.

4. Assumptions

a. A time constraint of one week was imposed on the Systems Analysis personnel by the PM. For this reason, several broad assumptions were made which might not have been made if more time was available. Those assumptions are listed below:

(1) The alternatives were planned with severe cost constraints. The PM assumed that he would have a fixed amount of money to spend each fiscal year. Both alternatives were outlined with this constraint in mind, and based on this reasoning, an analysis of cost variations was not included in the DRA.

(2) There should be no difference in the technical parameters of the equipments resulting from either alternative program. Neither alternative offers an advantage in this respect. Therefore, a performance comparison was not considered necessary.

b. These assumptions were discussed with the PM and his staff and concurred in prior to proceeding with the analysis.

5. Methodology

a. The PM's staff had developed a detailed program plan for each of the two alternatives. These plans outlined each subtask required and included its anticipated schedule. This information can be readily adapted for use in the RISCA computer model.

b. Risk In Schedule and Cost Analysis (RISCA) is a mathematical model which uses a Monte Carlo simulation to develop time and cost frequency distributions. It also accumulates probability of success information.

c. The first step in using this model is to prepare a pert type network where nodes represent milestones and arcs represent activities. The REMBASS staff assisted in converting their program plans to RISCA networks. In this effort, it is necessary to determine which activities are dependent on other activities and which activities can be accomplished concurrently.

d. The next step in the RISCA procedure is the collection of data corresponding to the network. For each activity in the network, estimates are obtained for optimistic, most likely and pessimistic times to complete that particular activity. An estimate of probability of success was also obtained. The model is also capable of accepting cost data, but this capability was not used in the analysis. The sources of information for input to RISCA were members of the REMBASS staff.

e. The last step is the exercising of the model. Five-hundred iterations are performed to develop the frequency distributions. The results are summarized in the following paragraphs.

6. RISCA Results

a. The RISCA results are summarized in Table 2.

b. RISCA outputs a system probability of success. This represents the percentage of times that the successful completion node of the network was reached. This number by itself is not extremely meaningful. The importance of this number is for comparison with another probability generated by another alternative network. Table 2 indicates that the system probabilities of success are approximately equal.

c. The other RISCA output utilized in this analysis is the time frequency distribution. The mean of the distribution and the 95th percentile value are shown as is the scheduled time period. The mean represents the expected value and the 95th percentile value means that there is a probability of .95 that the program schedule will not exceed that particular value.

7. Analysis

a. The probability of successfully completing the program was .75 for Alternative 1 and .73 for Alternative 2. The difference between these values is not considered significant. Intuitively, these numbers should be almost equal as the same basic subtasks are included in each program.

b. A detailed investigation was made of the network to determine why the probability of success was not higher. The cause was primarily due to the target position location subtask, with the target classification task contributing to a lesser degree.

c. The scheduled times to ED, IOC and FOC were compared to the mean and 95th percentile values extracted from the RISCA frequency distributions. The differences in this case were also not thought to be large enough to distinguish between alternatives.

d. Since the RISCA output showed a similarity rather than a difference between alternatives, a choice could not be made on this basis. The only other information available was the overall cost and schedule estimates previously shown in Table 1. Alternative 1 reaches the ED decision point one and one-half years earlier than Alternative 2. Also, $15,000,000 less is spent up to the ED point in Alternative 1. This was an important basis of comparison and this rationale was presented to PM, REMBASS in recommending Alternative 1.

8. Recommendations and Results

a. Alternative 1 was recommended based on the facts presented in the previous paragraph. The ED decision point occurs after the capability of meeting MN requirements is demonstrated. If the system fails to meet the requirements, the program may be cancelled. Even if all requirements are met, the Cost and Operational Effectiveness Analysis (due to be completed by the ED decision date) may show that the REMBASS is not cost effective, and the program may be cancelled for this reason. It is strongly felt that the fewer dollars spentup to this point and the sooner this determination can be made, the better the position the Army will be in.

b. The information in the analysis section and in the above paragraph was presented to PM, REMBASS and members of his staff. The recommendation was followed and Alternative 1 was selected. The PM selected pertinent parts of the analysis and inclnded it in his briefings to AMC personnel and ultimately to LTG Gribble.

TABLE 1

COMPARISON OF ALTERNATIVES

	Alternative 1 SEAOPSS	Alternative 2 Combined AD/ED
Cost		
To ED Decision	$12M	$27M
Total R&D	$52M	$48M
Schedule		
ED Decision	3Q FY 75	1Q FY 77
IOC	3Q FY 80	3Q FY 80
Full Capability	3Q FY 83	3Q FY 83

TABLE 2

RISCA RESULTS

Alternative	System Prob	ED (Mos)	IOC (Mos)	FOC (Mos)	
		24	84	120	(Scheduled)
1	.75	23	86	123	(RISCA Mean)
		24	87	127	(RISCA 95th Percentile)
		42	84	120	(Scheduled)
2	.73	43	87	122	(RISCA Mean)
		45	89	125	(RISCA 95th Percentile)

DECISION RISK ANALYSIS OF THE AN/TSQ-73

Seton M. Reid

US Army Electronics Command

1. Problem

The AN/TSQ-73 program had a requirement for the production of two prototype systems for ET/EST and other test programs. A proposal was made for the fabrication of a third prototype to be used to supplement the previous two prototypes in the testing program in order to reduce the testing time. This analysis was initiated to investigate the time and cost considerations associated with this proposal. Considerations of particular interest are as follows:

a. The time and cost of completion of ET/EST for the two and three prototype options.

b. The time and costs accrued through completion of the Tactical Air Control System/Tactical Air Defense System (TACS/TADS) tests for the two and three prototype options.

c. The time and costs through completion of ET/EST with the third prototype refurbished and used as a production model.

2. Alternatives

There are two alternatives open:

a. Accept the proposal and produce three prototypes, or

b. Reject the proposal and continue the testing program with two prototypes,

3. Methodology

The approach to this analysis was to create a MATHNET risk analysis network for the problem and to analyze the network from the standpoint of schedule and cost risk for a two prototype and three prototype program for the AN/TSQ-73.

MATHNET is a computer network analysis program that analyzes a network representation of a user's system with respect to cost and schedule. MATHNET uses a Monte Carlo simulation of a given network to provide frequency distributions of time and cost for the activities of the network analyzed. Simulation is used since there are a number of different paths that can be taken within a network, with each path containing different groups of time and cost frequency distributions. Simulation is the simplest method whereby random selections from these different distributions can be added to obtain a distribution of total time and costs accrued within a network.

The procedure for the use of MATHNET involves the following steps:

a. Network the system to be analyzed showing all dependent and independent activities.

b. Determine optimistic, most likely and pessimistic times for each activity.

c. Determine the fixed costs and variable costs for each activity.

d. Network the system using MATHNET language.

e. Execute MATHNET computer model for the required number of iterations.

f. Analyze the results.

g. Perform sensitivity analyses to determine the impact of parameter changes.

The network used as input to the MATHNET model is a very detailed flow chart which is developed through Macro and Micro Configurations.

The Macro Configuration is the construct by which the problem is presented to the analyst. Figure 1 is the Macro Flow Chart for the AN/TSQ-73 program. Alternative 1 would have two prototypes in the ET/EST phase. Alternative 2 would have three prototypes.

The Micro Configuration is a more detailed flow chart which is evolved from the macro configuration. Figure 2 is the Micro Flow Chart for the AN/TSQ-73 program.

4. Input Sources

The time and cost information corresponding to each of the activities in the Micro Flow Chart was submitted by PM, ARTADS.

Time information was submitted in a useable form for all activities. However, cost information was not submitted for each activity prior to ET/EST. Only a total cost for all activities up to the beginning of ET/EST was submitted. Also, the costs submitted as fixed and variable were not consistent with the definitions of these costs as used with the MATHNET program.

MATHNET defines fixed costs as that part of the activity cost which is independent of time. Variable cost is defined as the cost per unit time, e.g., (cost per week) incurred by an activity. The costs provided by PM, ARTADS were not in this form. For the data contained in Table 1, the fixed cost for each activity is defined as the total cost for the activity if it is completed in the most likely time. The variable cost provided is the cost per week incurred if the activity takes longer than the most likely time.

Because of the manner in which the data was provided it was necessary to make two changes to the actual MATHNET computer program.

The first change was to create a dummy activity in the network and to insert a section of FORTRAN statements in the program. This added logic determines the time accrued in the network up to the beginning of ET/EST. This time is then used in the equation, Cost = \$21.1 million + .195 t, to give a simulated total cost for all activities up to the beginning of ET/EST.

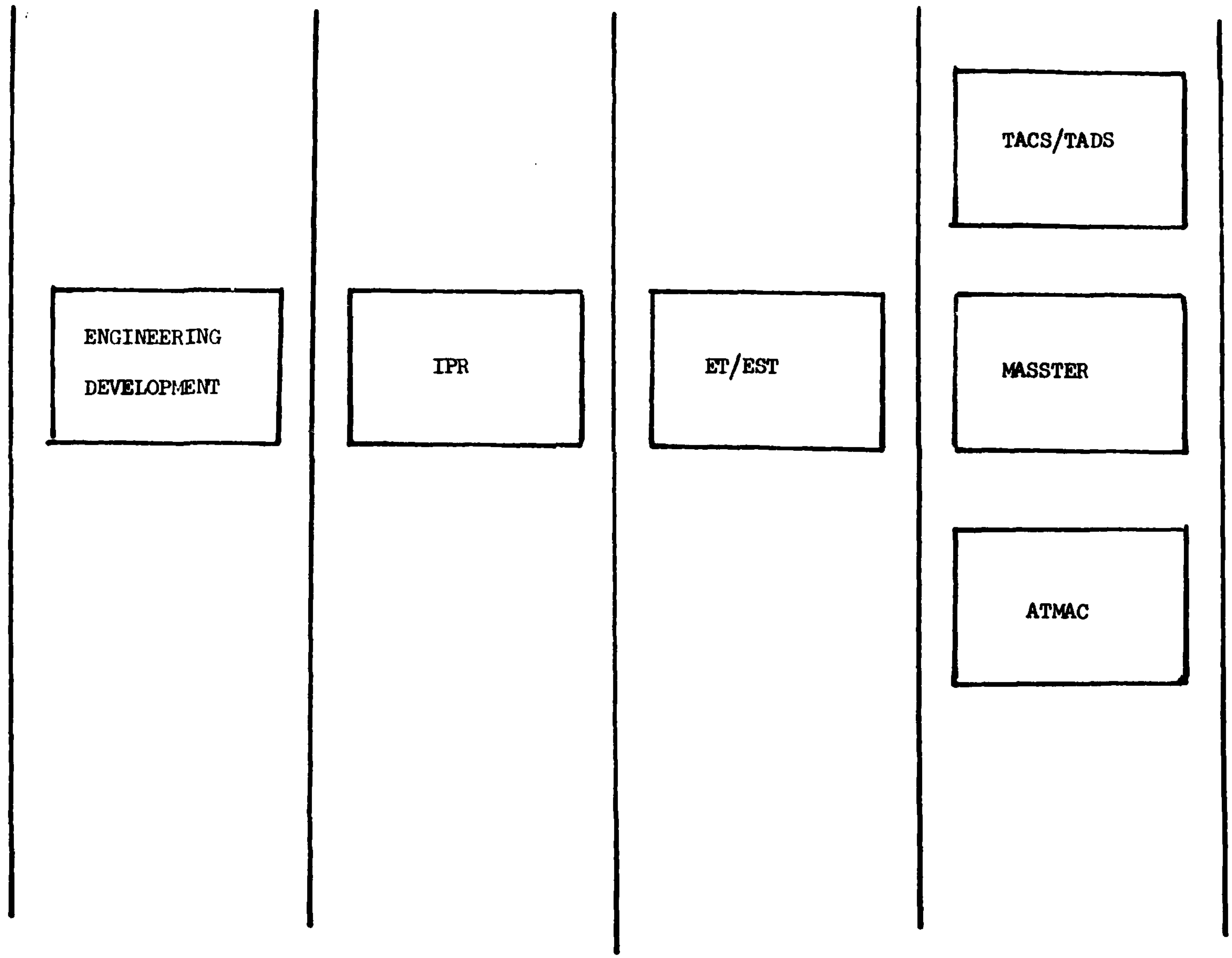


Figure 1 - Macro Flow Chart

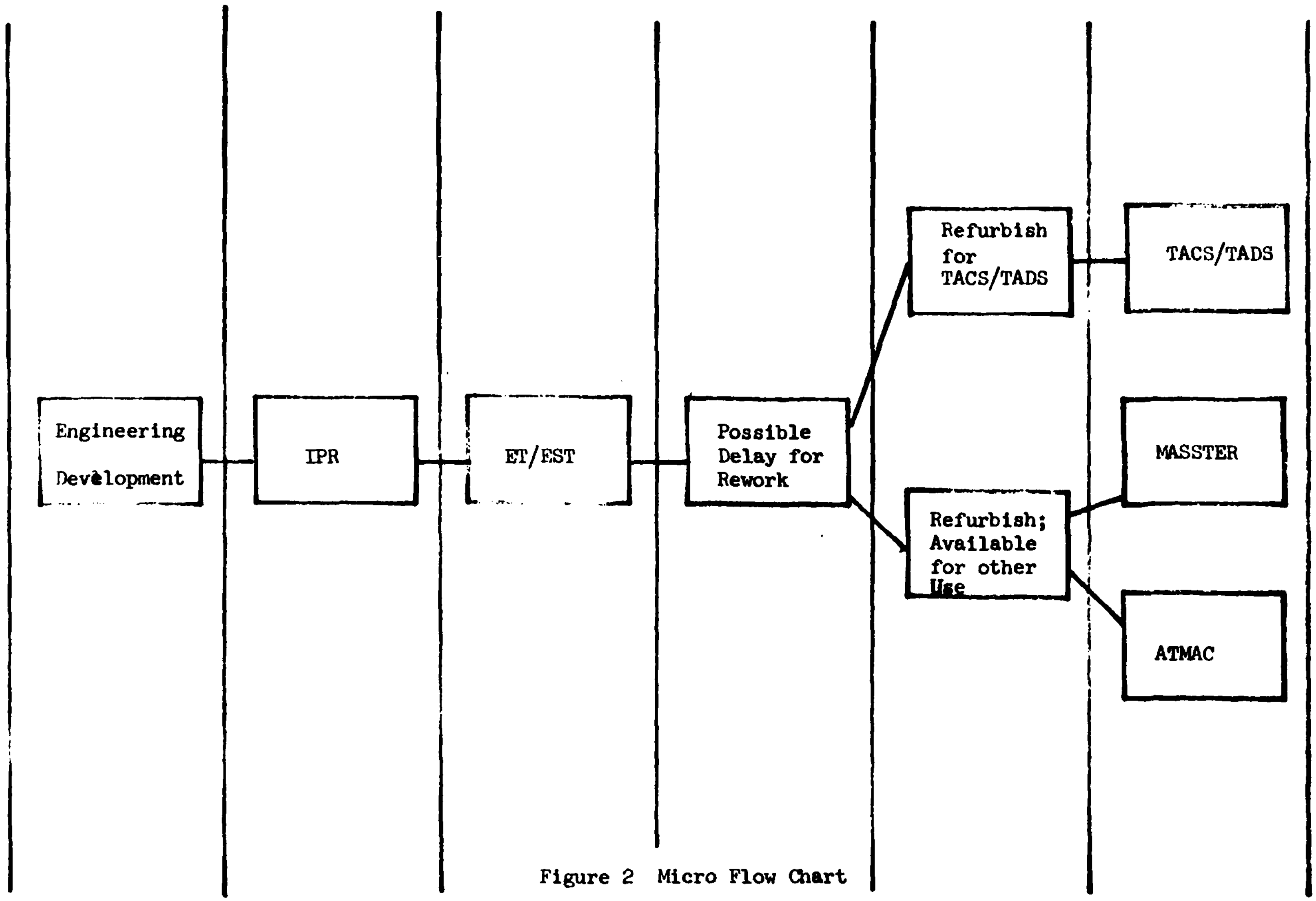


Figure 2 Micro Flow Chart

The second change applies to the cost equation used by MATHNET. It changes from: Fixed Cost + (Variable Cost x Activity Time) to: Most Likely Total Cost + (Variable Cost x Activity Time Above Most Likely Time). This change enables the use of the PM, ARTADS cost values in the MATHNET risk analysis.

5. Results

The MATHNET model was executed using 300 iterations for the "two prototype" configuration and 300 iterations for the "three prototype" configuration. The time to completion of all activities through TACS/TADS tests when only two prototypes are used ranges from 267 weeks to 296 weeks with a mean value at 276 weeks. The time to complete all activities through TACS/TADS tests, when there are three prototypes, ranges from 253 weeks to 280 weeks with a mean value at 264 weeks. Using three prototypes instead of two saves roughly 12 weeks through completion of TACS/TADS tests.

Considering the activities required to complete in order to refurbish a prototype for MASSTER, if two prototypes are used in the testing program, the time of completion ranges from 158 to 193 weeks with a mean time of 168 weeks. If three prototypes are used, the range drops to 148 to 174 weeks with a mean value of 156 weeks. This is also a savings of 12 weeks when there are three prototypes rather than two.

When two prototypes are used in the test program, the total time through completion of ET/EST, including any possible delay for modification, ranges from 155 weeks to 179 weeks with a mean at 162 weeks. When there are three prototypes, the range drops to 143 weeks to 168 weeks, with a mean at 151 weeks. The difference in the mean time to complete ET/EST in 10.6 weeks.

The weeks saved are at an increased cost due to the third prototype. For example, through the end of ET/EST, the costs total to a range of from $22.5 million to $25.8 million, with a mean of $23.1 million. When the third prototype is added, the range increases to $23.8 million to $26.3 million with a mean cost of $24.2 million. This represents an average cost increase of $1.1 million. This reflects a cost of $1.5 million to fabricate the third prototype minus the savings due to the shorter ET/EST. The costs accrued through the end of MASSTER and the end of TACS/TADS increase similarly.

If the third prototype could replace a production model of the AN/TSQ-73, the cost to add a third prototype would decrease from $1.5 million to $1.05 million.

Figure 3 shows the ranges and the mean values for the time to complete ET/EST and the total cost through completion of ET/EST.

6. Conclusions

a. Comparison through ET/EST of two prototype and three prototype systems.

It was determined that under the three prototype systems the program will complete modification of the prototype after ET/EST approximately 10.6 weeks sooner than under the two prototype system. However, this time saving is obtained with an increased cost of 1.1 million dollars. This is based on

2 PROTOTYPES			3 PROTOTYPES		
Low Point of Range	Mean Value	High Point of Range	Low Point of Range	Mean Value	High Point of Range
155.1 Weeks	162.1 Weeks	179.3 Weeks	143.4 Weeks	151.5 Weeks	167.9 Weeks
$22.5 Million	$23.1 Million	$25.8 Million	$23.8 Million	$24.2 Million	$26.3 Million

Figure 3 Time and Cost to Completion of ET/EST

the assumption that the third prototype is not refurbished and used for any other purpose after ET/EST.

b. TACS/TADS testing.

On the average the three prototype system will be ready to begin TACS/TADS tests 10.6 weeks earlier than the two prototype system. Because of the increased availability of the Army prototype to begin the tests when the Air Force prototype is available, it was determined that the tests would be completed approximately 12 weeks earlier under the three prototype system. This is due to the fact that there would be less chance of a delayed test under the three prototype system.

c. Prototype available for MASSTER.

Comparing the time that a prototype would be ready to be shipped to MASSTER under the two prototype system to the three prototype system it was determined that a prototype would be ready to be shipped to MASSTER approximately 12 weeks sooner under the three prototype system.

d. Use of third prototype for production model.

If the third prototype is refurbished for use as a production model, it was determined that the cost to the government will be decreased from 1.1 million to .7 million dollars. This decrease is reasonable since it costs only .3 million dollars to refurbish the prototype and .75 million to purchase a new production model.

XM 70 FIELD ARTILLERY COMPUTER PROCUREMENT -- RISK ANALYSIS

BY: Mr. Joseph Slattery
Frankford Arsenal

Introduction

This paper describes a Risk Analysis recently completed by the Systems Analysis Division, Plans Office, Frankford Arsenal. Because of the sensitive nature of the original program, nomenclature, time and cost estimates, and probabilities of success have been altered to maintain program anonymity. However, the basic technique and rationale remain unchanged.

Problem Description

This Risk Analysis is directed at identifying the time and cost risks associated with three alternatives in order to assist in the resolution of the XM 70 Field Artillery Computer Procurement problem. The three alternatives considered are:

A. Procure updated XM 70 Computer -

This alternative assumes a Termination for Convenience (T/C) action with the present contractor prior to updating and reprocurement. Updating will be limited to correction of known design deficiencies, although several circuits will be redesigned to use available integrated or hybrid circuits. Specifications will be revised to take advantage of recent relaxation of operating temperature requirements by CDC.

B. Develop and Procure New Computer -

This alternative assumes a Termination for Convenience (T/C) action with the present contractor prior to initiation of the development program. The specifications will define a Computer utilizing latest state-of-the-art integrated and hybrid circuitry throughout, and most recent developments in lightweight material which will result in significantly lower power input requirements, lower weight, higher reliability, and reduced hardware acquisition costs.

C. Reprocure Original XM 70 Computer -

This alternative assumes a Termination for Default (T/D) action against the present contractor prior to reprocurement. Terms and conditions of the contract will be identical to the present contract. Full advantage will be taken of the Pre-Solicitation Conference to insure against an over optimistic interpretation of the scope of the Pre-Production Evaluation (PPE) provisions of the contract. At time of award, the contractor's plan for execution of his PPE responsibilities will be made a part of the production contract.

Method

The three alternatives were networked through First Article Delivery as shown in Figures 1 through 3. The network structures for the production phase of each alternative are identical and are illustrated in Figure 4. Individual differences involve contract costs and in-house engineering support costs during production. A complete program network for a given alternative may be obtained by coupling Figure 1, 2 or 3 as desired to Figure 4.

Each important activity in the program from initiation to delivery of the 1050 computers including peripherals was represented by an arc while events or decision points were depicted by nodes. Times were included as triangular distributions which were derived from optimistic, most likely, and pessimistic estimates of team members for completion times of each activity. Contract costs foreach alternative were treated as triangular distributions based on previous contract bid experience while in-house engineering support costs were considered functions of time required to complete each activity. The networks were analyzed by Monte Carlo simulation utilizing Picatinny Arsenal SOLVNET Program.

General Rationale for Estimating Uncertainty Factors in Production-Related Contract Costs

The overall cost estimate for each of the alternatives is primarily driven by the unit production cost for each alternative.

Production-related costs of \$29,465,000 for Alternative A are based on abstract of previous bidding experience on the XM 70 Computer system escalated to the year of projected obligation. A 10% adjustment of this estimate was then made in consideration of several areas of electronic design simplification expected to result from updating of the TDP. An uncertainty factor of +20% and -10% was used in consideration of expected variances in competitive bid prices, market trends and the probability of valid engineering change costs.

The production-related cost estimate of \$24,600,000 for Alternative B is based on best technical judgment as to the extent of design simplification possible using latest state-of-the-art electronic technology throughout. Although the electronic design may be capable of as much as 40% simplification, the probable overall savings are strongly influenced by basic hybrid-electronic features which must be retained. It is therefore the considered judgment of Frankford Arsenal that the unit hardware cost of the Alternative B Computer will be approximately 65% of the cost of Alternative A. Because the design of Alternative B has not yet been established in sufficient detail, a higher uncertainty must be assumed. An uncertainty factor of +30% and -15% has therefore been assigned.

Production-related costs of \$33,000,050 for Alternative C are higher than Alternative A, based on use of the original TDP, with the data changes which will result from completion of PPE. It is expected however, that additional design simplification will be introduced during the PPE phase of Alternative C as a result of experience gained on the current contract and in-house developed product improvements. It is therefore probable that production costs will be reduced during contract performance by approximately 5%. The production cost uncertainty is otherwise equal to that for Alternative A, and is therefore assumed to be +20% and -15%.

Results and Discussion

Figure 5 summarizes the times, costs and success probabilities of the three alternative approaches for procuring 1050 Computer systems. The 85% and 99% certainty figures as well as the total range are given for the program time and cost. In addition, 85% certainty figures for unit cost of computers are provided. At this stage of the analysis, Higher Authority expanded performance requirements resulting in the elimination of Alternative C from further consideration. Figure 5 shows that there is a 90% probability of success for Alternative A; an 85% certainty that the 1050 computers will be delivered in not more than 67 months; an 85% certainty that the total program cost will not exceed 36.4 million; and an 85% certainty that Computer unit cost (based on 1050 quantity) will not exceed $22,798. Figure 5 further shows that there is a 85% probability of success for Alternative B; an 85% certainty that the 1050 Computers will be delivered in not more than 82 months an 85% certainty that the total program cost will not exceed 41 million; and an 85% certainty that the Computer unit cost (based on 1050 quantity) will not exceed $15,502.

Figure 6 compares the 85% certainty time figures of the three alternatives through delivery of First Article items. The time to complete each important activity is a cumulative time which includes that activity as well as all preceding activities. These bar graphs show that First Article Delivery will requir approximately 27 months for Alternative A and approximately 43 months for Alternative B.

Figure 7 displays the cumulative probability distributions versus time for the procurement of 1050 systems by the three alternative approaches. For any probability chosen, Alternative A will require less time than Alternative B.

Figure 8 gives the cumulative probability distributions versus cost for the three alternative approaches for procuring the Computer systems. For any fixed probability, the cost of Alternative A is less than Alternative B. The maximum possible cost of Alternative A is $39.4M; there is a 30% probabilit that Alternative B will exceed that amount.

Summary

The analysis discloses that there is an 85% certainty that Alternative A will provide hardware approximately 15 months earlier than Alternative B and the total program cost of Alternative A will be approximately $4.6 million less than Alternative B. However, the additional time and program cost for Alternative B would result in a design incorporating the latest state-of-the-art which is expected to result in a lower Computer unit hardware cost than Alternative A (approximately 13%), and as indicated in the qualitative and quantitative comparison dated 22 May 73, a significant improvement in reliability (approximately 200%), and a reduction in weight (approximately 25%) resulting from miniaturized circuitry.

ALTERNATIVE A - PROCURE UPDATED XM 70 FIELD ARTILLERY COMPUTER

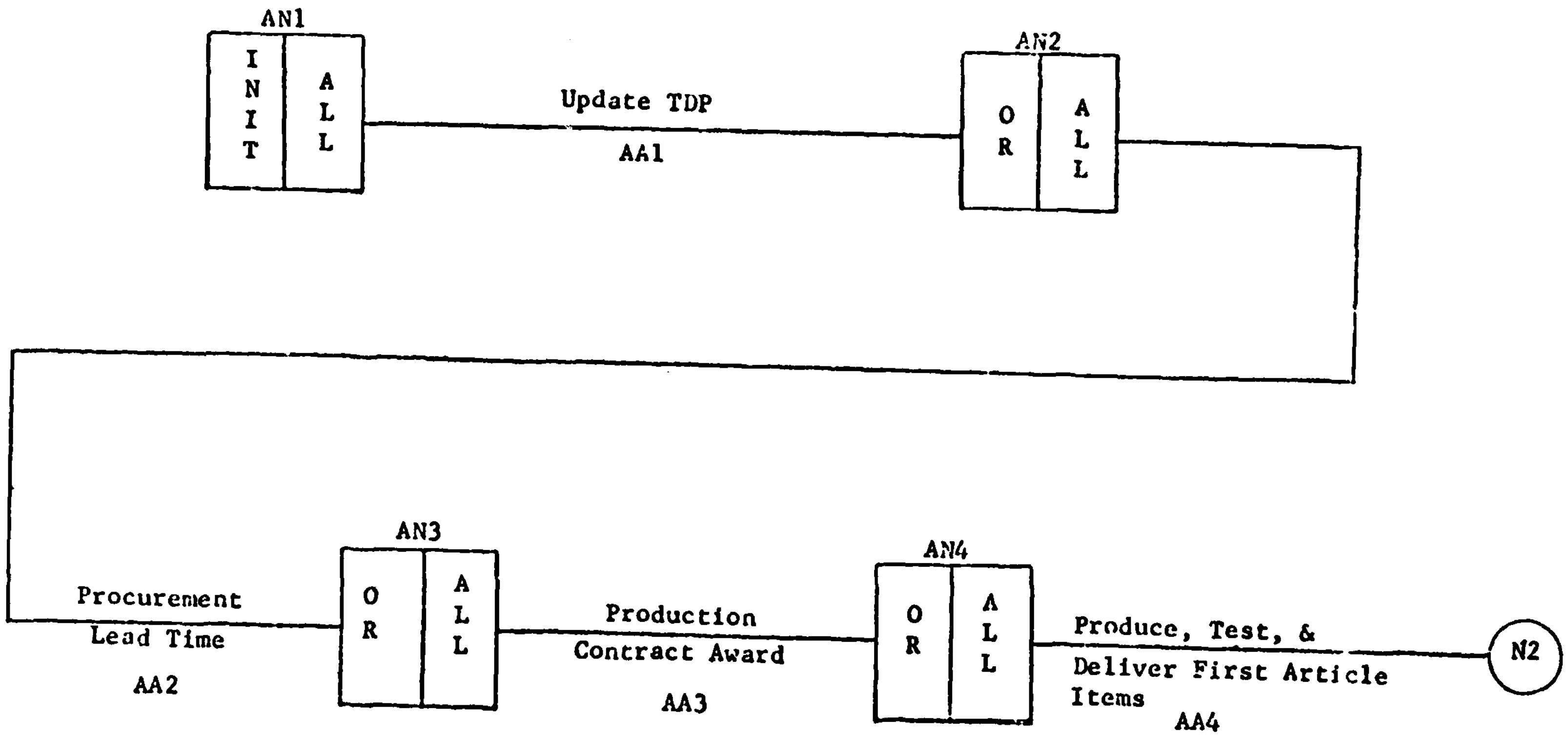


Figure 1

ALTERNATIVE B - DEVELOP AND PROCURE NEW FIELD ARTILLERY COMPUTERS

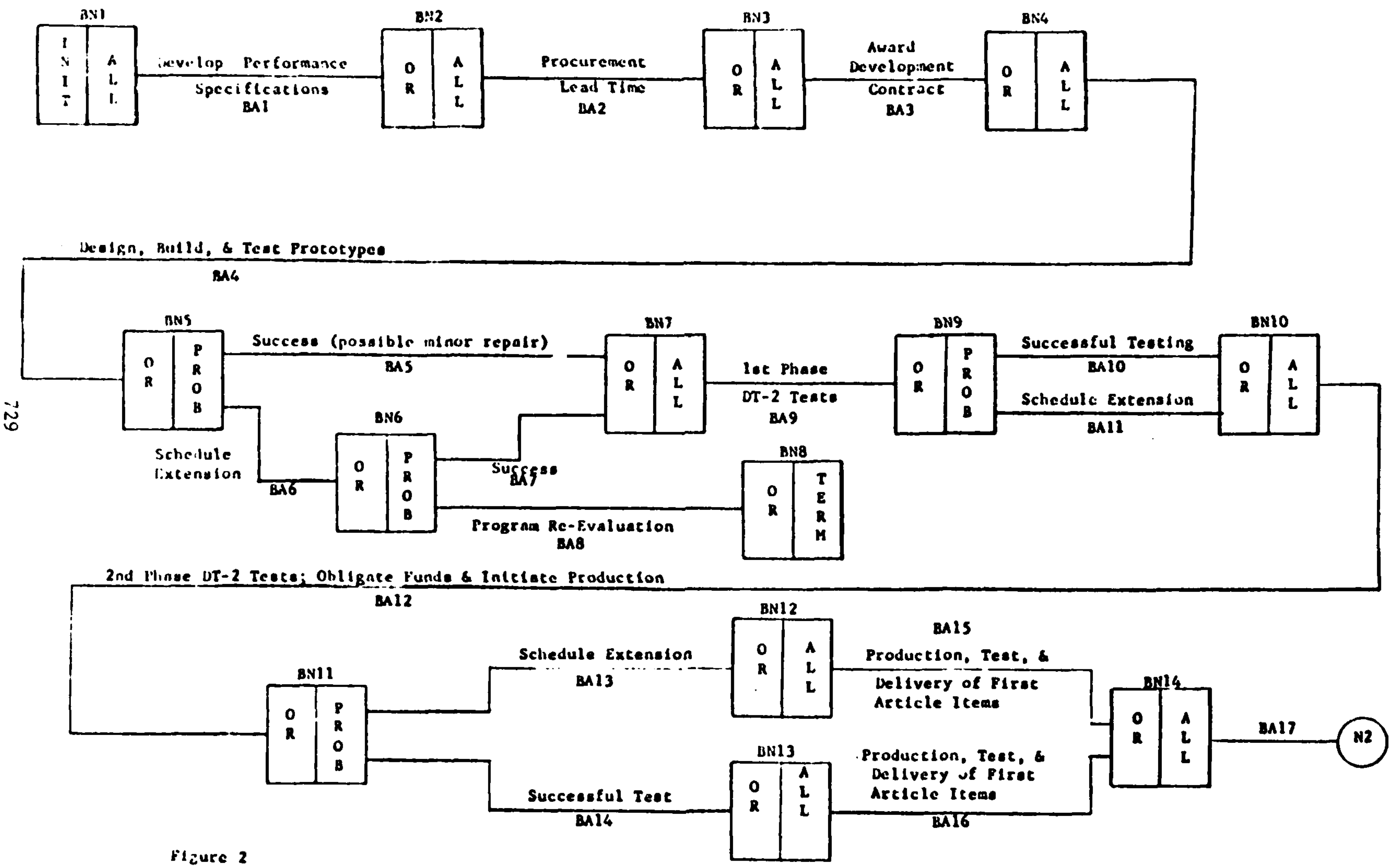


Figure 2

ALTERNATIVE C - REPROCURE ORIGINAL XM 70 FIELD ARTILLERY COMPUTERS

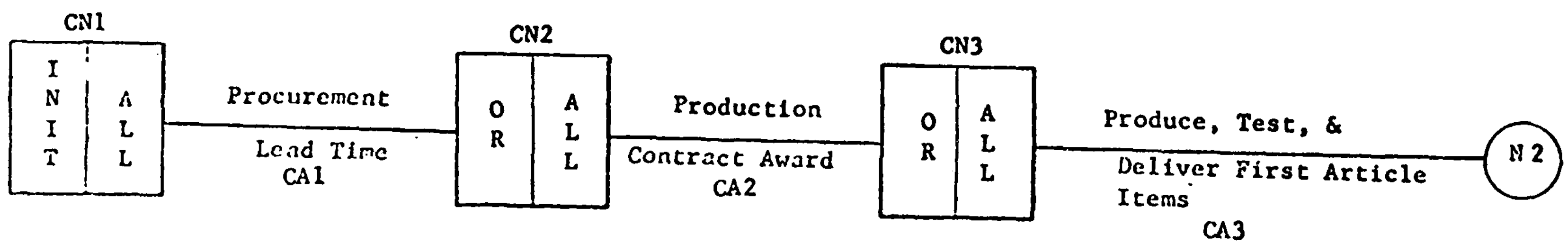


Figure 3

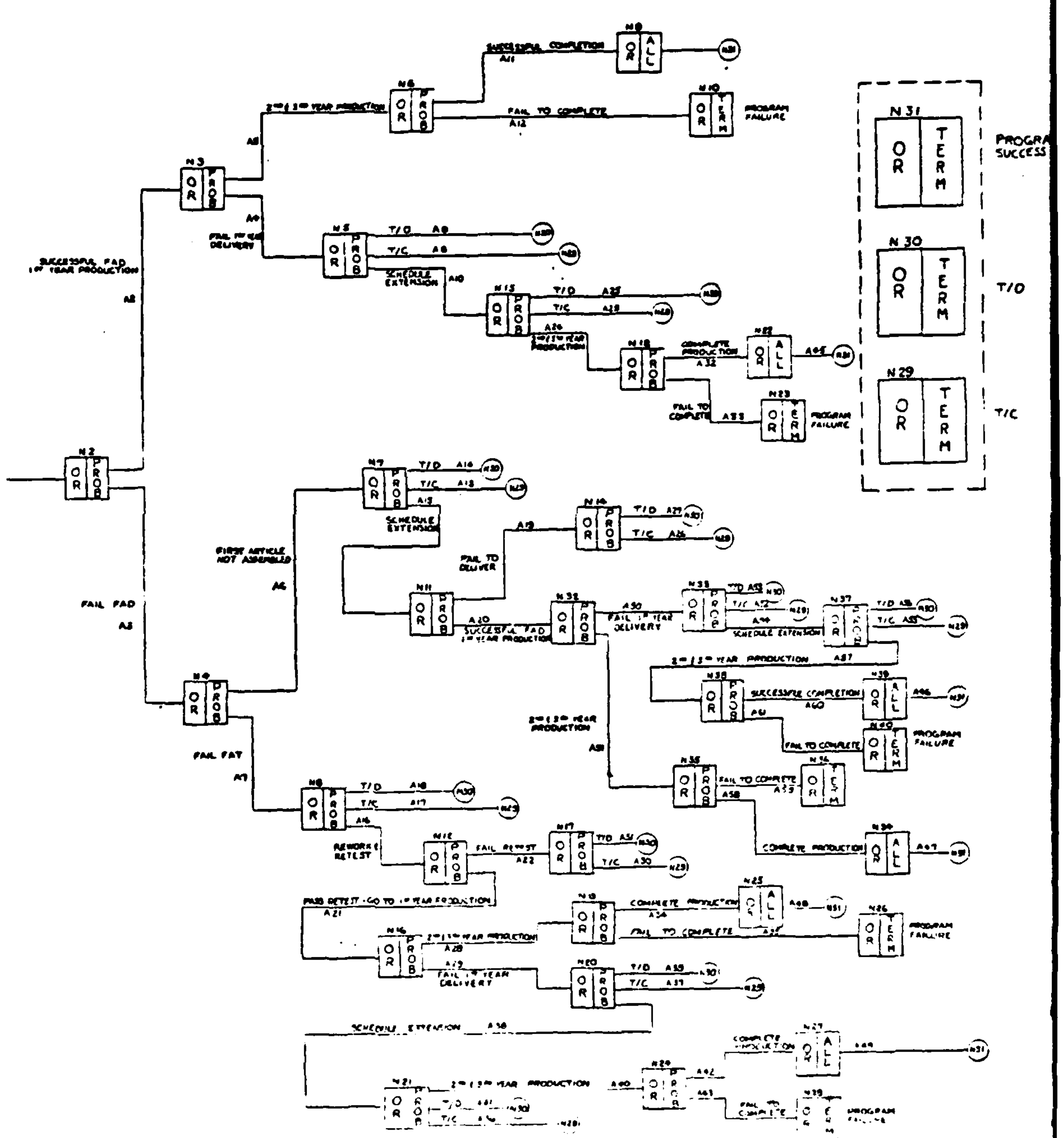


Figure 4

SUMMARY OF RESULTS OF FIELD ARTILLERY COMPUTER PROCUREMENT RISK ANALYSIS

	Alternatives		
	A T/C-Updated TDP	B T/C-New Development	C T/D-Original TDP
Probability of Success (%)	90	83	85
Time (months) to Deliver 1050 Systems			
85% certainty	67	82	63
99% certainty	74	88	67
Range	62-76	75-91	54-70
Program Cost ($M) **			
85% certainty	36.4	41	39.4
99% certainty	38.4	43.4	40.2
Range	30.6-39.4	33.2-44.8	32.0-42.8
Unit Cost of Computer ($) ***			
85%	22798	15502	25648

*Based on the assumption of 100% probability of success of T/D action.

**Costs indicated are exclusive of the projected costs for terminating the present contract.

***Based on 1050 quantity.

Figure 5

CRITICAL EVENTS LEADING TO FIRST ARTICLE DELIVERY

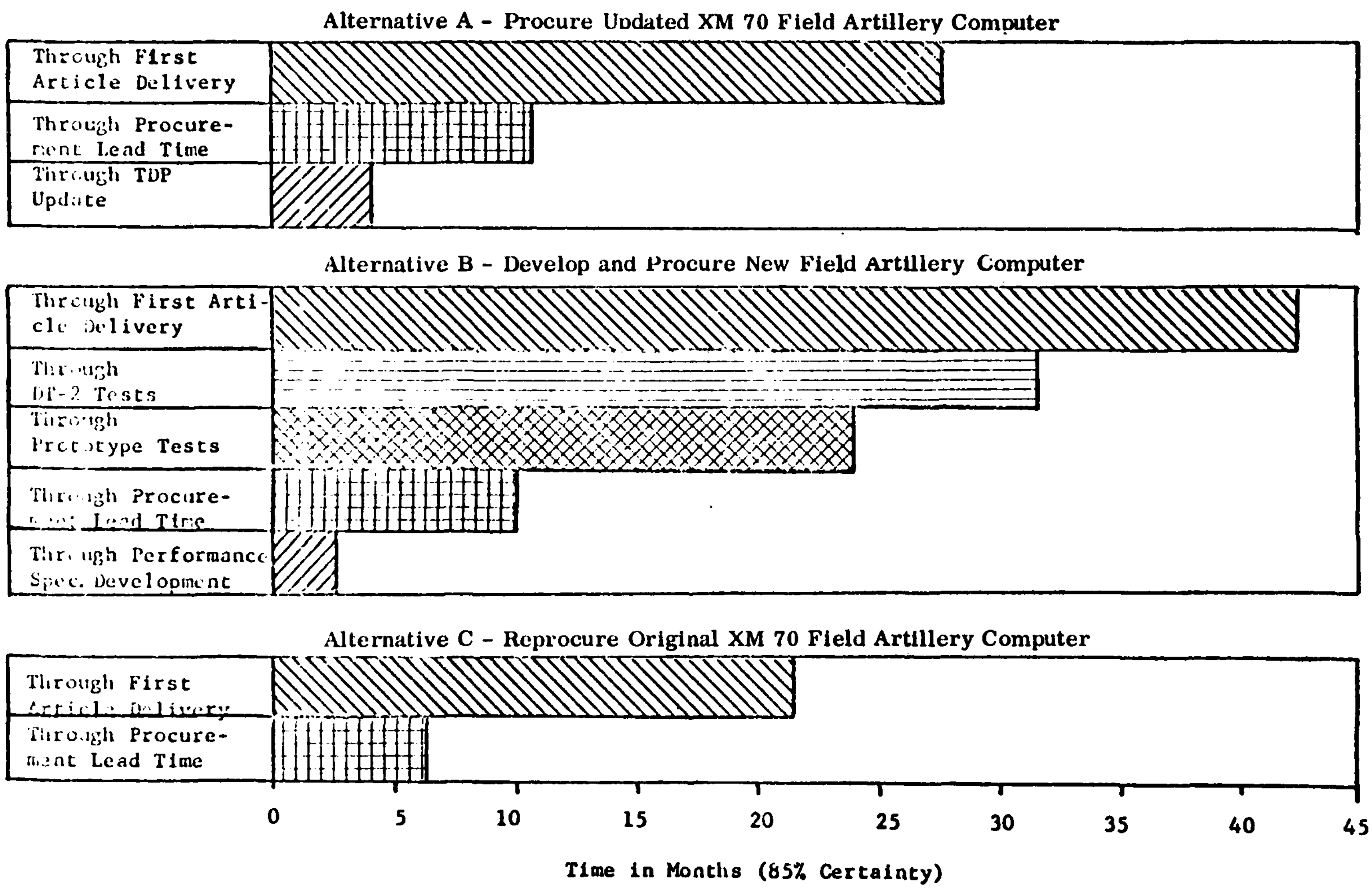


Figure 6

CUMULATIVE PROBABILITY DISTRIBUTION VS. TIME FOR FIELD ARTILLERY COMPUTER

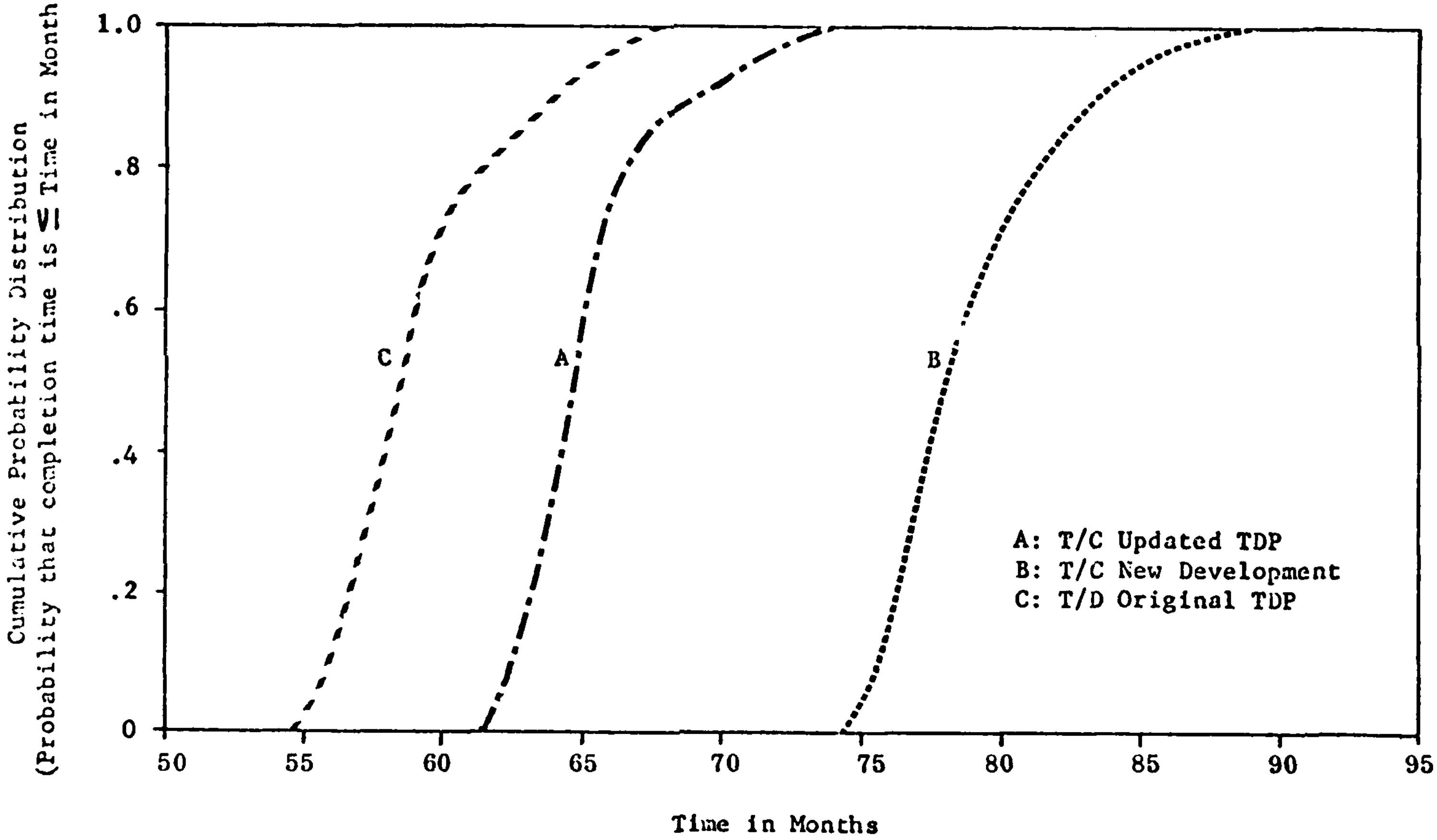
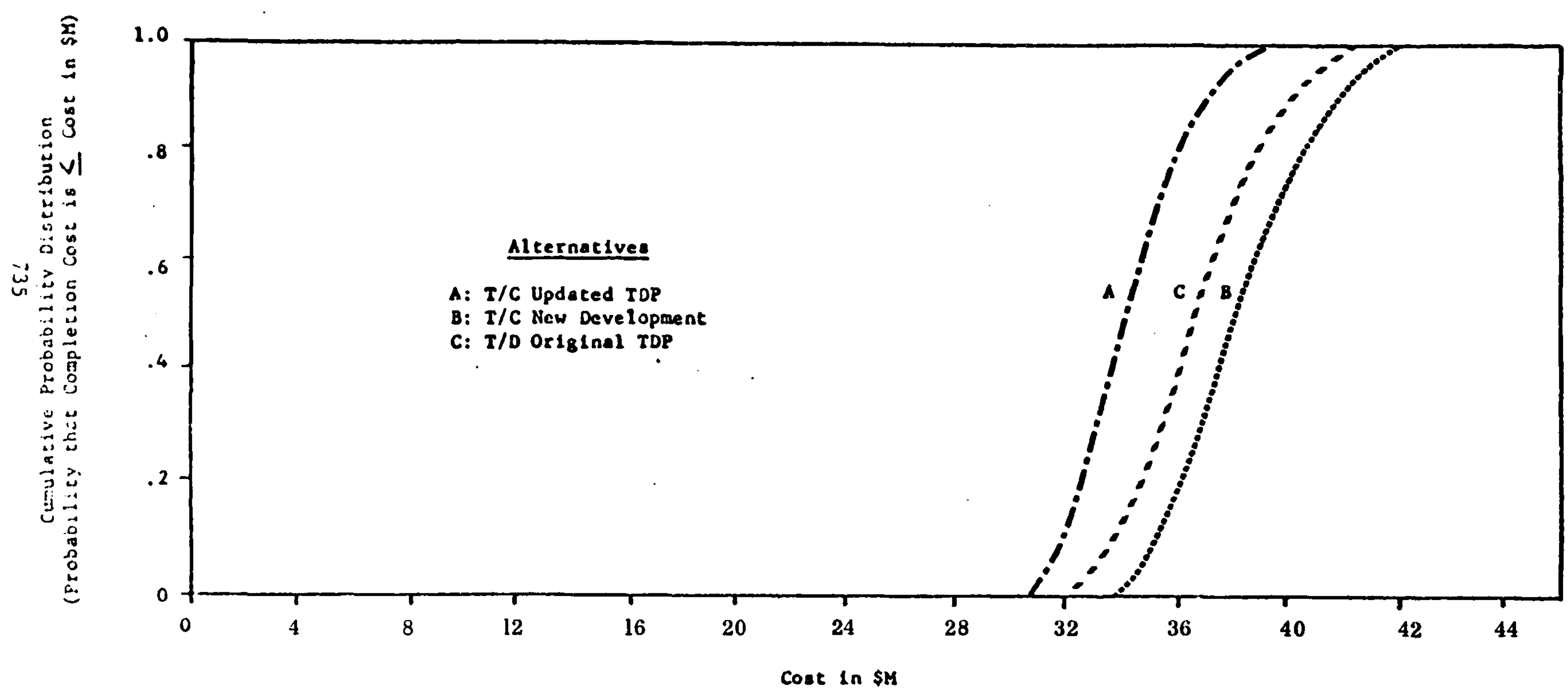


Figure 7

CUMULATIVE PROBABILITY DISTRIBUTION VS. COST FOR FIELD ARTILLERY COMPUTER PROCUREMENT



Note: Costs indicated are exclusive of the projected costs for terminating the present contract.

Figure 8

A RISK ANALYSIS OF THE IMPROVED COBRA ARMAMENT PROGRAM

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MR. DAVID CHAPPELL
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JUNE 1972

US ARMY AVIATION SYSTEMS COMMAND
ST. LOUIS, MO. 63166

SUMMARY

The purpose of this analysis was to evaluate the risks involved in the award of a production contract for the production of 192 TOW Cobra aircraft in Sep 72 rather than Jan 74. A risk analysis team was formed, headed by US Army Air Mobility Research and Development Laboratory with support from various offices of USAAVSCOM, USAMICOM, and USAWECOM.

The team determined the following:

a. The program has a low technical risk.

b. The original schedule leading to production is of "very low risk."

c. The accelerated schedule leading to production is of "medium risk."

I. INTRODUCTION

Following the Department of Defense Directive (DODD) 5000.1, entitled, "Acquisition of Major Defense Systems," and Army Materiel Command guidance correspondence on "decision risk analysis," project/product managers have been particularly conscious of the usefulness of risk assessment and of risk as an added dimension to facilitate decision-making in various stages of the materiel acquisition process. The Improved Cobra Armament Program (AH-1Q), involving the TOW-Cobra Armament

System, is scheduled for an In-Process Review (IPR) for earlier system production under a proposed accelerated schedule. The interest in an accelerated schedule is based on the tremendous success in recent anti-tank operations in Southeast Asia. In view of a possible reduction in the engineering development efforts, it is important to assess the program risks in terms of technical, cost, and schedule considerations. The objective of this study is to identify program risks and to assess risk levels of the accelerated program leading to the earlier production of the AH-1Q.

Since the AH-1Q primarily consists of the standard Cobra AH-1G plus improved helmet sight, stabilized sight, TOW missile, and improved M-28 gun system, the major considerations in the analysis involve the above major subsystems, plus system integration. As such, the technical assessment subscribes to the following major steps with data provided by technical engineers:

a. Identify potential problems, and assess probability of occurrences.

b. For each problem, evaluate consequence of failure.

c. Enumerate means to resolve problems, and attach probabilities of success of each.

d. Estimate impacts on schedule and on cost.

Next, schedule assessments are made to establish baseline values for all major events leading to the production phase and a schedule analysis is made as to the adequacy of acquisition time. The above are integrated into one overall program risk assessment which are included in the conclusions and recommendations.

II. IMPROVED COBRA ARMAMENT PROGRAM

The Improved Cobra Armament Program (ICAP) consists of the AH-1G aircraft, a dual function stabilized sight, missile guidance equipment, launchers, TOW missiles, M28A1 weapon subsystem and fire control which includes the pilot-gunner helmet sights and control panels.

The AH-1G Huey Cobra is a two place, high performance, single rotor attack helicopter powered by a single Lycoming T-53-L13 turbine engine flat rated at 1100 SHP. The cockpit is configured in a tandem seating arrangment to give equal and unlimited visibility to both the pilot and copilot/gunner with the copilot/gunner occupying the forward seat and the pilot directly aft and slightly above, the copilot/gunner normally fires the chin turret armament using a floor mounted pantograph sight. Side arm flight controls in the copilot/gunner's cockpit leaves its center portion free for the movement of the sight assembly. The pilot's station contains conventional helicopter flight controls, avionics and communications equipment plus a reticle sight. The pilot fires the wing stores but can also fire the chin turret in its stowed position. The basic armament configuration of the Cobra is the chin turret containing two 7.62mm miniguns or two 40mm grenade launchers or a combination of one each. The aircraft is further capable of accepting four external stores racks on the pylons various combinations of the following: 7.62mm minigun pod, the 2.75" rocket launcher, 7 tube pad, the 2.75" rocket launcher, 19 tube pod or the 20mm cannon.

The stabilized sight provides a stabilized line-of-sight to enhance visual observation and manual tracking of the point target and accurately control firing of the TOW and M28A1 weapon subsystems. The guidance equipment senses missile deviation from line-of-sight and generates command information to return the missile to the proper position. The launcher provides a launching mechanism which will allow TOW Missiles to be launched from their containers. The TOW Missile is identical to the currently produced missile used for the US Army infantry role. It is a small, highly accurate missile capable of defeating any known armor. The TOW is in volume production for US forces for ground and airborne application.

M28A1 Armament Subsystem - The M28A1 Armament Subsystem, used on the AH-1G Huey Cobra, is an electrically controller, hydraulically operated chin turrent providing mass fire power from installed 7.62mm (M134) Machine Guns or 40mm (XM-129) grenade launchers. The turret facilitates installation of four combinations of weapons, twin 7.62mm guns, twin 40mm launchers, or one 7.62mm gun and one 40mm launcher mounted interchangeably on either side of the turret. The subsystem has a storage capacity of 4,000 rounds of 7.62mm and 231 rounds of 40mm ammunition for each weapon installed supporting rates of fire of 2,000 and 4,000 SPM for the 7.62mm weapons and 400 SPM for 40mm launcher. Electrical and hydraulic power are obtained from the aircraft.

Turret (M28A1) - The M28A1 turret, when operated by the gunner in a fully flexible mode, provides for a wide range of fire between 107.5° left and right azimuth and +18.0° elevation to -50° depression. Firing of the weapons by the pilot is accomplished with the turret located at the forward stowed position.

Modifications are required to the M28A1 subsystem for the Improved Armament AH-1G to enable it to perform the following operational modes:

Primary Gun Mode - The M28A1 turret accepts pointing commands from modified XM-26 stabilized sight.

Secondary Gun Mode - The M28A1 turret accepts pointing commands from the pilot or copilot's helmet sight.

Helmet Sight Subsystem - The helmet sight subsystem will provide the pilot and gunner with the "heads up" ability to acquire, track, and fire the M28A1 subsystem upon targets while maintaining area visibility and control of the aircraft. This capability may best be accomplished by mounting a sight reticle over the aviator's eye and causing on-board flexible weapons systems to move automatically in azimuth and elevation as the aviator moves the sight reticle by moving his head.

The ICAP helicopter has been given an official designation of AH-1Q.

III. TECHNICAL RISK ASSESSMENT

Introduction

The purpose of the technical risk assessment is to provide a documented evaluation of the technical risk associated with the ICAP, including the effects of the accelerated schedule. A separate technical risk assessment of the original baseline schedule was not performed, because of its inherently low risk and because of time limitations. However, the approach was justified indirectly by the results, which showed the technical risk to be low for the early production program.

The results of the analysis are given in terms of three types of impacts which technical problems could have upon the program. These are the probability of success, and the expected cost and time required for the resolution of technical problems. The impacts are given separately for each of the separate subsystems, and for the overall system, as listed in Summary Table 1.

Methodology

The risk assessment methodology can be described as follows. The armament system is divided into seven major subsystems, which are first considered separately and later combined. These are the Launcher, Guidance and Control, Stabilized Sight, Helmet Sight, Flexible Weapon, Aircraft and Integration, and Laser Range Finder. Based upon the judgment of the assembled team, the technical problems which could possibly occur in each subsystem are defined, along with the probable consequences of their occurrence. Probability of occurrence is assigned to each of these problems based upon the team's familiarity with the subsystems. For the defined problems, one or more possible solutions are given, in the sequence in which they would be applied. Probabilities of success are assigned to the proposed solutions, again based upon the team's judgment. As the final inputs to the analysis, impacts are estimated in terms of the cost and time required to apply the solutions if the problems did occur.

The following is done for each subsystem: For each hypothetical problem within the subsystem, "probable impacts" of the first problem solution are obtained from the probability of occurrence multipled by the estimated impacts. The probability of failure, or of going to the second solution, if one exists, is then determined from the mathematical data given. The expected impacts of the second solution are calculated, plus the probability of failure or going to the third solution, and so forth. All the problems for the given subsystem are then combined to give overall probability of success and the expected cost and schedule impacts for the subsystem. This procedure is called "folding back." The overall system probability of success is the product of the subsystem probabilities. In this context, non-success, or "failure," only signifies that the required system characteristics are not obtained within the scope of the cost and time impacts projected for the proposed solutions given.

Although it was not explicitly stated during the analysis, the cost and schedule impacts as estimated are believed to apply to the cost and time required to develop and demonstrate the improved hardware that meets the system requirements. As such, the impacts would not account for recurring costs of retrofitting production aircraft. These costs are considered to be outside the scope of this section and are discussed in Section IV.

When combining the subsystem impacts, the expected subsystem cost impacts are added for overall system impact. However, the schedule impacts for the various subsystems are not directly additive, since the subsystems are developed in parallel. The same is true for schedule impacts for different problems within each subsystem. For the purposes of the technical risk assessment, the expected schedule impact for each subsystem is taken as equal to the longest expected impact for an individual problem within the subsystem.

A general impact would be anticipated in the areas of logistics, configuration management, spares, reliability, and maintainability as a result of the proposed changes of phasing between production and R&D activities. However, the technical risk assessment is directed toward specific technical problem areas as stated herein. Other means are available to the decision makers to assess the areas of general program concern which are beyond the scope of a technical risk assessment.

Summary of Results

The results of the technical risk assessment as described in this section are summarized briefly in Table 1. Detailed supporting data concerning the potential subsystem problem areas, methods of solution and the associated numerical inputs, are contained in Appendix A.

TABLE 1

TECHNICAL RISK SUMMARY

	Predicted Probability of	Expected Cost Impact - Thousands	Expected Schedule Impact - Months
Launcher	.99	48	1.2
Guidance & Control	.99	120	.7
Stabilized Sight	.96	10	negligible
Helmet Sight	.99	2	negligible
Flexible Weapon	1.00	0	0
Acft & Integration	.98	125	2
Laser Range Finder	.93	35	1.4
Overall, with Laser Range Finder	.85	340	Same as longest element, i.e, 2 months
Overall, without Laser Range Finder	.92	305	

IV. SCHEDULE ANALYSIS

The objective of this analysis was to evaluate the schedule risk with respect to an accelerated program with the assumption that there will be no impact on R&D Program as in the original ICAP program.

A basic network was established consisting of different activities that the Contractor (Bell) and Sub-contractors (Hughes and Sperry) were responsible for and the schedule risk was developed associated with the accelerated program.

In the schedule risk analysis, three distinct and interrelated problem were present. The initial consideration was, "What is the risk associated with the acceleration of the pre-production activities under the assumption of low risk or no risk as far as the technical aspects of the systems are concerned?"

The problem was that of assessing the magnitude of risk present in meeting the original ICAP schedule and the proposed modifications to that schedule.

The schedule risk analysis employed a subjective approach to solve the problems encountered. A group of experts, familiar with the pre-manufacturing activities of each of the contractors, were polled as to the reality of the contractor proposed schedule. The experts were asked to estimate the probabilities of completion of each of the contractor activities in varying time frames, thus associating a probability estimate to a specific time frame. This methodological approach assumed no technical problems encountered by any of the contractors.

The alternatives considered were:

a. Present Improved Cobra Armament Program Schedule.

b. 8-9 Month Pre-System Integration Cycle.

c. 12-13 Month Pre-System Integration Cycle.

d. 16-17 Month Pre-System Integration Cycle.

RESULTS OF ANALYSIS

Pre-System Integration Program Length (Months)	Probability of Success	Risk Level*
24	.95 - 1.00	Very low
16 - 17	.90 - 1.00	Very low
12 - 13	.70 - .80	Medium
8 - 9	.50 - .60	Very High

* The team used as definition the following: (1) Very high risk .5-.6; (2) High risk .6-.7; (3) Medium risk .7-.8; (4) Low risk .8-.9; and (5) Very low .9-1.0.

Appriximately two months are required for systems integration. The 12 - 13 month schedule above corresponds with the accelerated ICAP.

V. CONCLUSIONS

The following are the team's conclusions:

a. The program has low technical risk.
   .85 probability of success with the Laser Range Finder.
   .92 probability of success without the Laser Range Finder.

b. The original schedule leading to production is of "very low risk" - .99 probability of success.

c. The accelerated schedule leading to production is of "medium risk" - .70 probability of success.

If the accelerated schedule is chosen, the team would like the product manager to validate this analysis by tracking the actual problems, cost and schedule slippages, if any.

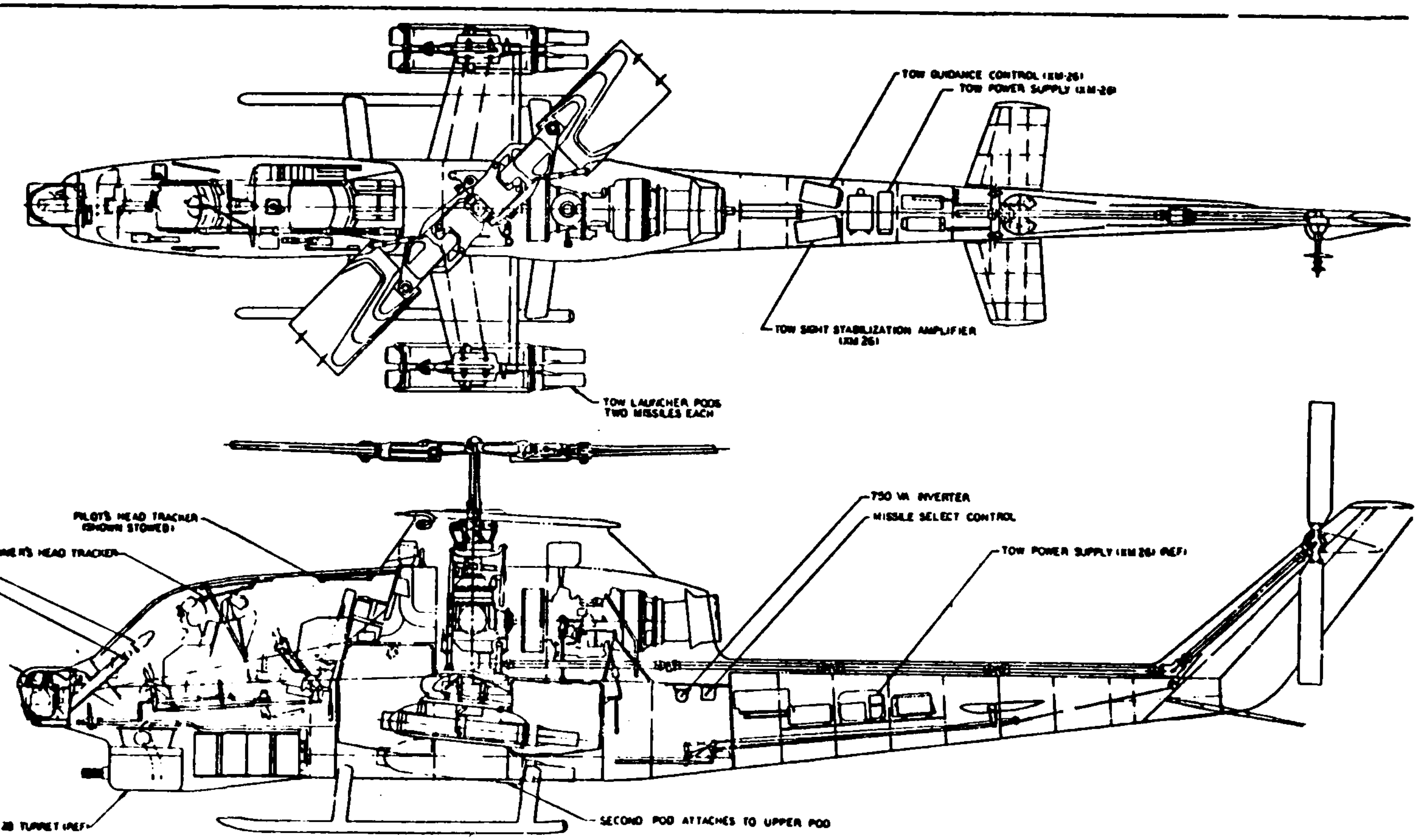

FIGURE 1 Illustration of Equipment Location

RADAR HARDWARE SECOND BUY DECISION RISK ANALYSIS

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This paper presents the technique used by the author to perform a Decision Risk Analysis (DRA) concerning a radar hardware second buy. The DRA addressed two major alternatives for procuring the hardware second buy; these alternatives were (1) sole source and (2) competitive procurement. The two major areas of "uncertainty" or "risks" investigated for each alternative were (1) total program costs, and (2) total program time schedule.

The data presented and used in this paper is for the purpose of "example" only and is unclassified.

SITUATION: The U.S. Army has procured and deployed a total of X "Super See" radar units along with its associated equipment and hardware.

The delivery of the X radar units to the government according to the original contract was to be spread out over a period of ten months. Due to many unforseen problems the prime contractor experienced major difficulty in meeting the radar delivery schedule. In fact, the final unit was not delivered until during the 15th month.

After the procurement of the X Super See radar units a Department of the Army requirement existed for Y more Super See radar units. Due to the unpleasant experiences that the government endured with the "first buy" prime contractor it was expressed by many managers at different echelons that a "new" contractor should be chosen for the second buy. Also, it was felt that if a new contractor was chosen the total cost to the government per radar unit would be significantly reduced. If, however, a new contractor was to be chosen it was a known fact that the production lead time (PLT) before the delivery of the first radar unit would be considerably longer than the PLT if the second buy is made from the original contractor.

It was therefore decided that the total program time and cost schedules associated with (1) competitive and (2) sole source procurement alternatives for the Super See second hardware buy should be investigated. This study would attempt to identify and quantify the risks and uncertainty associated with program time and costs for the two procurement options. Once these uncertainties are quantified the different procurement actions can be more realistically compared. The subject DRA would identify the option that can best meet the DA requirements. The DRA would also identify the option that would cost less overall money to the government.

Methodology and Development of Procurement Options

Presented in this section of the paper are the different procurement options used in the DRA, the assumptions necessary for these plans and their associated delivery schedules and costs.

Assumptions

1. The technical data package for the Super See and its associated hardware will be adequate to support competitive procurement.

2. Competition will be between firms who have built similar hardware and who are qualified radar producers.

3. Hardware cost will be reduced by 20 percent for the competitive market.

4. The second buy will consist of 54 radars and nine "other equipment".

With assistance of procurement and production experts three basic procurement plans were developed for the Super See second buy. They were the following:

1. Plan A - Sole Source to Prime.

2. Plan B - Competitive with first article.

3. Plan B1 - Competitive with production sample.

Each procurement option has its unique program schedule of activities. The major activities necessary to conduct the DRA for each procurement plan is shown in Figure 1. The length of time required for each activity, i.e. 15 months for production lead time, is the time to be specified in second buy contract.

Development of Time and Cost Schedules for Procurement Plans

The government has the choice of going either competitive or sole source for the second buy. If competitive is chosen, prime or a new producer will be selected. If sole source is chosen, of course, prime will be selected. Regardless of the plan finally chosen each contractor will make an estimate (bid) of the total dollars required to complete the contractual package. The total time for the contract will be specified by the government; these times are given in Figure 1. Observe in this figure that the time for each activity is also broken out. For example, in Plan B, the contractor would develop his cost estimate assuming a production lead time (PLT) of 15 months, the listed delivery schedule, first article test lasting six months, initial production test (IPT) by TECOM lasting ten months, and a PLT after first article testing of 12 months.

We know that when a contractor actually begins to perform under this second buy contract the time required for these activities may not be the same as the contractual package indicated. The initial PLT may be 13 months or 20 months instead of the 15 months in the contract, first article testing may take 8 months instead of 6, IPT may be 6 months instead of 10, and PLT after first article may be 10 months instead of 12. It also may take the contractor longer or less time to deliver 54 radar sets than the contract schedule specified. The same type of

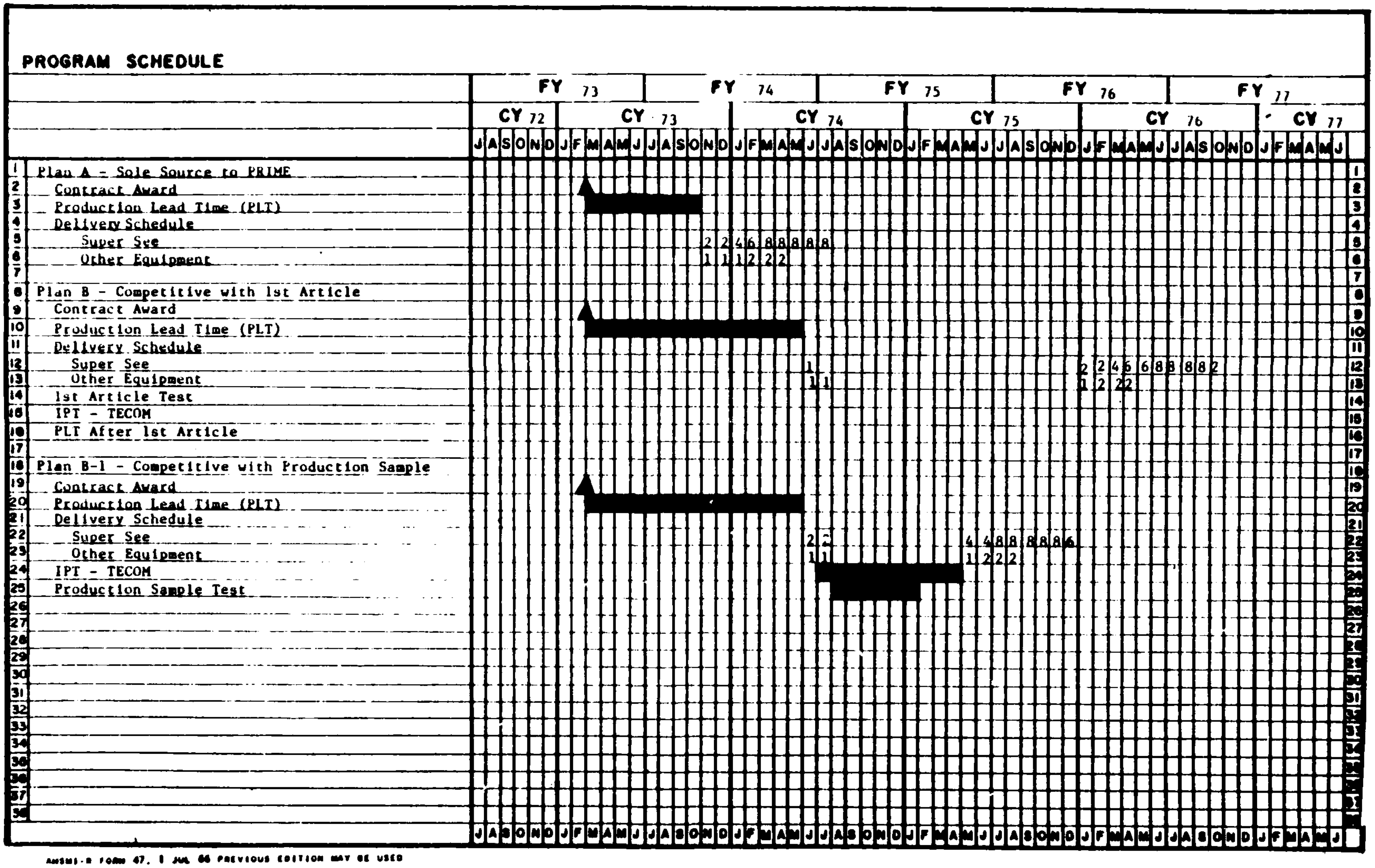

Figure 1. Procurement Plans for Super See Hardware Second Buy

variance can be expected as far as cost is concerned. Differences in actual cost can be anticipated due to government shortcomings as well as contractor reasons. The government may have to pay extra for design deficiencies, technical data package errors, ..., etc.

We can detect very quickly that "time" and "cost" will behave like a random variable. We see that (1) these variables cannot be predicted in the future with certainty, (2) if a specific activity was repeated by a contractor many times each "replication" would not have the same numerical value associated with it, and (3) specific time and cost intervals can be estimated with a specific degree of confidence. Thus the "real world" time and cost schedule for each activity should be treated to reflect their true nature, i.e. as random variables with their underlying population distributional form.

Based upon their expertise the Procurement and Production experts made estimates as to the "real world" or actual time required for the various activities of each plan. Likewise, the associated monies have been estimated. The estimates are in the form of a "triangular distribution:" (1) the most optimistic value; (2) the most likely value (or average); and (3) the least likely or most pessimistic value. The time and cost estimates are given in Tables I through IV. The costs include the engineering services that the government must buy from prime to support the first buy. If the government goes to a new producer it will be necessary to buy engineering services from prime to support the first 90 radars until the new producer begins to deliver radars. At that time theoretically, the government could go competitive for engineering services to support the first and second buy.

Table I. Time Schedule Estimates for Super See Second Buy Procurement Plans with Prime Chosen

Elements	Plan "A"			Plan "B"			Plan "B-1"		
	O	E	P	O	E	P	O	E	P
PLT	7	8	10	10	12	15	10	12	15
Del First Article				1.5	2	4	1.5	2	4
MICOM 1st Article Test				5	6	8			
Prod Test MICOM							5	6	8
IPT TECOM				9	10	13	9	10	13
PLT After 1st Article				5	6	8	5	6	8
Del Schedule Radar	11	12	14	11	12	14	11	12	14

Table II. Time Schedule Estimates for Super See Second Buy Procurement Plans with New Producer Chosen

Elements	Plan "B"			Plan "B-1"		
	O	E	P	O	E	P
PLT	13	15	20	13	15	20
Del First Article	1.5	2	4	1.5	2	4
MICOM 1st Article Test	5	6	8			
Prod Test MICOM				5	6	8
IPT TECOM	9	10	13	9	10	13
PLT After 1st Article	10	12	14	8	9	10
Del Schedule Radar	11	12	13	11	12	18

Table III. Total Cost Estimates for Super See Second Buy Procurement Plans with Prime Chosen

Elements	Plan "A"			Plan "B"			Plan "B-1"		
	O	E	P	O	E	P	O	E	P
Start-up				1.3	1.5	1.7	1.3	1.5	1.7
First Article Hdwe				1.4	1.4	1.5	1.4	1.4	1.5
First Article Test				.477	.575	.771	.477	.575	.771
Hardware	28.5	29.5	30.8	22.6	23.5	24.4	22.6	23.5	24.4
Engr Service	3.70	3.90	4.3	6.3	7.0	9.0	6.4	7.0	9.0
SAIE							.500	.500	.500
Production GAP				.470	.564	.752	.470	.564	.752

Table IV. Total Cost Estimates for Super See Second Buy Procurement Plans with New Contractor Chosen

Elements	Plan "B"			Plan "B-1"		
	O	E	P	O	E	P
Start-up	2.12	2.2	2.50	2.12	2.2	2.50
First Article Hdwe	1.4	1.4	2.03	1.4	1.4	2.03
First Article Test	.477	.575	.771	.477	.575	.771
Hardware	22.6	23.5	24.4	22.6	23.5	28.7
Engr Service	8.3	8.6	11.8	6.4	7.0	10.1
SAIE	.500	.500	.500	.500	.500	.500
Production GAP	1.5	1.60	1.70	.756	.85	.94

STATNET - Simulation Model

The analysis tool utilized to perform this DRA was the "STATNET" Model. This model has been used frequently during the past year to conduct risk analyses. Basically, one inputs into the model a "statistical type PERT" network including the flow of program activities in their logical order. Associated with each activity, i.e. PLT, TECOM test, first article test, ..., etc., is a time distribution (schedule) and a cost distribution. These distributions are treated as random variables and can be characterized by several different probability laws and schemes. For each activity the model statistically samples the appropriate distribution for an estimate of length of time required to complete that activity. For that specific time an estimate for cost is also generated. Based upon 500 replications of a particular case the statistics for total time and cost distributions are obtained.

The modeling and representation of the time and cost random variables for this study were in the form of "triangular distributions." Estimates are made in the form of "lowest possible value," "most likely value," and "highest possible value." These values were given in Tables I through IV and correspond to the estimates given under O, E, and P, respectively.

Network Development of Procurement Options for STATNET

Recall from Figure 1 that the various procurement options and their associated activities were given. To use these in the simulation model it is necessary to construct a "network flow" of (1) initiation of activities, (2) the activities themselves, and (3) initiation of other activities given that some have been completed previously.

For STATNET the "model network" consists of a series of Nodes and Arcs. The Arcs represent program activities such as production lead time (PLT), actual delivery of radars (RDS), first article test, ..., etc. The Nodes represent completion of appropriate activities as well as initiation of other activities. The specific Nodes used in this DRA have the following meaning:

INIT	ALL	Read as "initiate, All Node". This is an initial Node for the beginning of each procurement plan. The output section is ALL and this says to "fire" or initiate all activities that originate at this Node.
AND	ALL	Read as "And, All Node". This Node means that all incoming Arcs must be completed before the initiation of an outgoing Arc can be made. All outgoing Arcs will be fired or initiated.
AND	PROB	Read as "And, Probabilistic Node". All incoming Arcs must be completed before any outgoing Arc can be initiated. This Node must have at least two outgoing Arcs with a probability associated with each Arc. The sum of the probabilities must equal 1.0. Only one outgoing Arc can be taken.

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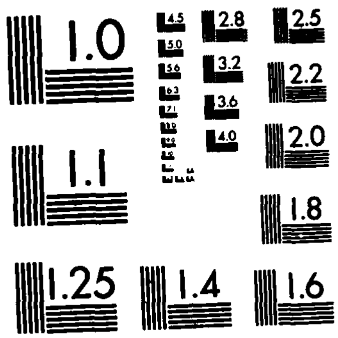
1.0
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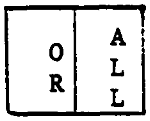

Read as "Or, All Node". The first input Arc to be completed will trigger the firing or initiation of all outgoing Arcs.

Read as "And, Terminate Node". This is a terminal Node. The model stops when all input Arcs are completed.

Based upon the procurement options and their activities (Figure 1) along with their time and cost estimates (Tables I through IV) the networks shown in Figures 2 through 6 were used in this DRA.

Above each Arc is a series of three numbers. These are the time estimates for that specific Arc with the first, second, and third number corresponding to the O, E, and P time estimate, respectively. Below each Arc is an equation depicting the cost for that specific Arc. The cost equation is a linear regression equation with a fixed cost and a variable cost which is a function of time (t). The variable (t) is the time that STATNET uses for the Arc during the present replication. The cost equations were developed from the cost data from Tables III and IV.

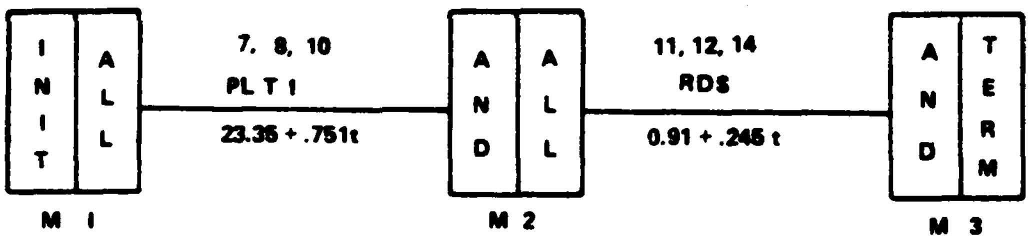

Figure 2. Plan A, Sole Source to Prime

Presentation and Discussion of Results

After 500 replications of each network (Figures 2 through 6) the output of the model is a distribution depicting cumulative probability versus total time for each procurement plan. These are shown in Figures 7 through 12.

The time distributions are shown in Figures 7 through 9. It is apparent from the data shown that Plan A offers the shortest time schedule for the second buy. There is a 50 percent likelihood that the

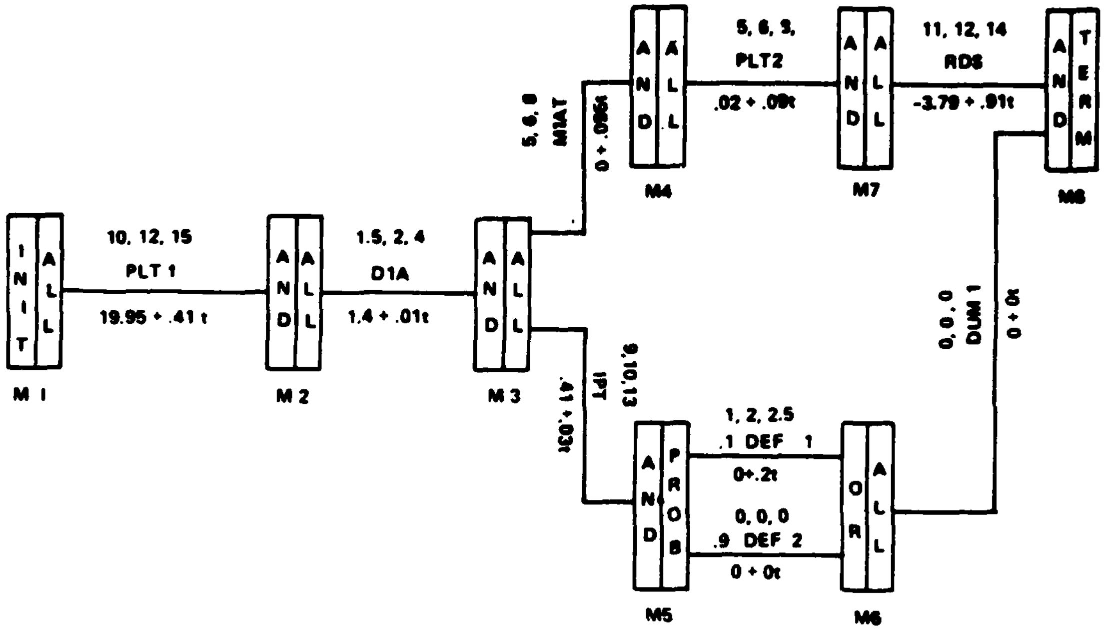

Figure 3. Plan B, Competitive with Prime Chosen for Second Buy

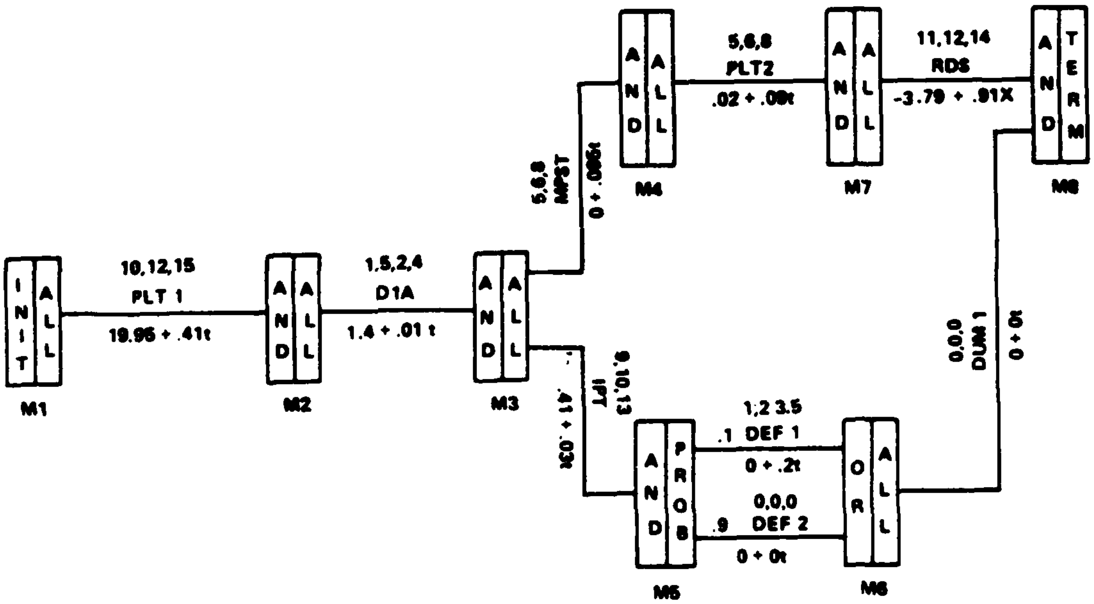

Figure 4. Plan B-1, Competitive with Prime Chosen for Second Buy

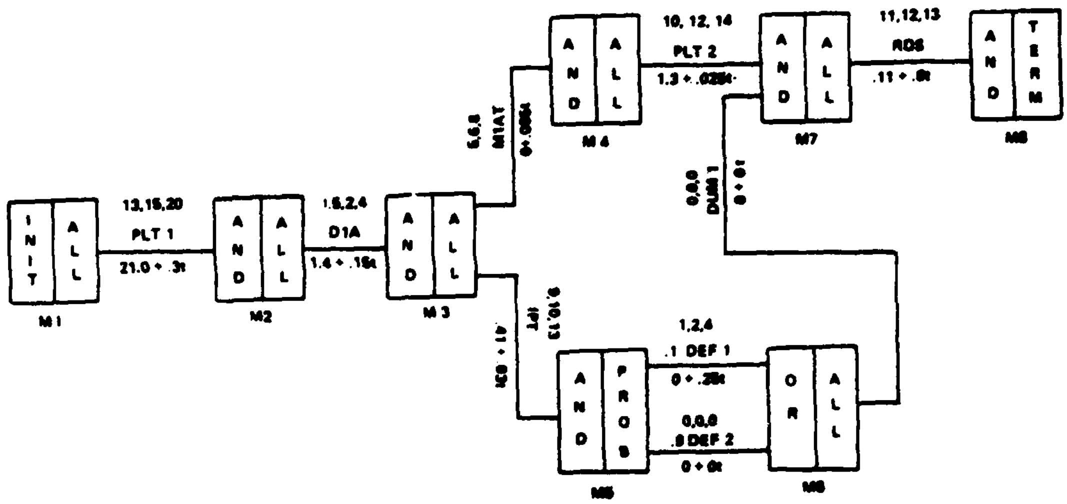

Figure 5. Plan B, Competitive, New Contractor Chosen for Second Buy

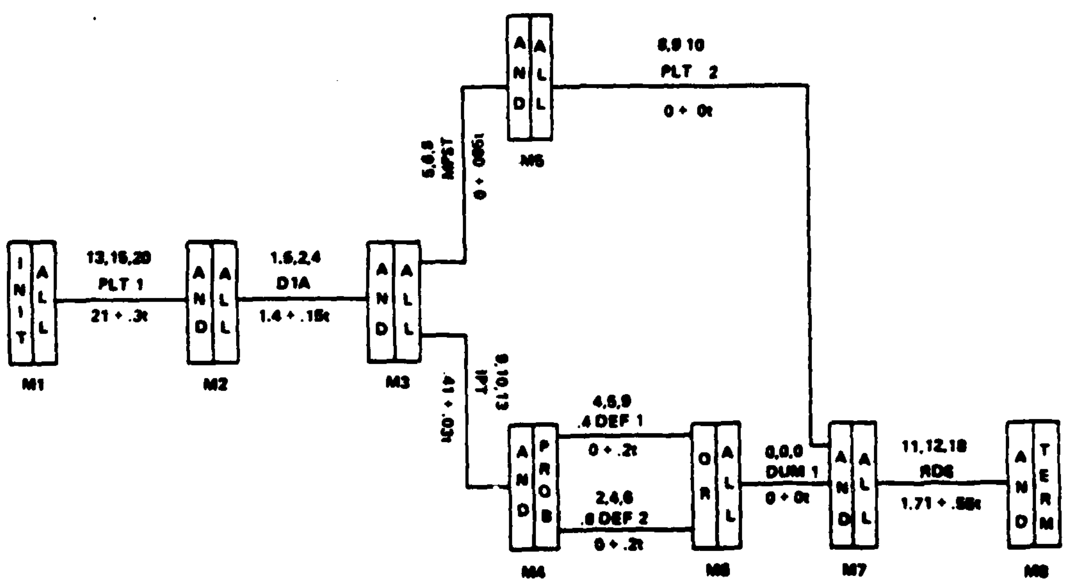

Figure 6. Plan B-1, Competitive, New Contractor Chosen for Second Buy

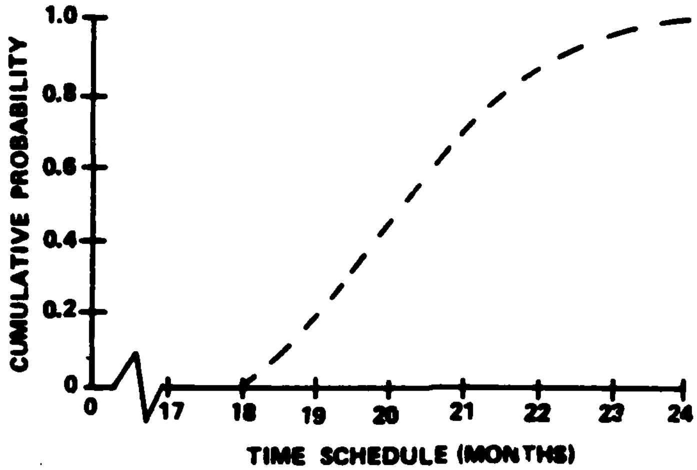

Figure 7. Time Schedule Distribution for Procurement Plan A

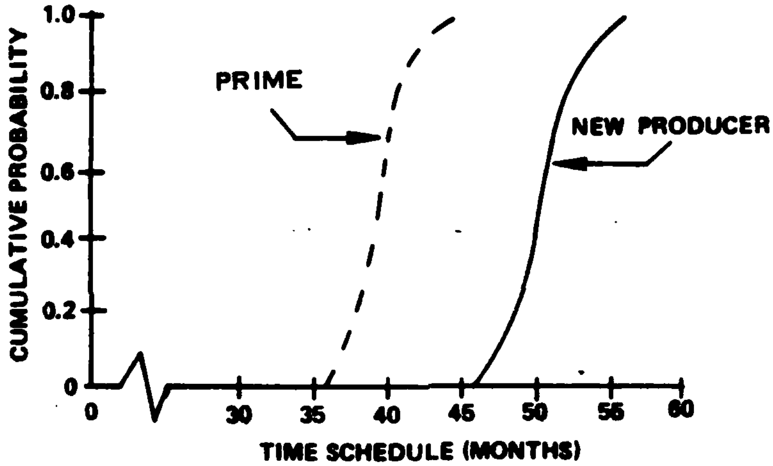

Figure 8. Time Schedule Distribution for Procurement Plan B

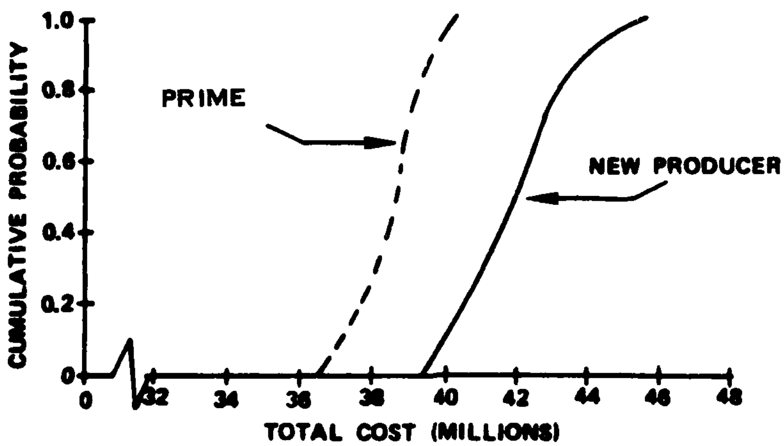

Figure 9. Time Schedule Distribution for Procurement Plan B-i

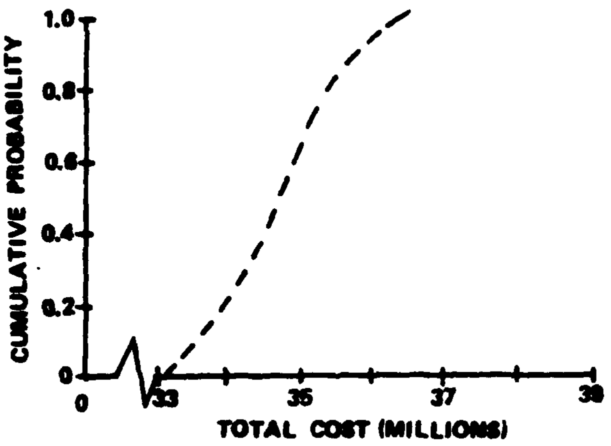

Figure 10. Total Cost Distribution for Procurement Plan A

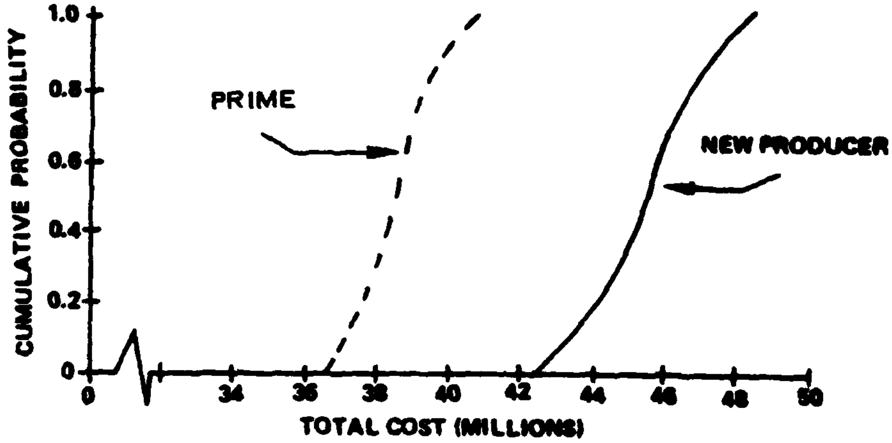

Figure 11. Total Cost Distribution for Procurement Plan B

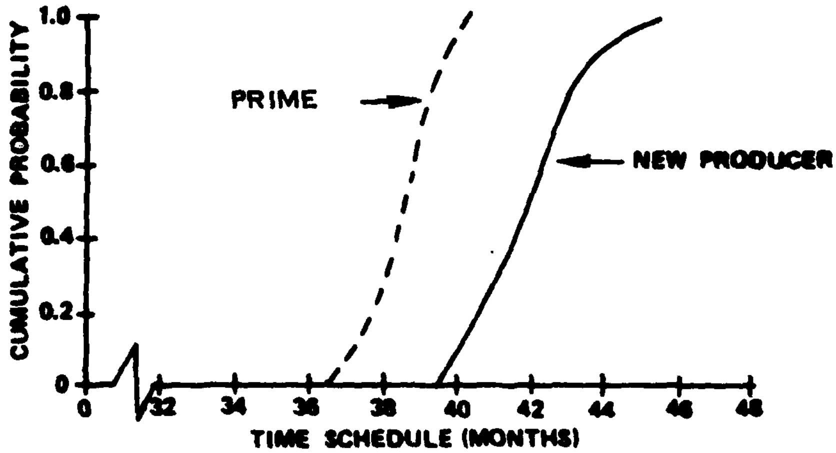

Figure 12. Total Cost Distribution for Procurement Plan B-1

total time for Plan A will be no greater than 20 months and a 90 percent likelihood that it will not exceed 22 months. The input data supplied for the time schedule shows that the time schedule for Plan A will not be less than 18 months nor any greater than 24 months.

For the competitive plans it is seen that Prime in each case offers the shortest time schedule. For Prime time schedules Plan B-1 offers less risks than Plan B. If a new producer is chosen it can be seen that Plan B is the most risky; its minimum value is approximately 46 months and its maximum value is approximately 56 months. Thus there is a spread of uncertainty of approximately 10 months.

There appears to be no difference in the time risks and uncertainty for Plan B-1 if Prime is chosen and, likewise, if a new producer is chosen.

The data shown in Table V summarizes the time distributions in a compact form. The probabilities in the table are that the time schedule (in months) will not exceed the value shown in the extreme left hand column of Table V. The probabilities are given for the four basic procurement plans and whether Prime or a new producer (if applicable) is chosen for a second buy. For example, for Plan B-1 the probability of the time schedule not exceeding 40 months for Prime or a new producer is 0.98 and 0.10, respectively.

Figures 10 through 12 present the distributions of total costs associated with the various procurement plans. We see that the expected cost associated with Plan A is less than any option that was investigated.

For each competitive plan we see that Prime estimated costs are always less than the corresponding new producers plan. There is very little difference in the Prime cost distributions for any of the competitive plans. Plan B is the most expensive if a new producer is chosen.

Table V. Probability of Time Schedules not Exceeding a Particular Length of Time for Various Procurement Options

Time Schedule	Plan A	Plan B		Plan B-1	
(≤ Shown Months)	Prime	Prime	NP	Prime	NP
15	0	0	0	0	0
20	0.48	0	0	0	0
25	1.0	0	0	0	0
30	1.0	0	0	0	0
35	1.0	0	0	0	0
40	1.0	.60	0	.98	.10
45	1.0	1.0	0	1.0	.98
50	1.0	1.0	.40	1.0	1.0
55	1.0	1.0	.98	1.0	1.0
60	1.0	1.0	1.0	1.0	1.0

Conclusions

This Decision Risk Analysis (DRA) addressed the uncertainties associated with time schedules and costs for the Super See second hardware buy. The study investigated in detail sole source and competitive procurement plans for the second buy. Based upon the assumptions adhered to throughout this study and the results of the STATNET simulation, the following conclusions seem appropriate:

1. Sole source procurement for the second buy will cost the Government less money with the end item being delivered much sooner than any of the competitive plans.

2. The analysis indicates that for any competitive procurement plan Prime can deliver sooner with less associated costs than a new producer can.

3. If a new producer is chosen, Plan B-1 offers a shorter time schedule distribution and cost distribution than Plan B offers. The spread for the distribution associated with Plan B-1 is less than for Plan B.

4. In most all competitive procurement plans the maximum estimated value (time and costs) for Prime does not exceed the minimum estimated value for a new producer.

5. For the competitive options a new producer displays a larger variability (variance) with its time and cost distributions than does prime.

AD P000660

SMALL CALIBER AMMUNITION MODERNIZATION PROGRAM EVALUATION AND REVIEW (SCAMPER)

A CONTRAST IN TECHNIQUES

MR. DEAN P. WESTERMAN

US ARMY MATERIEL SYSTEMS ANALYSIS AGENCY

Today's environment in analysis and decision making is wrought with a multitude of "standard" analytic methods and forms of analysis that should be thought of as a way of thinking rather than a method. The techniques, which are intended to serve somewhat the same purpose as the forms of analysis, may be categorized under the general headings of economic analysis and cost analysis. The forms of analysis are more generally known as systems analysis and decision risk analysis. If we define systems analysis as common sense with quantitative foundations, then decision risk analysis (DRA) is a form of systems analysis that recognizes the cracks in the foundation. Economic analysis, in Government circles, tends to dwell upon the savings realized by choosing one alternative over the other and cost analysis deals simply with only the cost of each alternative. Frequently, both cost analysis and economic analysis are employed for decision making purposes. However, there is a danger. Neither form of analysis considers realistically, if at all, the benefits/effectiveness or the risks of each alternative under consideration. Consequently, the view one receives of the possible choices might well be distorted. This paper deals with this final point. The results of a decision risk analysis are contrasted with those achieved by other techniques. The vehicle for this comparison is a recently completed study by the Army Materiel Systems Analysis Agency of the Small Caliber Ammunition Modernization Program.

SCAMP, as the modernization program is popularly called, envisions a fully automated, computer served production line or module that receives raw materials and has, as output, a packaged round of ammunition. This is contrasted to the current process which is characterized by a labor intensive operation utilizing machinery dating back to the early 1940's and a technology dating at least to the early part of this century.

The reason a decision risk analysis was deemed necessary is demonstrated in Table 1. This table also provides a small piece of insight into the breadth of the study and the various disciplines required for its successful completion. It should be noted that relatively few of the elements of the study are known with any degree of certainty. In fact, even the status of the current equipment cannot be projected with confidence.

Table 2 shows the composition of one end of the alternatives spectrum, a complete production line of modernized equipment. A module is defined as the combination of one submodule of each type, interlinked by a component transfer system.

TABLE 1

WHY DRA ?

STUDY ELEMENT	STATUS
CAPITAL EQUIPMENT COST	
CURRENT PROCESS	RELATIVELY UNCERTAIN
SCAMP	RELATIVELY UNCERTAIN
MANPOWER	
CURRENT PROCESS	CERTAIN
SCAMP	UNCERTAIN
EQUIPMENT DESIGN	
CURRENT PROCESS	CERTAIN
SCAMP	RELATIVELY UNCERTAIN
PERFORMANCE	
CURRENT PROCESS	CERTAIN (NOW)
SCAMP	UNCERTAIN
MANUFACTURING PROCESSES	
BRASS	CERTAIN
STEEL	RELATIVELY UNCERTAIN
ALUMINUM	UNCERTAIN
OTHER	VAGUE

TABLE 2

A SCAMP MODULE CONSISTS OF THE FOLLOWING SUBMODULES :

- CASE MANUFACTURE
- BULLET MANUFACTURE
- PRIMER INSERT
- LOAD AND ASSEMBLE
- PACKING
- BALLISTIC TEST
- COMPONENT TRANSFER
- PROCESS QUALITY CONTROL SYSTEM

Since the objective against which the alternatives are measured is the requirement to produce ammunition in order to meet specified demand levels, the "goodness" of two of the submodules, ballistic test and process quality control system, is not measured. These submodules are designed to improve the quality of ammunition; the remaining submodules are designed to produce quantities of ammunition.

At the other end of the alternatives spectrum is the ever faithful "do nothing" case. By "do nothing" is meant that nor the current equipment is replaced by modernized equipment. However, i must be remembered that the current equipment alternative or baseline is sumed to be rather old and, consequently, must be replaced in kind. Thi ssumption will be numerically altered later in the results. Between th two extremes, full substitution of modernized equipment and the baseline a multitude of alternatives. For example, modernized bullet manufac could be substituted for current bullet manufacture machinery while the remainder of the production facility is left untouched. There could be multiple substitutions of modernized equipment. However, due to time and space limitations, only the extremes will be treated.

In order to prevent this discussion from leaving the impression that AMSAA's study is a cost study, the overall approach will be reviewed. First, a detailed engineering look was taken at Lake City Army Ammunition Plant. Serving many purposes, this portion of the analysis was divided among providing a detailed examination of the production process, verifying engineered standards and creating standards when voids existed, counting machines, counting personnel, cross checking counts with standard labor calculations, examining scrap and reject rates in order to determine the causative factors, tracing machine history and reviewing plans for improvement of current equipment. These activities have resulted in a complete process manual for the production of 5.56mm ball ammunition which is being adopted for training purposes by Lake City. Of course, the primary purpose of the activity was to provide basic input into AMSAA's study. On the surface, it would appear that such efforts as machine counts were trivial. However, the production of small caliber ammunition is so dynamic a process that today's data might well be tomorrow's history. In fact, we currently have three sets of data on machine count for roughly the same time period. None of these data sets agree.

The second engineering step was, of course, to examine the modernized equipment concepts and prototypes in as much detail as was possible.

Concurrent with the engineering efforts was a phase of the study designed to develop models that would predict the performance of the modernized equipment and current equipment under varying assumptions concerning repair policy, failure rate, buffer placement and size and maintenance times.

In addition to the engineering and modeling tasks, the nearly fatal task of attempting to sort out the cost accounting system was undertaken.

Here the problems of production dynamics are multiplied by the number of overhead accounts. Simple regression techniques were inadequate since, essentially, a change in the state-of-the-art was being treated. Once again, engineering expertise was required to assist in forecasting the magnitude of overhead changes.

These efforts (plus a multitude of auxiliary activities treating demand levels, labor force structure and material supply) were brought together to portray our results in the most basic form possible--the cost to do a task.

Before turning to the results of our computations, the anatomy of the cost of a round of 5.56mm ammunition, as currently being manufactured by Lake City Army Ammunition Plant, must be examined. The normal definition of per round cost excludes all dollars but operating dollars. Consequently, capital investments are not included. The bulk of the per-round cost (51 percent of the total) is, as may or may not be expected, for the purchase of raw materials. If reject rates were reduced to zero, this figure would be reduced by about three percentage points. Direct labor, on the other hand, represents only about 14 percent of the total. Massive reductions in direct personnel can, of course, affect the per round cost. However, the effect is rather severely diminished since this portion of the pie is rather small. It is recognized that reductions in the labor force have a reflected effect in overhead requirements which represent 32 percent of the total. However, our sorting through of the nearly 300 overhead accounts has led to the following classification: 24 percent is fixed, 40 percent is a function of the number of rounds produced, and 36 percent is a function of the number of direct labor personnel. Consequently, the reflected effects of labor reduction are diminished by the relatively small size of the overhead accounts that can be affected.

It must be repeated that this study is not a cost study. If it must be characterized, the ingredients are one part cost, two parts modeling, nine parts industrial engineering and twenty parts analysis of the results. The reason the results are expressed in terms of dollars is that dollars are a convenient common denominator.

As previously stated, the results of the economic/performance risk portion of the study are in terms of cost to perform a given task. The task is to meet a peacetime demand level for ten years and then to mobilize the facility in order to meet the higher wartime demand levels. Since this paper is unclassified, the levels of demand are not specified. However, they are as realistic as our ability to predict future political events.

The results are shown in Figure 1. This graph compares the resource requirements for various alternatives to perform a given task. The X axis is in terms of years of mobilization. The Y axis is the cumulative cost of doing this task measured in millions of dollars. The intercept (zero years of mobilization) is the ten year peacetime cost. This cost includes all of the monies required to purchase new equipment, buildings (when appropriate) and to operate the plant. The baseline case is the current process, machinery and labor force required to accomplish the task. The other curve represents full substitution of modernized equipment.

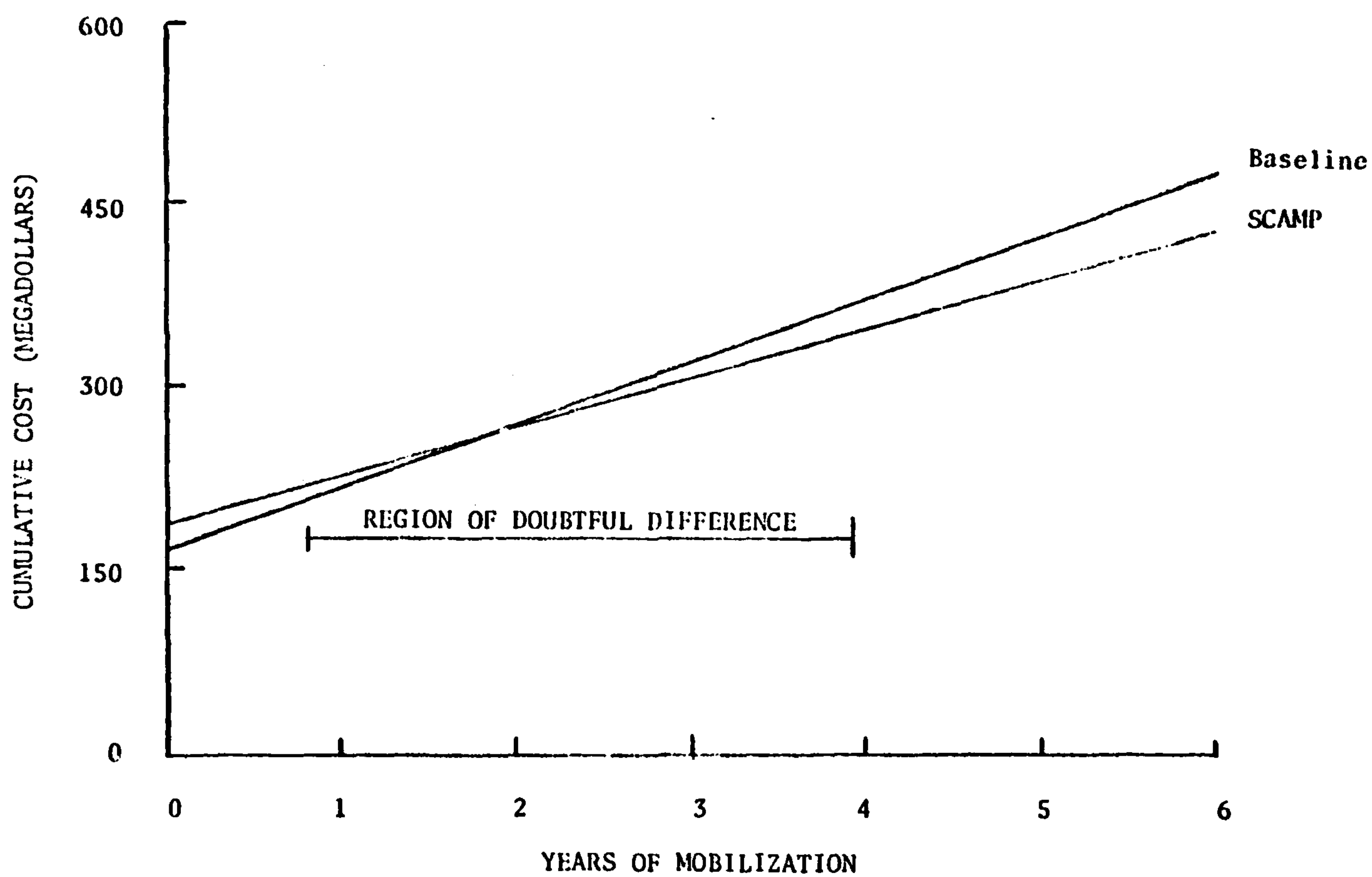

FIGURE 1 Equal Capability Resource Comparison

There are two points that must be discussed before discussing the results. It has always been of some concern that results, even when presented in a simple graphic form as shown here, are somewhat difficult to interpret. Obviously, in this sample case, the alternative appears to be superior to the baseline after approximately one and one-half years of mobilization (in other words, it costs less). Is that fact particularly meaningful? The first aid incorporated into the graph is the region of doubtful difference. This region, which is generated by a somewhat loose statistical method, takes into account the variability that is predicted for each line and defines that region of the graph within which the relative position of each curve (one superior to the other) could easily be reversed. The probability of reversal depends upon which portion of the region one is examining. Outside of the region, the relative position of the lines are meaningful but the magnitude of the difference could be other than what is shown.

The other point is that it is not the number of years of mobilization that is important. Rather, it is the number of years of mobilization relative to the number of years of peacetime. In the past 70 odd years the United States has spent from 20 to 40 percent of its time either in support of, or direct involvement in, some conflict. Translating this to the graph, which is based on 10 years of peacetime, a crossover point should occur (for an alternative to be clearly superior) prior to the sixth year of mobilization. Of course, the earlier the crossover, the firmer one's conviction can be relative to the superiority of an alternative.

This graph represents an optimistic case. Since the modernized equipment is new and essentially unproven, its stated performance from engineering estimates and the stated cost and manpower requirements must be termed optimistic. In this case, there appears to be a savings in the out years of mobilization. If, however, the modernized equipment manpower were 50 percent higher than that predicted, the capital investment 25 percent higher, machine efficiency in the .85 range instead of the .90+ range, the results change as shown in Figure 2. If current equipment need not be replaced, the results are as shown in Figure 3. Here the conclusions are decidedly reversed.

If we turn to the popular economic analysis technique, the payback ratio, the view is somewhat different. In essence, the payback ratio is the savings accrued by not pursuing one alternative divided by the capital investment cost of the other alternative. A payback ratio of 1.2 means that for every dollar invested, $1.20 is saved. The conditions under which the payback ratio for the modernized equipment is computed are as follows: 1. optimistic (predicted) modernized performance and resource requirements are used; 2. the time frame is ten years; 3. the demand level is for full mobilization; 4. equipment life is ten years; and 5. current equipment must be replaced. The results of this calculation, using the same data utilized in the decision risk analysis, are shown in Figure 4. Even if current equipment does not need to be replaced, the payback ratio is greater than 1.0 as is shown in Figure 5.

The cost analysis approach to the problem can, if properly structured,

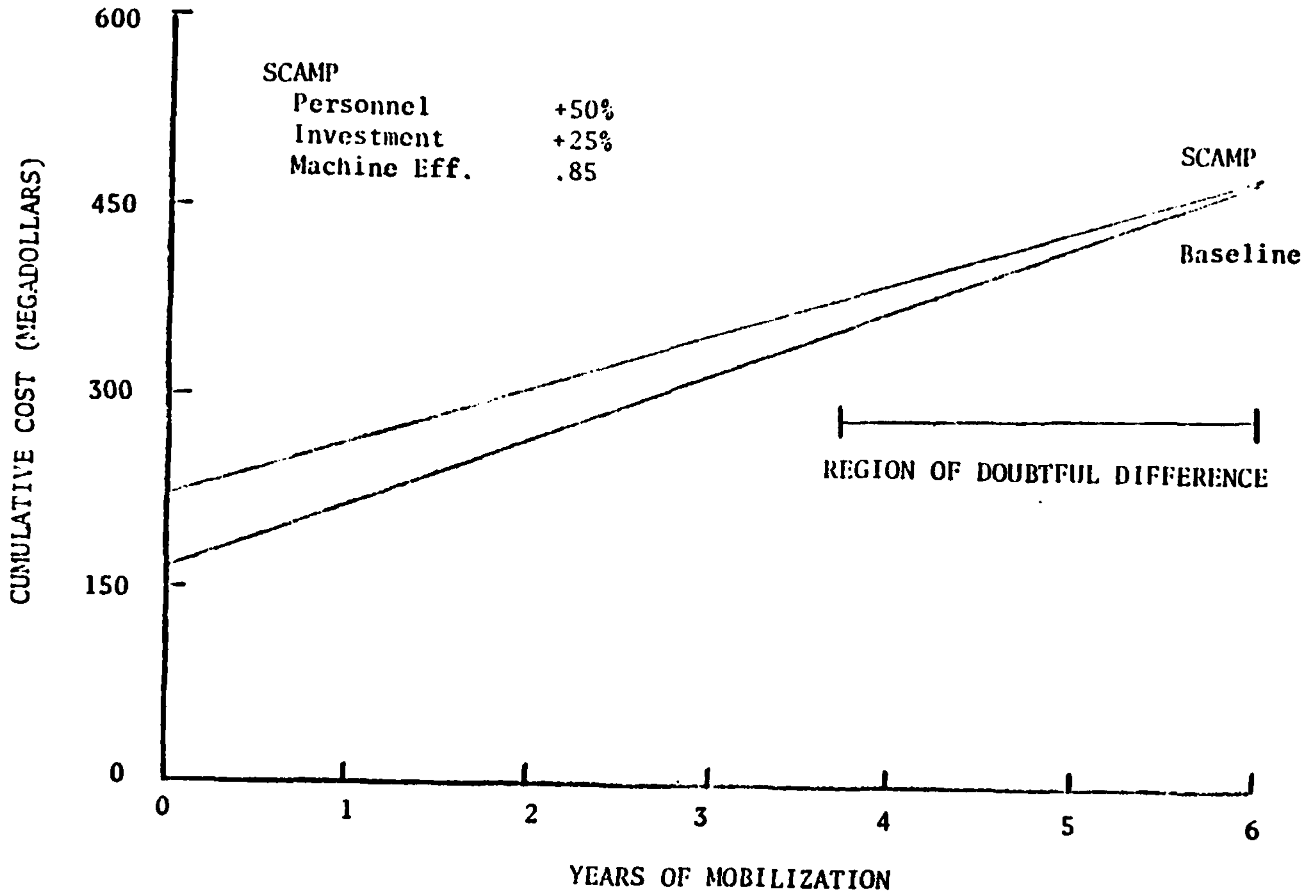

FIGURE 2 Equal Capability Resource Comparison

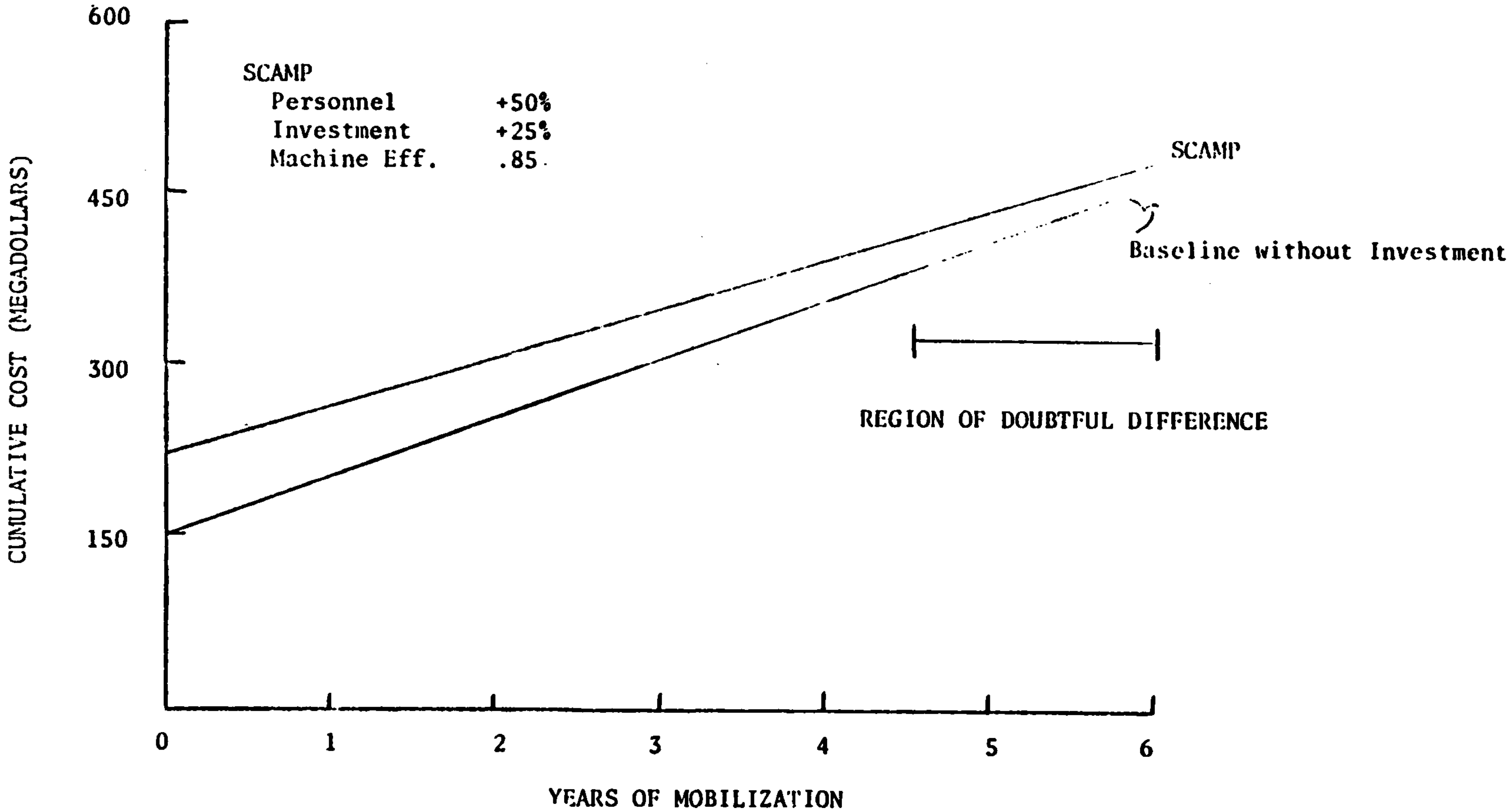

Figure 3 Equal Capability Resource Comparison

FIGURE 4

$$\text{PAYBACK RATIO} = \frac{\text{SAVINGS}}{\text{CAPITAL INVESTMENT}} = 2.05$$

FIGURE 5

PAYBACK RATIO

(WITHOUT CURRENT EQUIPMENT REPLACEMENT)

1.84

yield similar results as the subset of decision risk analysis currently under discussion. Figure 6 shows the results of two possible calculations. The first set of numbers shows the total cost for ten years of peacetime and the bottom set of numbers shows the total cost of ten years of mobilization.

Before summing up, it must be mentioned that only the economic/performance risk portion of AMSAA's study has been presented. In addition, only a small portion of that effort has been discussed. The study also contains an engineering risk section. This deals with natural resource problems and their effect on the requirement for using alternative materials for case and bullet manufacture and the ability of the equipment to meet this altered requirement. Furthermore, externalities such as sound levels, sabotage and reaction times receive some treatment. These other aspects of the study tend to support the findings and conclusions of the economic/performance risk section.

In summary, the message of the payback ratio is buy the modernized equipment; the message of the cost analysis is buy the modernized equipment (maybe); and the message of the decision risk analysis is extreme caution—"fly before you buy" and examine closely that which could be replaced.

The underlying message is that the standard techniques can and do, in this particular case, lead one to erroneous conclusions. Buying equipment on the basis of ten years of full mobilization when, in fact, the equipment must also be used in peacetime is a rather loose basis for the expenditure of large sums of money. This, in effect, ignores the distribution of requirements placed upon the alternatives and focuses on the extreme case. We can no longer afford "peak-load" criterion. It should be noted, however, that the DRA does not scarifice the Army's ability to produce ammunition. All alternatives are equally capable.

To repeat a message heard many times (but evidently not often enough)--there are no standard or cookbook techniques for analysis just as there are no standard problems. Each is an individual case, and no amount of standardization can be substituted for good, thoughtful analysis. We should not diminish our quest for better approaches and techniques; however, we should certainly multiply our efforts to discover and develop better analysts.

Interactive Graphics in Force Planning, War Gaming, and Military Systems Analysis

Captain Louis P. Costa

US Army Concepts Analysis Agency

1. Introduction

This paper cites recent applications of interactive graphic data processing techniques to a variety of military problems under study at the US Army Concepts Analysis Agency (CAA). First, a brief description will be given of the UNIVAC hardware and associated software supporting these applications at CAA. Next, the characteristics of five currently operational packages will be summarized to illustrate the application of interactive graphics to specific problems in force planning, war gaming and military systems analysis. Finally, some progress in the conception and development of new applications is reported.

2. System Description

a. Hardware

The CAA data processing facility comprises a UNIVAC 1108 Unit Processor system with three banks of 65K core memory and a terminal configuration depicted in Figure 1. The on-line graphics hardware consists of three UNIVAC 1557/1558 Graphics Display Subsystems (DSS) operating as independent remote terminals of the central processor via a high speed communications network.

Each DSS consists principally of a 1557 Display Controller and a 1558 Display Console. The Display Controller is itself a computer with a 16K, 18-bit word programable memory with a 700-nanosecond cycle time. Using a powerful 26-instruction repertoire, it exercises control over and handles many of the display functions of its associated Display Console thus reducing the burden on the central processor. It handles all interrupts and communications with the display operator and its input/output capability provides communications with the central processor.

The Display Console includes a 19-inch diameter CRT giving a 12-inch square viewing area with a raster count of 1024 by 1024. It is also equipped with an alphanumeric and function keyboard and a light pen, by means of which the operator interacts with the operating system or an executing program or display. The Display Console is capable of plotting character strings in two sizes and orientations and vectors as solid, dashed, or centerline line segments or as end points. Images may be displayed at three programable intensity levels (including 'off').

CENTRAL SITE AND TERMINAL CONFIGURATION

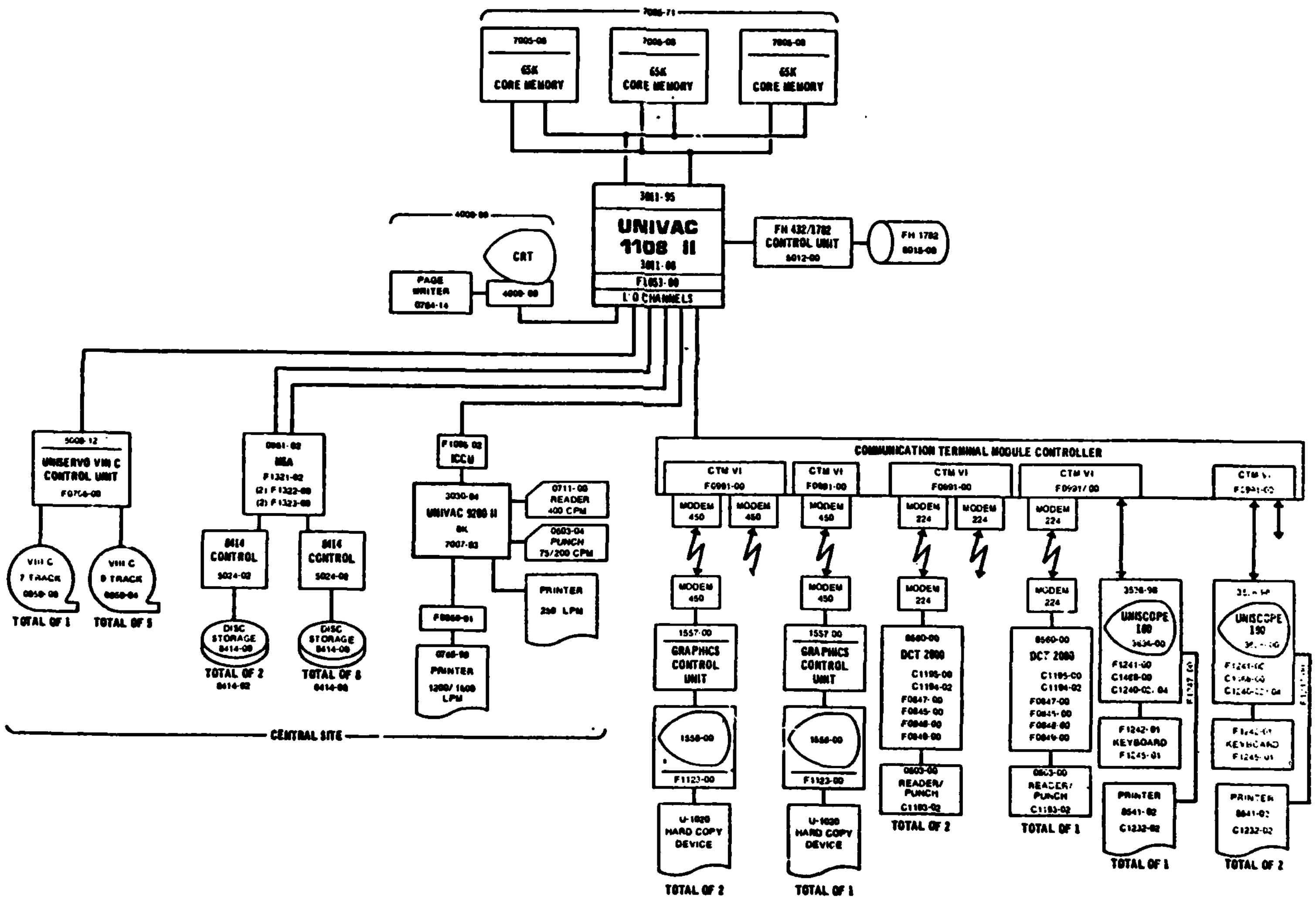

Figure 1. US Army Concepts Analysis Agency Data Processing Facility.

A useful accessory to the Display Console is the U-1020 Hard Copy Device which yields 8-1/2 by 11 inch working-copy reproductions of stable CRT displays at the option of the operator. A means of generating off-line CALCOMP record-copy plots of CRT displays is also available to the operator.

b. Software

The UNIVAC Interactive Graphics Support Package, UNIGRASP, is the software which, in conjunction with the UNIVAC 1100 series computer EXEC 8 operating system, provides for graphics applications programing and graphics program execution and control. UNIGRASP consists of: (1) the UNIGRASP library subroutines, (2) the Display Monitor, and (3) the communications handlers.

The UNIGRASP library subroutines are called by applications programs to build and manipulate graphics images and to provide interactive communications with the display operator. The Display Monitor is the software resident in the Display Controller which allows it to carry out the control and processing functions previously described. The UNIGRASP communications handlers facilitate communications between the DSS and the central processor. They handle error checking, message timeouts and retransmissions, and data verification of buffers.

The applications programer need only concern himself with the UNIGRASP library subroutines since the Display Monitor and communications handlers function autonomously.

3. Applications

a. Force Planning

Initial applications of interactive graphics to the force planning function at CAA have centered on two models of the Army's FOREWON Force-Planning System: the Force Analysis Simulation of Theater Administrative and Logistic Support (FASTALS) and A Tactical, Logistical, and Air Simulation (ATLAS). Both applications use interactive graphics to expedite convergence on predefined exercise objectives. Key results of each model interaction are graphically summarized and displayed. Analysis of these results suggests the adjustments to be made to the model input at each succeeding interaction until the exercise objectives are met. This execution analysis cycle is further expedited by the ability of the DSS to call system input/output file processors (demand mode operation) in conjunction with its ability to execute interactive graphics applications programs (graphics mode operation).

(1) FASTALS Graphics

FASTALS is used to compute the combat service support requirements associated with a hypothesized military operation. FASTALS input consists of a planner's scenario, a data base, and a trooplist of combat and selected combat support forces specified to support the hypothesized tactical aspects of the mission. The ultimate output of FASTALS is a time-phased trooplist of units geographically distributed in a theater of operations and balanced with respect to type (combat, combat support, and combat service support) such that no fewer units by type can support the prescribed mission. FASTALS converges on the objective trooplist by successively computing and matching requirements against capabilities, by time period and according to support category.

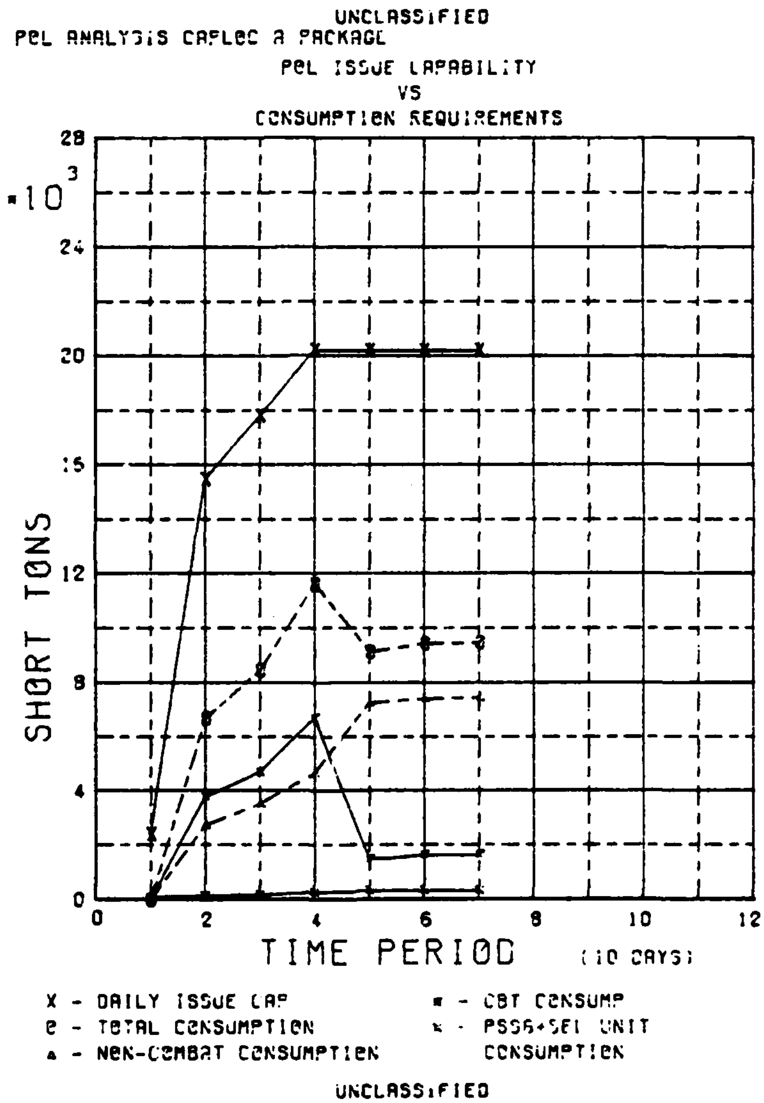

Figure 2. A FASTALS Graphics Display.

Mismatches require trooplist adjustment and recomputation and assessment of the results.

FASTALS graphics is an applications program which expedites the assessment by graphically portraying requirements versus capabilities upon completion of each FASTALS iteration. The plot in Figure 2 illustrates a typical FASTALS Graphics display for the POL category of supply.

(2) Graphics ATLAS Support Program (GASP)

ATLAS is the theater-level combat model of the FOREWON System.

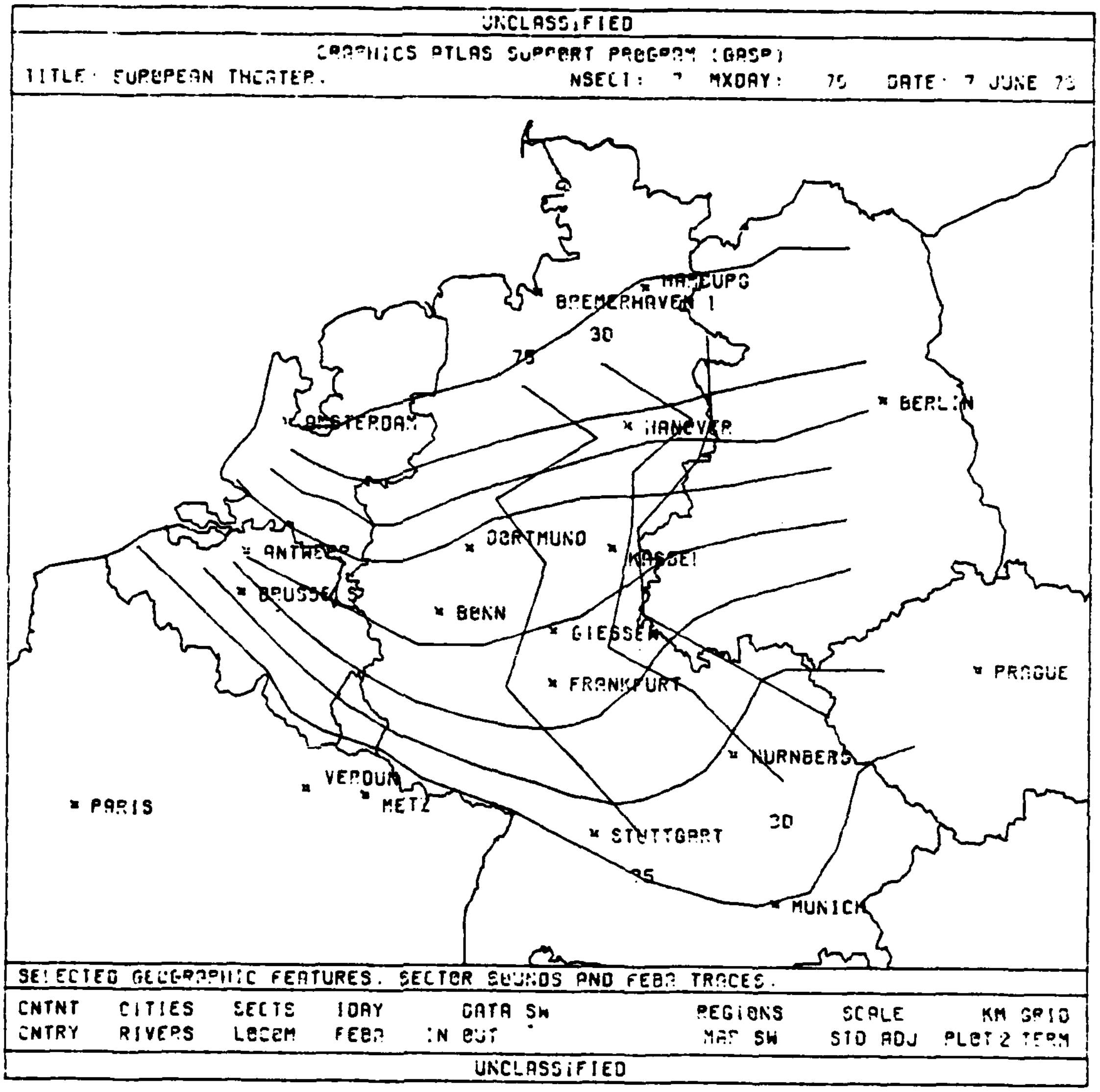

Figure 3. A GASP Display.

It portrays attrition and movement of opposing forces based on their relative combat effectiveness. The campaign is represented in up to ten essentially independent sectors each corresponding roughly to a corps-sized avenue of approach. Sector boundaries, lines of communication, barriers, phase lines and other geographically-oriented scenario descriptors may be directly related in the model to a user-specified region defined by lat/long coordinates.

ATLAS may be exercised either in a requirements or in a capabilities mode. In both cases, the analyst must monitor the progress of the campaign in each sector over time to insure the technical feasibility as well as the military realizability of the model-predicted results. Movement of the forward edge of the battle area (FEBA) and attrition are among the principal variables reviewed by analysts in this connection.

GASP is an applications program which facilitates the validation of ATLAS runs by superimposing a graphic representation of FEBA over time on the geographic background pertinent to the campaign. As suggested in Figure 3, a variety of display options are open to the display operator including various geographic and political descriptors and a variable size grid overlay (used both to estimate distances and to redefine regions to be displayed). GASP also permits the display operator to review (scroll) quantitative data in the ATLAS input and output files pertinent to the campaign being analyzed. Definitions of terms contained in these files may also be displayed at the option of the operator to facilitate interpretation.

As in the FASTALS application, the execution-analysis cycle is sufficiently short to allow rapid convergence on a satisfactory base case given raw data or rapid evaluation of 'excursions' from a given base case.

b. War Gaming

Applications of interactive graphics to war gaming at CAA include TARTARUS Graphics, a routine which interfaces the war game player with the TARTARUS Model, and Nuclear Targeter, a routine which assists the analyst in detailed nuclear fire planning. The force planning applications previously described sought convergence on predefined exercise objectives by successive iterations of complete execution-analysis cycles. These war gaming applications, in contrast, allow the analyst to interrupt and evaluate an exercise at logical intervals and to dynamically influence its future course by providing for the introduction of appropriate control measures.

(1) TARTARUS Graphics

TARTARUS is a theater-level, ground combat, war gaming model which predicts the interactions of up to 300 opposing division or brigade size units. The model portrays attrition, movement and movement suppression, fire suppression, and the effects of movement on firing capability. The effects of employing close air support and nuclear weapons can also be represented.

The game is played in logical intervals, input in minutes, which specify how often target lists are updated and how often game reports are generated. Frag orders may be introduced at player option between logical intervals to control unit deployment in subsequent intervals.

TARTARUS Graphics provides the player with a graphic description of the state of the game at any logical interval. As depicted in Figure 4, the display consists of a geographic representation of unit

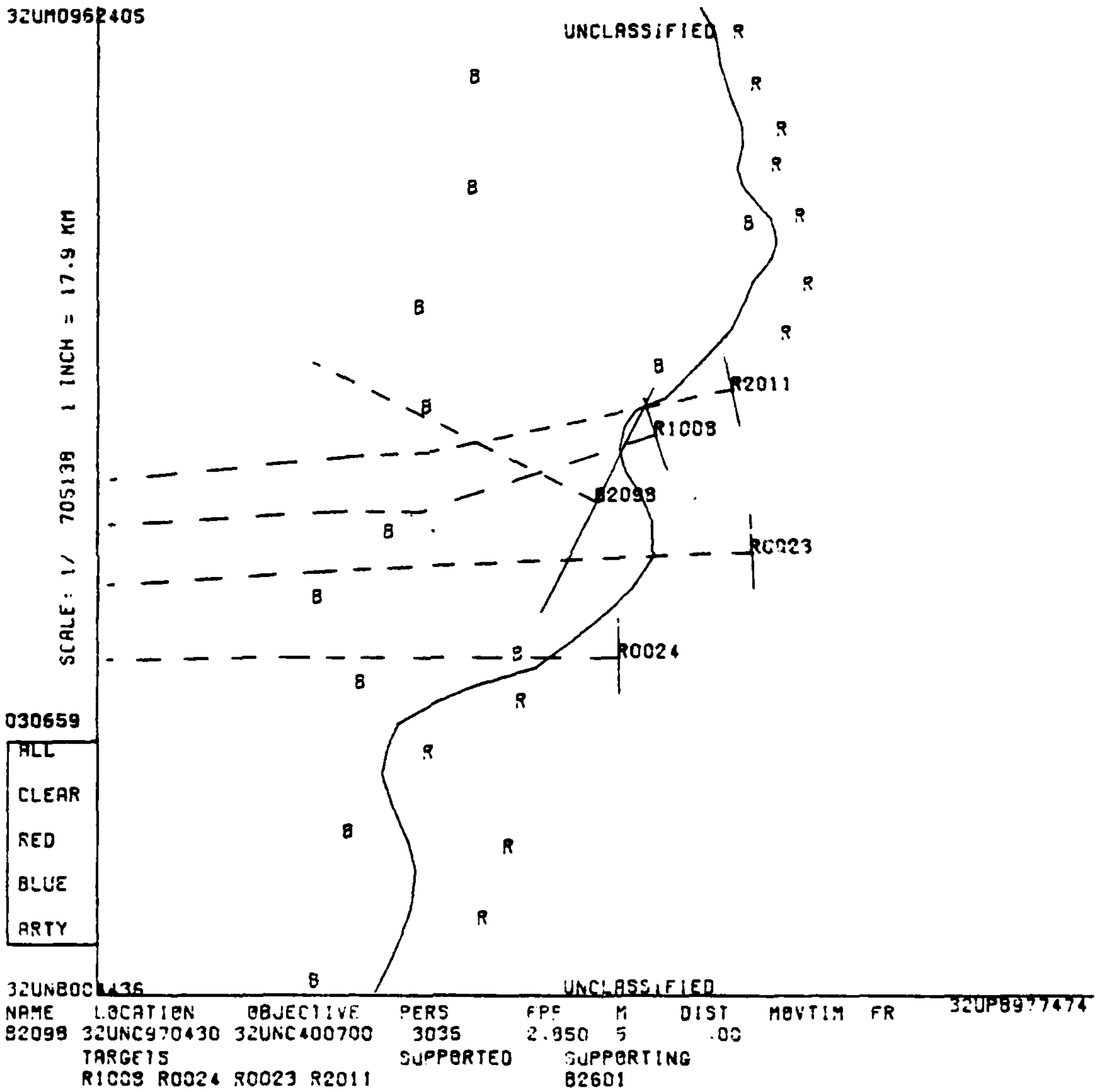

Figure 4. A TARTARUS Graphics Display

locations and a summary of the values of key game variables. A variety of display options may be selected by the operator including: display all Red and/or Blue units; display Red and/or Blue artillery units; display the location and frontage of any unit and its targets;

draw the implied FEBA; change the scale (and scope) of the display; identify a unit's objective(s), its personnel strength, its FPP, and any supported or supporting units. Analysis of this information in graphics form facilitates identification of required control measures.

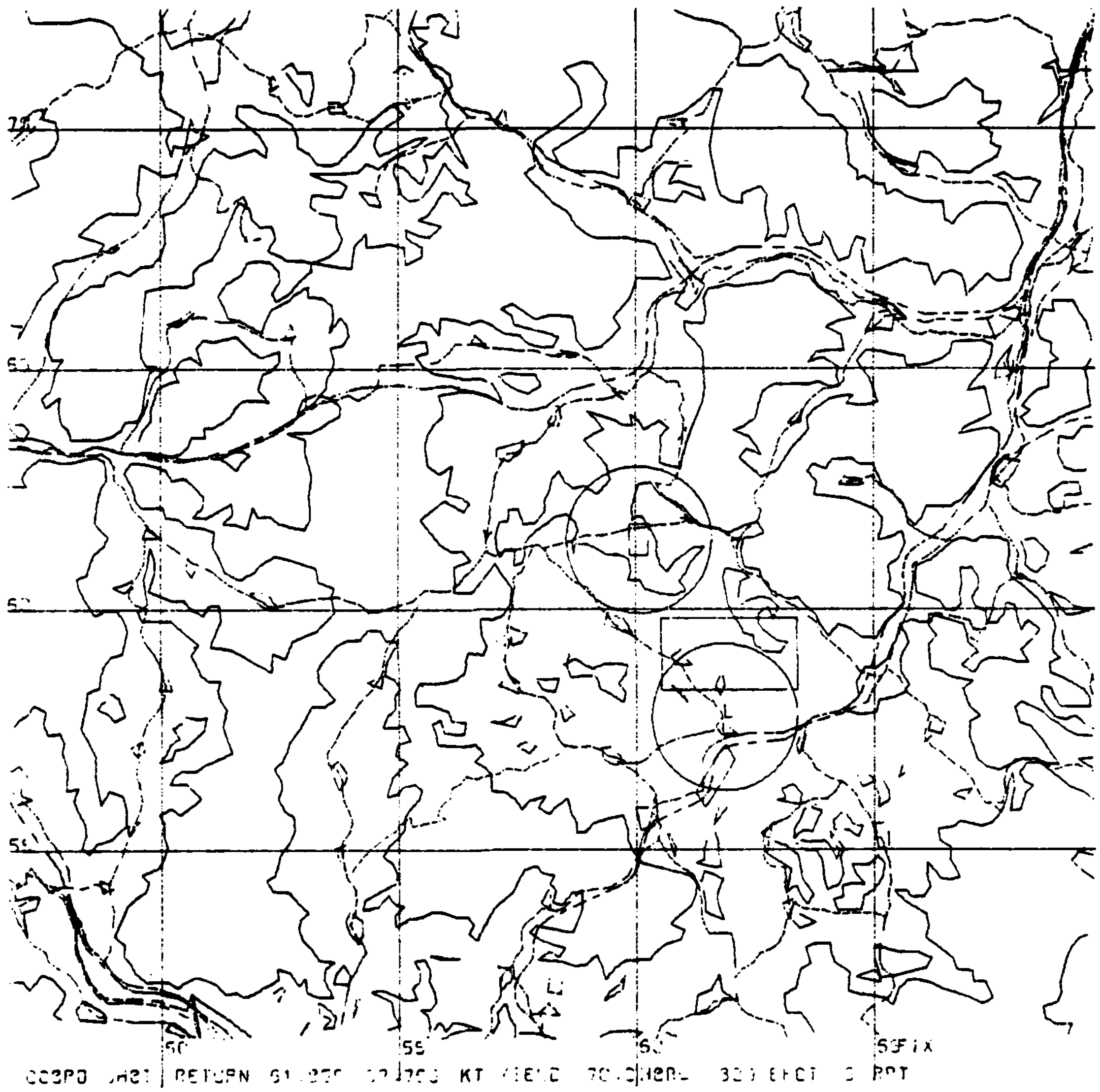

Figure 5. A Nuclear Targeter Display.

(2) Nuclear Targeter

The Target Acquisition Routine (TAR) and the Nuclear Assessment Routine (NAR) are used in high resolution simulations of fire exchanges in a theater of operations. They may be played independently or in conjunction with a large scale war game such as TARTARUS. In either case, they are exercised in one or more logical intervals, the results at each interval being used to drive the succeeding one. Implicit in the application of these routines is the preparation of a detailed fire plan, an exceedingly tedious task in large scale games.

Nuclear Targeter is an interactive graphics routine which simulates alternative, discrete assignments of fire missions on targeted units in a theater of operations and provides an immediate assessment of the corresponding damage circle for a stipulated effect. As suggested by Figure 5, the Nuclear Targeter display operator can identify targets by type, by location, and in topographic context. He may then key-in trial fire mission specifications and call for displays of target damage and collateral effects under a variety of hardness and exposure conditions. By iterating this procedure the operator can interactively build a fire plan to accomplish an assigned mission much more efficiently than previous, manual methods allowed. The possibilities of optimization are clearly suggested in the future development of Nuclear Targeter and promise to render it an even more powerful war gaming tool.

c. Military Systems Analysis

An application of interactive graphics at CAA to the quantitative analysis of military systems is called the Graphic Interactive Analytic Network Technique (GIANT). GIANT applies flow-graph models to systems which can be characterized by known, generally non-linear functions of related variables. Graph transformations and numerical analysis are interactively performed on the models to derive particular solutions to questions in analysis or to generate and catalog parametric solutions to more general systems problems.

Figure 6 depicts a hypothetical system (principal design factors of an AUTODIN switch), its assumed flow graph model, and one of the eight specified relations which comprise known quantitative data relating principal system variables. The derived parametric relation in the display was interactively computed and dynamically cataloged using the flow graph model in conjunction with each of the eight specified relations. Other relations among the variables could similarly be derived.

GIANT may find future use in the sensitivity analysis of large scale models and war games. It may also be used to evaluate alternative materiel systems such as the various BUSHMASTER candidates.

d. New Applications

One of the more recent applications of interactive graphics at CAA is being developed by the Defense Communications Agency-System Engineering Facility (DCA-SEF). It comprises a network model of the Defense Communications System (DCS) together with a series of network length minimization algorithms. In conjunction with other sizing and cost models it may be used to engineer the DCS of the future.

Another application under development is a graph model of a theater transportation system. An initial design objective is simply to display the network required to transport, over time, the logistics requirements specified by the FASTALS Model for a campaign in a theater of operations. Subsequent developments might include means of inter-

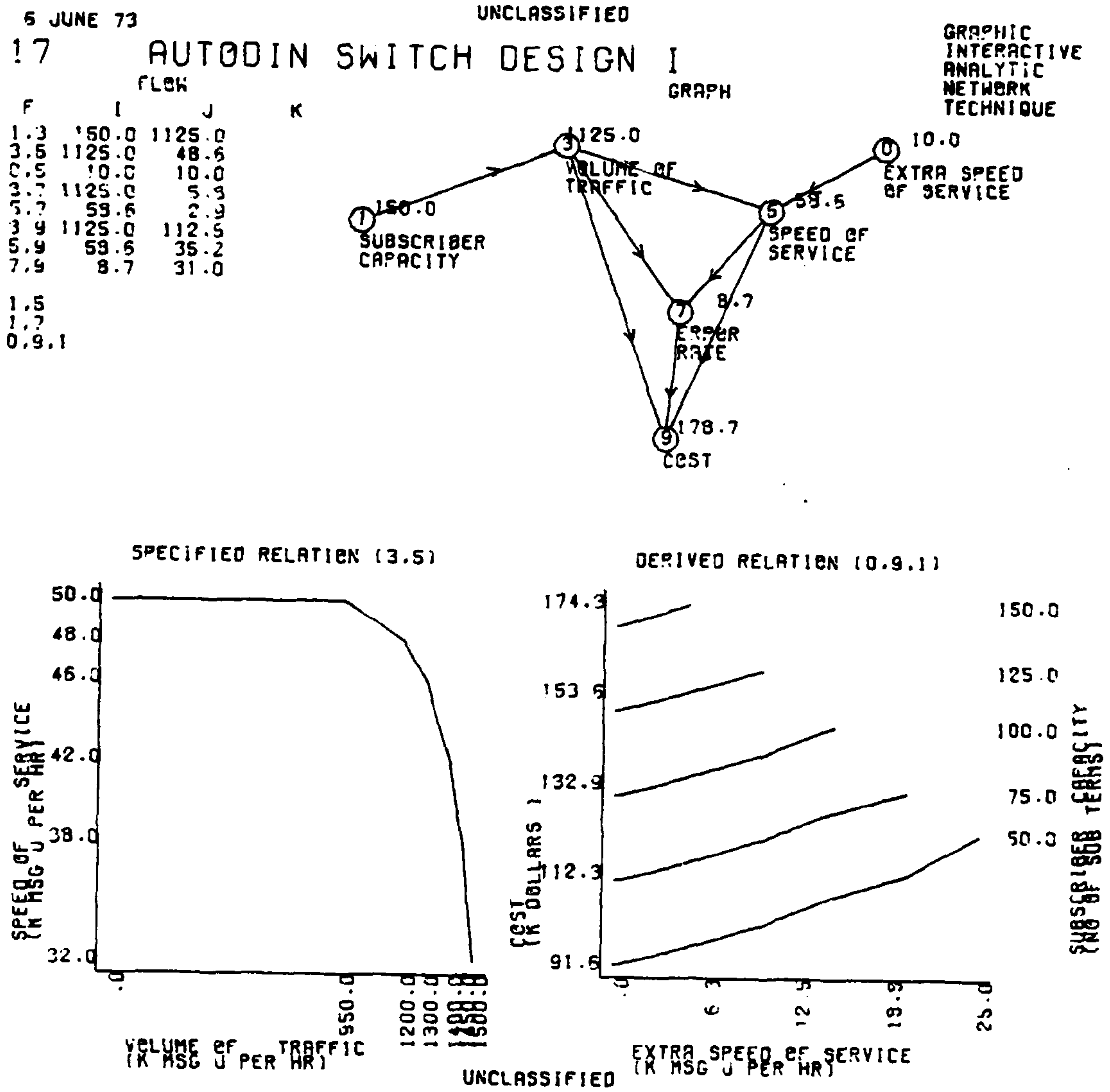

Figure 6. A GIANT Display.

actively reconfiguring and optimizing the network to meet contingent objectives under various constraints.

A final application, in the early stages of conception, is the play of two-person, limited information games using one graphics terminal for each player and possibly a third for a controller.

4. Conclusion

a. Payoff

While the application of interactive graphics has met with initial success at CAA, it is probably not yet clear that the high cost of acquiring and maintaining this capability is justified. In pursuing this objective, it is incumbent on the designer to develop more, imaginative, and genuinely useful applications - applications which show a distinct payoff over alternative data processing/problem solving techniques. It is equally important that the use of these newly developed applications be stimulated so that their full payoff is realized.

In theory, interactive graphics has narrowed the man-machine communications gap by a quantum step. It remains for the designer and the user, in concert, to demonstrate the viability of that theory.

b. Acknowledgment

The author acknowledges with thanks the contributions of LTC John Daugherty, Jr., Miss Patricia McGroddy, and Mr. David Howes of CAA, and of Dr. Eugene Kaiser of DCA-SEF; designers of FASTALS Graphics, TARTARUS Graphics, Nuclear Targeter, and the DCS communications network models, respectively.

OR/SA TECHNIQUES IN COMPUTER AIDED DESIGN OF MATERIEL

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1. AN ANALYTICAL VIEW OF MATERIEL DESIGN

Spectacular gains in the basic sciences and technologies during the past two decades have provided tools and techniques that may be used for advanced military systems, with qualitatively new capabilities. Along with this deluge of advanced technology has come the realization that organized techniques are required for making best use of the fundamental technology in advanced systems. This body of techniques has become known as System Engineering. A simplified model of the system engineering process is shown in Fig 1.

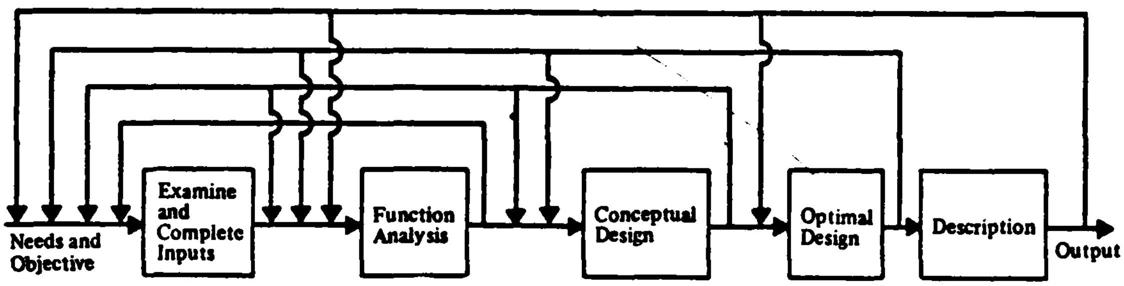

Figure 1. A System Engineering Model

As explained in the basic literature on System Engineering [1,2], the process illustrated in Fig 1 begins with a definition of needs and objectives in quantitative form, to include definition of quantitative performance requirements. The System Engineer then analyzes the various functions that the system must perform and quantifies the performance requirements associated with each basic function. With this understanding of detailed technical performance requirements of his system and subsystems, he then exercises his engineering experience to obtain conceptual approaches to meeting system and subsystem requirements. According to the system engineering philosophy, he then optimizes each of the different conceptual design approaches and compares these optimized candidate systems to obtain the best solution of his problem, which is then described or specified as the output of his design process. The various feedback loops shown in Fig 1 simply illustrate that the system engineering process is, indeed, an iterative endeavor.

If an OR analyst critically reviews the extensive literature on system engineering, he will likely become frustrated with the often imprecise and incorrect use of the term "optimization" and "optimum" design. Seldom is a well-defined objective function defined as a real valued measure of system worth. Similarly, one seldom finds a clearly defined set of quantitative system performance constraints that must be satisfied over an established range of environmental parameters. The experienced OR analyst will probably ask the question, "Why aren't the techniques of nonlinear programming and calculus of variations brought to bear in this design process?"

Organized optimization techniques have been rather slow to find their way into the tool kit of the design engineer. The principal reason for this delay appears to be the complexity of system design problems and the basic difficulties in obtaining a clear definition of quantitative design constraints for systems that may have a multitude of failure modes and performance limitations. These difficulties are being overcome in selected fields of system design, notably in control system development. Only very recently, however, have organized optimization techniques found their way into mechanical system design and materiel development. Recent literature contributing to this aspect of materiel design may be found in references [2-5]. The purpose of this paper is to summarize recent developments in application of optimization techniques to mechanical system design, with principal application in structures and machine design. An extensive treatment of the techniques summarized here may be found in the recent AMC Design Handbook, Computer Aided Design and Mechanical Systems [6].

2. OPTIMAL DESIGN AS A NONLINEAR PROGRAMMING PROBLEM

In order to be more specific about the form of optimal design problems associated with mechanical systems and materiel, two examples are briefly formulated. First, consider a design problem whereby a laser transmission device, or perhaps a gun, is to be mounted on a tower or gun mount. A schematic of the problem is shown in Fig 2. The basic problem is to design a structure that supports the device under consideration and which is as light as possible to facilitate transportation and erection on the battlefield. A basic design requirement for this structure is that the device mounted on the top shall not have an angular deflection of more than θ radians, in order to hit the receiver, or target. The loading that is to be considered is a wind load of a given velocity, which would cause angular deflection of the top of the tower.

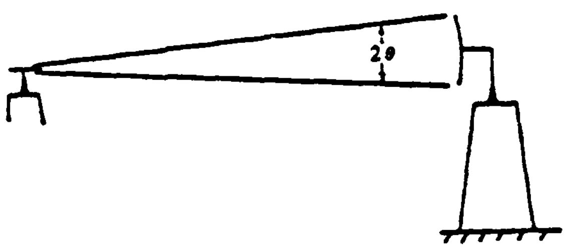

Figure 2. Structural Requirement

Four different conceptual designs that might fill the need are shown in Fig 3. The first two concepts, Fig 3(A) and (B), involve rigidly fixing the tower at its base to the fundamental supporting structure. In both towers variable spacing, as a function of height, is allowed between the vertical members of the structure. In addition, one of the concepts allows for varying the area of the main structural members as a function of height. The second set of concepts, Figs 3(C) and (D), involves similar towers that are pinned at their base to the supporting structure and that are supported by guy wires at the top of the structure. It should be noted that the conceptual designs in Fig 3 can have as many subsections with different areas and spacing as desired. Three are shown for convenience in the Figure. In each of the conceptual towers of Fig 3, the variables b_1 through b_3 specify spacing of the members of the tower. In two of the concepts, Figs 3 (B) and (D), b_4 through b_6 specify the variable areas in the construction of the main vertical member. These variables serve as design variables, in that the designer can choose these variables and completely specify the design of the tower.

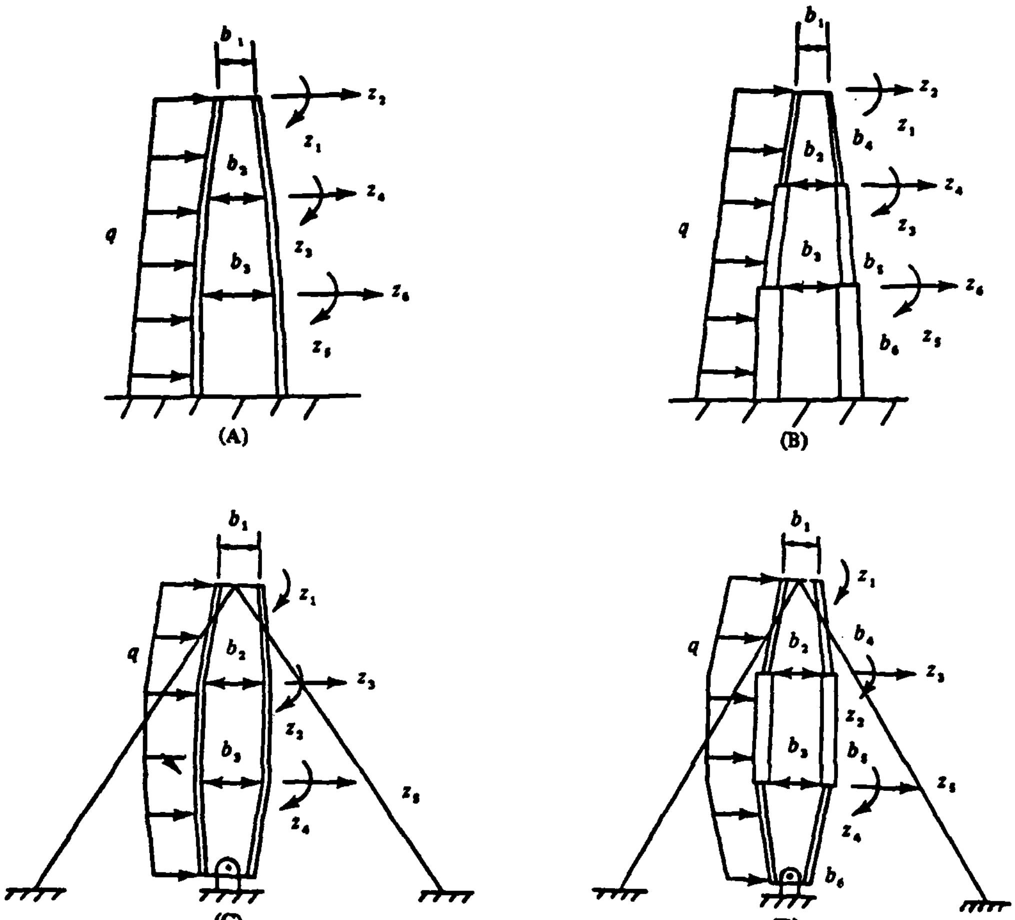

Figure 3. Conceptual Designs

A principal part of the design problem is treatment of the behavior of the structure under wind load, since one of the major constraints on behavior of the structure is that the angular deflection of the top of the tower not exceed an angle θ. For this reason, the angular deflection of each of the joints must be determined, along with lateral deflection due to wind loading. Not shown in Fig 3, but required in the construction, are cross members which maintain spacing of the main vertical members.

In order to formulate the optimal design problem mathematically, first define vectors of design variables b_i and state variables z_i. In vector form, these are

$$b = [b_1, b_2, \ldots b_m]^T \text{ and } z = [z_1, z_2, \ldots z_n]^T \quad (1)$$

Using finite element structural analysis techniques, define the stiffness matrix as

$$A(b) = [a_{ij}(b)]_{nxn} \quad (2)$$

where the dependence of the stiffness matrix on the design variables is explicitly shown. Using this matrix, structural response due to wind loading is given by the following matrix equation

$$A(b)z = q \quad (3)$$

where q is the wind loading matrix

Now that the relationship between the design variables and the structural response is specified by eq. 3, the next step in formulating an optimal design problem is the identification of constraints. In order to prevent structural areas from going to zero, resulting in an unstable structure, it is required that the design variables be bounded uniformly away from zero. This is given formally by the inequality

$$b_i \geq b_{io} > 0, i = 1, \ldots, m. \quad (4)$$

The fundamental constraint in the present problem is that the angular deflection at the top of the tower shall not exceed the angle θ. This is expressed analytically by the inequality

$$|z_1| \leq \theta \quad (5)$$

The final step in formulation of an optimal design problem is to identify the cost function to be minimized. In the present case, the cost function is structural weight and is given by

$$J = \gamma \sum_{i=1}^{m} c_i b_i \quad (6)$$

where γ is material density and c_i are weighting factors representing lengths of structural elements and weight requirements for lateral stiffeners.

The optimal structural design problem is now well formulated, from a mathematical point of view. The objective is to find the design variables b that satisfy constraint eqs. 4 and 5 and which minimize the structural weight given by eq. 6.

With this specific example as a model, a general optimal design problem may be defined as determination of the design variable b to minimize the cost function

$$J = f(z,b), \quad (7)$$

subject to the conditions

$$h(z,b) = 0 \quad (8)$$

and

$$\phi(z,b) \le 0 \tag{9}$$

where $h(z,b) = [h_1(z,b),\ldots,h_n(z,b)]^T$ and $\phi(z,b) = [\phi_1(z,b),\ldots,\phi_m(z,b)]^T$.

In this design formulation eq. 8 is a state equation that determines the state variable z uniquely as a function of the design variable b. From advanced calculus, the implicit function theorem guarantees that the Jacobian matrix $\frac{\partial h}{\partial z}$ is non-singular. This formulation of the optimal design problem is surprisingly general and can serve to represent a large class of materiel optimal design problems. The peculiar feature of making a distinction between state and design variables is retained, since it is at the foundation of real-world materiel design problems. If one wished, he could define a new variable which was simply a vector of all the design and state variables, in which case eqs. 7 through 9 would revert to a classical nonlinear programming problem. Retaining the distinctive features of the state and design variables, however, allows for development of optimization techniques that take into full account the extensive knowledge of engineering techniques for solution of governing equations associated with structures and other mechanical systems.

3. ADAPTATION OF OR/SA TECHNIQUES FOR OPTIMAL DESIGN

Methods of solving the nonlinear program of eqs. 7 through 9 may be categorized roughly into three classes: (a) necessary condition methods, (b) sequentially unconstrained minimization techniques, and (c) steepest descent techniques. All three of these techniques have been used with varying degrees of success in solving a variety of optimal design problems. A key consideration in determining the relative desirability of these methods is the dimension of the problem being treated. In practical materiel system design problems, particularly structural design problems, the dimension of the vector z can be upwards of 100 and for structural design could be on the order of 1,000. The design variable vector is generally somewhat smaller, but would typically involve 30 to 100 variables. One must, therefore, be very conscious of computational efficiency when choosing a nonlinear programming technique to solve the design problem.

a. Necessary Condition Methods

Necessary conditions for the nonlinear programming problem may be obtained through direct application of the Kuhn-Tucker conditions [6]. By partitioning the Lagrange multiplier vector, the Kuhn-Tucker conditions guarantee that there exist a vector multiplier λ associated with eq. 8 and a non-negative multiplier μ associated with eq. 9, such that for

$$H = f(z,b) + \lambda^T h(z,b) + \mu^T \phi(z,b), \tag{10}$$

the necessary conditions may be written as

$$\frac{\partial H}{\partial z}^T = 0 = \frac{\partial f}{\partial z}^T + \frac{\partial h}{\partial z}^T \lambda + \frac{\partial \phi}{\partial z}^T \mu, \qquad (11)$$

$$\frac{\partial H}{\partial b}^T = 0 = \frac{\partial f}{\partial b} + \frac{\partial h}{\partial b}^T \lambda + \frac{\partial \phi}{\partial b}^T \mu, \qquad (12)$$

and

$$\mu_i \phi_i(z,b) = 0, \; i = 1,\ldots,m \qquad (13)$$

If one counts equations, he finds that 8, 11, 12 and 13 comprise a number of equations equal to the number of variables in the vectors z, b, λ and μ. It is, therefore, plausible to consider solving this set of simultaneous equations for the various variables involved. This has been done for a few relatively idealized optimal design problems. The major drawback to direct solution of the necessary conditions is the extremely nonlinear nature of these equations. In particular, eq. 13 is a form of logic condition that states that either μ_i or ϕ_i is zero. This sort of condition is extremely messy to handle analytically. As noted in the preceeding, the dimension of the design and state variables in these problems is generally quite high. This fact, together with the essentially nonlinear nature of the necessary condition tends to preclude practical implementation of solution techniques based on the necessary conditions.

b. Sequentially Unconstrained Minimization Techniques

One of the most powerful techniques for solving nonlinear programming problems involves augmentation of the cost function by a penalty function that accounts for violation of constraints of the problem. The new augmented cost function is minimized without regard to constraints by well-known unconstrained minimization techniques. The penalty function is then modified and the process repeated. Numerous techniques of this general form have been suggested since 1943. A very careful and complete development of these techniques by the authors who were primarily responsible for complete development of this field is in reference [7].

For the particular problem at hand a mixed interior/exterior sequentially unconstrained minimization technique is generally proposed. The augmented cost function is generally given as

$$F(z,b) = f(z,b) - r \sum_{i=1}^{m} \frac{1}{\phi_i(z,b)} + \frac{1}{r^{1/2}} \sum_{i=1}^{n} h_i^2(z,b), \qquad (14)$$

where r is a real valued parameter. Considered as a function of both z and b, the function is minimized for a given value of r, to obtain z(r) and b(r). The value of r is then decreased and the problem solved again. This procedure is continued with r approaching zero. It is shown in [7] that this iterative technique will, in relatively general problems, converge to a solution of the original nonlinear programming problem.

Much as in the case of necessary condition techniques, the sequentially unconstrained minimization technique is sensitive to the dimension of the problem. This factor indicates that the technique might be refined by taking advantage of the special nature of the state and design variables, rather than simply lumping them into a combined vector for the purpose of the computation algorithm outlined above. If one critically reviews the literature in which this technique is applied to design optimization problems, [3], one finds that the state variables are usually eliminated through ad-hoc techniques. In this way, the dimension of the unconstrained minimization problem to be solved is decreased and the technique currently works rather well. Research is currently underway to evaluate the possibility of more explicitly taking advantage of the peculiar features of the state and design variables.

c. Methods of Steepest Descent

In the early 1960's Bryson and his co-workers [8] developed a technique for optimal control that closely resembles the classical method of steepest descent developed by Rosen in the early 1950's [9]. The key distinction in Bryson's work is that the explicit distinction between state and design variables is maintained throughout the development and efficient computational techniques are developed to take advantage of the specific nature of the design problems. While Bryson's work is developed and applied to the optimal control problem, the basic ideas carry over very nicely into the materiel optimization problem being considered in this paper and in AMC Design Handbook 706-192 [6]. In [6], the writer has tailored the steepest descent formulation of Bryson to take better advantage of the special characteristics of the materiel design problem being addressed. Since this technique is relatively new, it will be described here in some detail.

Let δb be a small change in the design variable $b^{(0)}$. Any change in the design variable will result in a change in the structural response, denoted by δz. The nature of the structural analysis problem guarantees that small δb yields small δz. Further, a Taylor series approximation of terms appearing in eq. 3 yields

$$A(b^{(0)})\delta z + \frac{\partial}{\partial b} \left(A(b)z\Big|_{b=b^{(0)}}\right)\delta b = 0.$$

If an inequality constraint is violated, such as $b_i < b_{io}$, then in order to correct the constraint error it is required that $\delta b_i > b_{io} - b_i$. Or, if the angular deflection constraint is violated, for example, $z_1 > \theta$, then, to correct the constraint error it is required that $\delta z_1 < \theta - z_1$. Finally, the change in structural weight due to the change in design δb is given by $\delta J = \gamma \sum_{i=1}^{m} c_i \delta b_i$.

The object in the linearized problem is to determine δb so as to minimize δJ, subject to the linearized constraints. Due to the special nature of this problem, the optimum change δb can be determined in closed form. For a detailed derivation of this optimum perturbation, the reader is referred to Chapter 5 of [6]. For discussion here, the results of this calculation will be denoted by $\delta b = \eta B + C$, where the vectors B and C depend on $b^{(0)}$, constraint errors, and equations of the problem.

The parameter η is an undetermined parameter that plays the role of a step size, when viewed in the geometry of design variable space. An effective method of choosing step size is given in [6]. Once δb is known, $\delta b^{(1)} = b^{(0)} + \delta b$ becomes a new estimate and the process is continued until the gradient vector B approaches zero.

The optimum towers for each of the four basic configurations chosen are shown in Fig 4, with a table of results being given in Table 1. These results were obtained in [6] using a finite element model with approximately forty elements so that the resulting structure has an essentially continuous distribution of material and spacing. The weights shown in Table 1, corresponding to no design variables are simply the weights of the optimum towers having uniform members and no variation in spacing. Note that there is a significant reduction in structural weight for the tapered optimum towers over uniform towers. Extensive examples of this kind are presented in Chapters 5, 7, and 9 of [6].

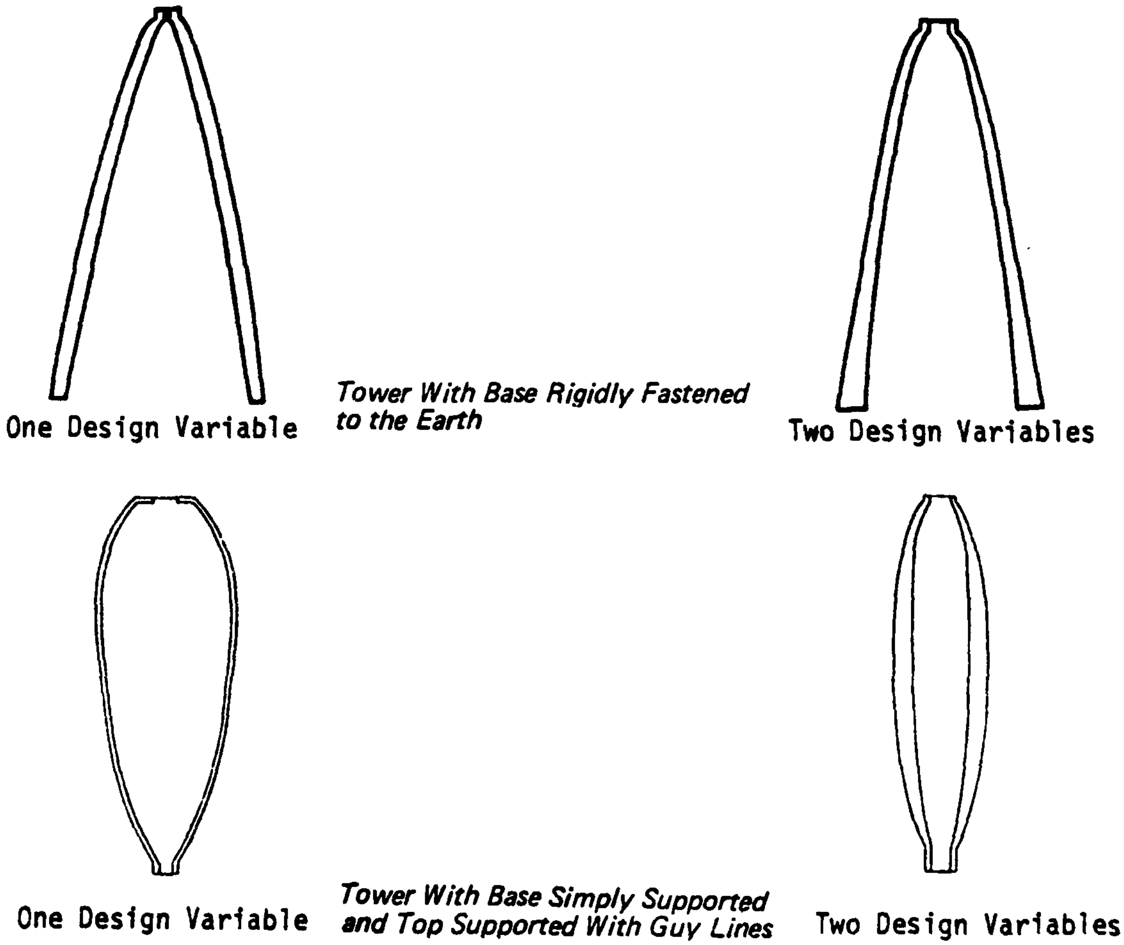

Figure 4. Profiles of Optimum Towers.

TABLE 1

WEIGHTS OF TOWERS

	Cantilevered	Cantilevered	Cantilevered	Guy-line Supported	Guy-line Supported	Guy-line Supported
Number of Design Variables	0	1	2	0	1	2
Best Weight	W = 2440.6 lb	W = 2111.4	W = 1827.9	W = 1563.99	W = 1356.6	W = 1265.71
Height	h = 63.7 in.	h_{max} = 91.4	h_{max} = 80.2	h = 46	h_{max} = 46.5	h_{max} = 36.55
Cross-sectional area of member	A = 7.96 in^2	A = 6.97	A_{max} = 10.03	A = 3.84	A = 4.434	A_{max} = 4.95

4. MINIMUM WEIGHT STRUCTURAL DESIGN

One of the most advanced areas of materiel design optimization at the current time is lightweight structural design. This field was initially developed by Schmidt and co-workers at Case University and subsequently by numerous other developers, as noted in [6]. Since the purpose of this paper is to illustrate application of OR/SA techniques and materiel design, several examples of lightweight structural optimization problems will be briefly described and results given without details of the solution technique. The purpose of these examples is to give the reader insight into the class of materiel design problems that can be treated by OR/SA techniques.

In addition to the displacement and design variable constraints defined for the structural example of Sections 1 and 3 of this paper, natural frequency and buckling constraints often need to be imposed. Equations governing the natural frequency and buckling of a structure are typified by the eigenvalue problem $K(b)y = \zeta M(b)y$, where the matrixes $K(b)$ and $M(b)$ are stiffness and mass matrixes associated with the physical properties of the structure, ζ is the eigenvalue (proportional to the square of natural frequency), and y is the eigenmode of the structure. Sensitivity coefficients associated with the eigenvalue are derived in reference [6]. Natural frequency and buckling constraints for the problem treated here are typified by the condition that $\zeta \geq \zeta_0$.

A general computer program for solution of truss optimization problems has been developed and used for numerous examples and test problems, [6,10] to illustrate the type of problem that can be solved using this steepest descent technique. Consider first the transmission tower depicted in Fig. 5. Cross sectional areas of the 25 structural members were treated as the design variables. Eighteen physical degrees of freedom are associated with each of six load conditions, so there are 108 degrees of freedom in the state variable of this problem. The total number of design and state variables is, then, 143. Constraints were placed on stress, buckling, displacement, and natural frequency of the structure. The steepest descent technique was used to solve this problem on an IBM 360/65 computer, with results indicated in the convergence chart of Fig. 6. The lower of the two curves represents a solution of the problem in which only stress and displacement constraints are enforced, with an associated optimal weight of 546 pounds. When buckling and natural frequency constraints are added, the heavier optimum results as noted by the upper curve with an optimum weight of 590 pounds. In the first case, convergence was achieved in only eight iterations with a total computing time of just 23 seconds. When the additional constraints were accounted for, convergence occurred in approximately ten iterations with a computation time of 40 seconds.

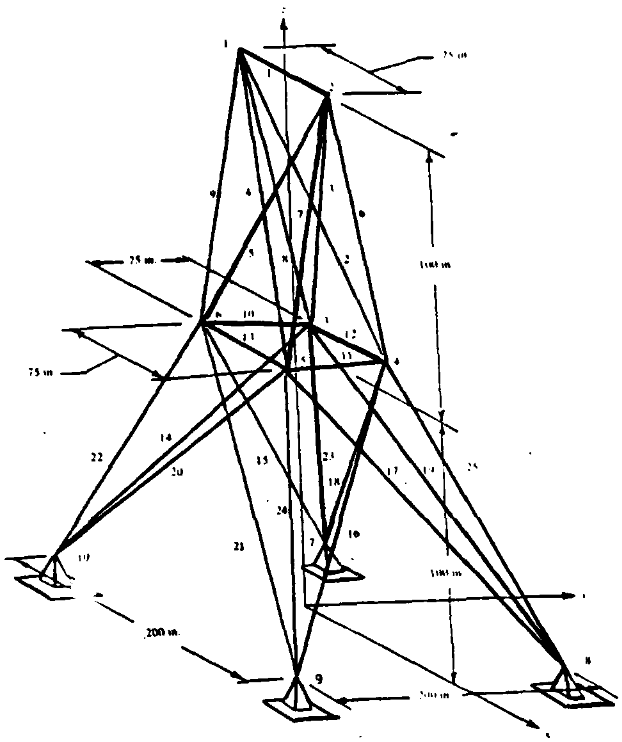

Fig. 5. Transmission Tower

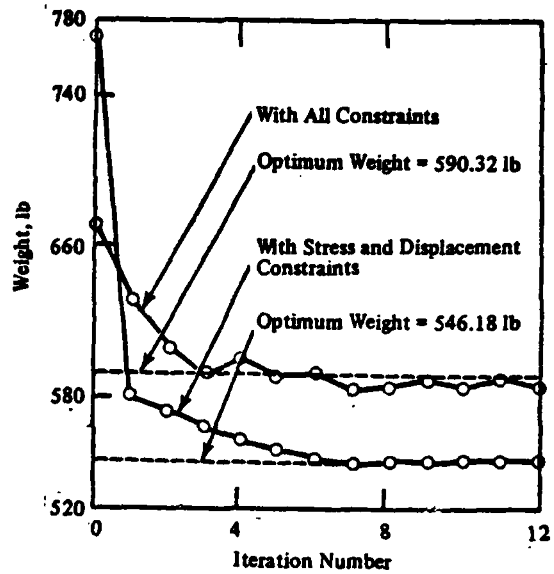

Fig. 6
Iteration vs. Weight Curves, Transmission Tower

A larger scale truss optimization problem is illustrated in Fig. 7, in which a plane truss transmission tower is optimized for minimum weight. In this problem, the cross sectional area of each of the 47 members is treated as a design variable. Two degrees of freedom are associated with each of the 22 modes in the structure, but for just one loading condition. This problem, therefore, has only 44 degrees of freedom in its state variable. This test problem was solved first with only stress constraints imposed and second with the full range of stress displacement, buckling, and natural frequency constraints imposed. Computational results are shown in Fig. 8. Again it may be noted that convergence occurs in less than eight iterations for both problems and that the more severely constrainted problem has a larger optimum weight. Computation time on an IBM 360/65 computer was approximately 58 seconds. The problem with all constraints required approximately 75 seconds on the same machine.

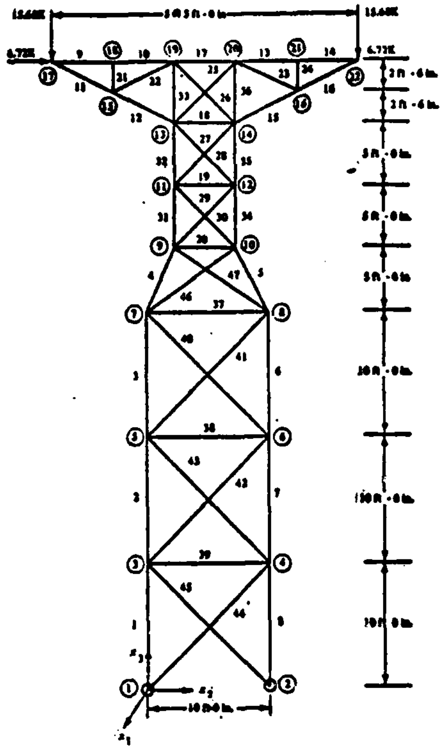

Fig. 7. 47–Bar Plane Truss

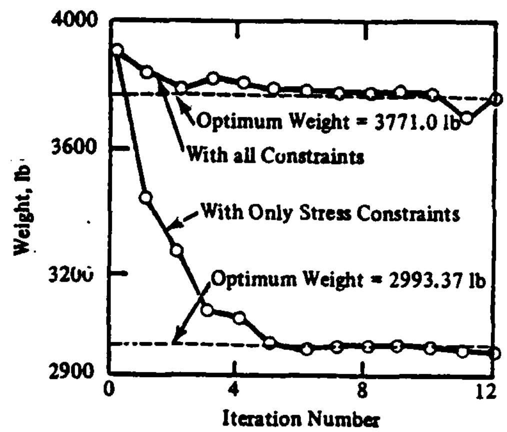

Fig. 8
Iteration vs. Weight Curves, 47 Bar Plane Truss

5. DESIGN OF AN ARTILLERY RECOIL MECHANISM

As an application of this same optimization technique to a weapon design problem, certain aspects of the design of a lightweight artillery piece will be outlined, A requirement was stated for a lightweight artillery piece that can be fired with very short implacement time. For this reason, it was determined that the weapon must be capable of being fired while it is resting on its tires. A photograph of the first prototype of this weapon is shown in Fig. 9.

The recoil mechanism for this weapon was designed according to traditional recoil mechanism design goals. Namely, the objective in the design was for a constant retarding force which is transmitted by the recoil mechanism to the undercarriage, as shown by the solid curve in Fig. 10. A recoil mechanism was designed and delivered approximately this recoil force r(t) as a function of time. When the weapon was built and fired, a nearly constant recoil occurred, as desired; but, at high angles of fire, the weapon exhibited unacceptable dynamic response. During firing, the tires of the weapon compressed and after firing and the subsequent release of the recoil forces, the weapon rebounded off the ground approximately 6 inches. This unacceptable behavior required a redesign cycle for the recoil mechanism with a design goal of minimizing the dynamic response, or hop, of the weapon after firing.

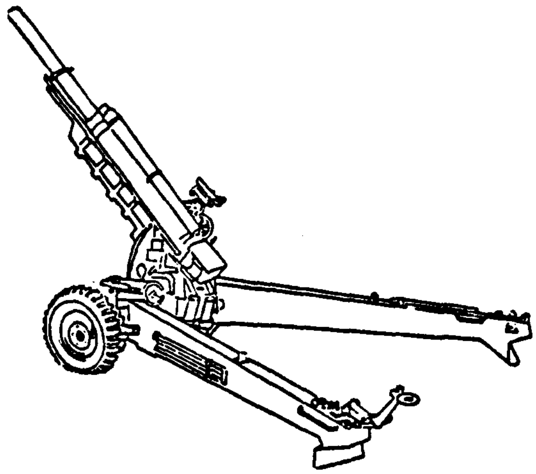

Fig. 9
Howitzer, Towed, 105mm, XM164

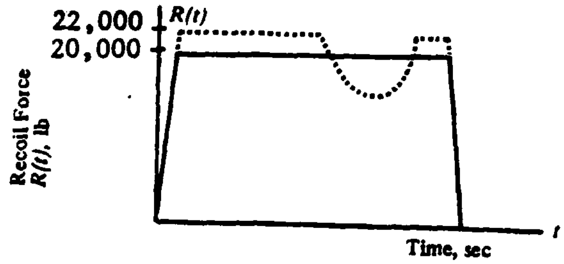

Fig. 10
Nominal and Optimal Design

It was determined that the peak recoil force could be allowed to reach 22,000 pounds without damaging the support structure. The optimization problem is then to determine the recoil force R(t) as a function of time such that $R(t) < 22{,}000$ and the peak dynamic response denoted by $J = \max_t\{h(t)\}$ is as small as possible, where h(t) is the height of the tires off the ground at any time t. Graphically, this problem is to determine a recoil force which lies beneath the 22,000 pound level in Fig. 10 and which minimizes the peak dynamic response of the weapon. In this problem, the dynamic response h(t) is determined by the second order differential equations of motion of the artillery piece. The same philosophy of small design changes about some nominal estimate, as in the structural design problem of paragraph 3, was employed in this case. Here, however, the problem more resembles a calculus of variations problem. The dotted curve in Fig. 10 shows the optimum retarding force that reduced the peak dynamic response to .5 inch. Details of the solution are found in [6].

6. CONCLUSIONS

While the optimization techniques developed and used by OR/SA analysts are not yet in common use in materiel design, there is a positive trend that indicates they will become effective design tools. As noted in this paper, it appears clear that the techniques will have to be adopted to the features of the classes of materiel design in question. The examples outlined and discussed in this paper are intended only as illustrations of the kind of design problems that can be addressed. The interested reader is referred to [6] for a complete treatment of a larger class of materiel design problems.

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EXTENDED PERT

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In noticing a need to generalize PERT, Freeman[1,2] deserves credit for having proposed that engineers and system planners take cognizance of technical performance and scarce resources as well as time. To this end, he attempted to show, without proof, that it is possible to find an optimal combination of time, technical performance level and resources for any project. The notation he developed has been retained by this paper wherever possible.

Formulation of a Mathematical Model

Consider any business network composed of activities and events that require stages at which decisions must be made before the project can go on to the next stage. Such a system is depicted in Figure 1.

In this illustration all of the activities have been numbered $i = 1, 2, \ldots, n$. The critical-time-path activities represented by the heavy arrows have been labeled "j". Other variables that appear in Figure 1 are dexcribed below[3,4].

m_i - Expected cost of resources allotted to i^{th} activity. This term represents a dollar figure attached to all resources such as men by number and competence, money, tools, machines, fissionable material for nuclear reactors, water for agricultural and industrial purposes, water for the generation of hydroelectric power, fuel for a space ship, and so on. Furthermore, this cost figure must include capital, depreciation, taxes, overhead, salaries, etc.

p_i - Expected performance of event marking end of i^{th} activity. This variable is inclusive of reliability, maintainability, operability and all other "-ilities" that relate to technical quality. Performance can be measured as the probability that the event successfully performs its function according to specification. As an example, a television picture tube specification may be a function of size, number of scanning lines, number of pictures per second, mean time between failures, and other factors that comprise the above mentioned "-ilities". The tube's performance can then be measured in dimensions of probability by saying that probability of success is the number of times the specification will be met in a large number of trial performances.

t_i - Expected time to accomplish i^{th} activity. The subscript cp_j on t_{cp} is used to indicate that element of time which is allotted to the j^{th} activity of the critical time path.

The "m_i", "p_i", "t_i" variables are described as expected values in each definition given above. This implies that if any one of these three variables could in general be represented by a new variable "y", then "y_e" is the expected value of "y". So, as was postulated by McBride[5], it is assumed from the beta distribution that

$$y_e = \frac{1}{3}\left[2b + \frac{1}{2}(a + c)\right], \tag{1}$$

and

$$\sigma^2(y_e) = \left[\frac{1}{6}(c - a)\right]^2, \tag{2}$$

where "a", "b", and "c" represent optimistic, most-likely, and pessimistic values of "y" respectively and "σ" is the variance which measures the uncertainty involved in the expectation of "y".

Up to now, this paper has discussed variables associated with individual activities. At this time, the following conclusion can be drawn:

$$m_i = f_i(p_i, t_i), \tag{3}$$

where f_i is a function which enables one to calculate m_i when numbers are provided for p_i and t_i.

The next consideration is the effect of those parameters which are connected with the network as a whole. The following values describe the end product:

M - Cost of overall project. This parameter is given by the equation

$$M = \sum_{i=1}^{n} m_i \tag{4}$$

P - Performance of entire project. This quality factor is a function of the performance of each event; or

$$P = g(p_i). \tag{5}$$

For example, in a series situation comprised on only independent probabilities, equation (5) becomes the special case

$$P = \prod_{i=1}^{n} p_i. \tag{6}$$

T - Time to complete entire project. The overall duration of the project is measured by the equation

$$T = \sum_{\text{all } j} t_{cp_j} \tag{7}$$

where t_{cp_j} is the critical path expected time for activity "j".

V - Value in dollars of entire project. This utility factor is a quantitative description in the dollar dimension of how much a project is worth to its owner. It is measured as a function of the products' need in the market place. Determination of project value depends on whether the item is developed for commercial or military use. Two sources which provide sound basis for determining project worth are reference [6] for military managers and Chapters 9 and 10 of reference [7] for commercial planners. The problem of determining project value is treated as being beyond the scope of this composition. For the remainder of this paper, it is taken for granted that a formula for system worth can be found such that

$$V = h(P, T), \tag{8}$$

where h is a function which enables one to calculate V when numbers are provided for T and P.

Determination of the cost and value functions given by equations (4) and (8) enables the system organizer to calculate profit or return, R, by the formula

$$R = V - M. \tag{9}$$

In order to obtain the two functions of M and V that are necessary in establishing the relationship between the parameters of the internal elements of the network and the overall network, it is not unreasonable for project managers to ask for two types of tables as shown below.

V	P	T
64	.8	2
40	.8	5
16	.8	8
72	.9	2
45	.9	5
18	.9	8
80	1.0	2
50	1.0	5
20	1.0	8

NETWORK VALUE
Table 1

m_i	p_i	t_i
5	.95	3
6	.95	2
7	.95	1
6	.975	3
7	.975	2
8	.975	1
9	1.000	3
12	1.000	2
16	1.000	1

ACTIVITY COST
Table 2

Table 1 provides the value function $V = h(P, T)$. It lists combinations of overall network value, reliability, and time as they are interrelated. Table 2 yields an internal activity cost, reliability, time relationship $m_i = f_i(p_i, t_i)$ for every activity of the network. There will be one network value table and n activity cost tables for a system diagram like the one shown in Figure 1. The numbers in Table 2 are expected values. For example, the data provider may have to fill in the m_i column of the activity cost table where the values of the p_i and t_i columns are given to him. If this were the case, he could be asked by management to provide the values a_i, b_i and c_i which would be reduced to m by the network analyzer using the equation

$$m_i = \frac{1}{3} \left[2b_i + \frac{a_i + c_i}{2} \right]. \tag{10}$$

This study has not attempted to find the optimum number of rows of information required by Tables 1 and 2. However, nine lines of data will probably be sufficient for these tables in order to adequately describe a surface in three-dimensional space. If fewer than nine rows were used, it probably would be difficult to spot any surface irregularities. More than nine lines should probably not be requested because the cost of generating additional lines would probably out weigh the necessity for having them. Additionally, after nine rows of data generation, data providers may have a tendency to invent numbers just for the sake of fulfilling a requirement. The validity of such numbers would be questionable.

Construction of a project is subject to constraints. The overall resources that can be expended on a project are beset with scarcities and limitations. Also, time is curtailed by schedules and contracts. Furthermore, performance must meet certain acceptability standards as demanded by customer needs and safety requirements. These resource, time and probability constraints are represented as M_{max}, T_{max}, and P_{min} respectively. Additionally, negative values of resources and time are meaningless and performance probability cannot exceed one. Taking this into account, equations (4), (5) and (7) can be rewritten to include their constraints.

$$M = \sum_{i=1}^{n} m_i, \qquad 0 < M \le M_{max}, \tag{11}$$

$$T = \sum_{all\ j} t_{cp_j}, \qquad 0 < T \le T_{max} \tag{12}$$

$$P = g(p_i), \qquad P_{min} \le P \le 1. \tag{13}$$

Having calculated P and T from equations (13) and (12), one can obtain a corresponding V from the network value table. If the calculated values of P and T do not correspond exactly with those in the table, V can be found by linear interpolation. It seems reasonable that the requested data could be arranged as shown in Table 3. If P lies between the known values P_1 and P_2 and if T lies between T_2 and T_3, then V lies between V_2 and V_6. The degree of accuracy for which V can be predicted depends on which type of interpolation or surface fitting is used to determine it.

If, for the u^{th} line of data, u is the subscript on the first column, v on the second and w on the third, then u(v, w) can be determined. Using linear first order interpolation, one way of finding V for the particular arrangement of Table 3 is by the formula

$$V = \begin{cases} \frac{1}{2}\left[\frac{(T - T_w)}{(T_{w+1} - T_w)} (V_{u+1} - V_u) + \frac{(T - T_w)}{(T_{w+1} - T_w)} (V_{u+4} - V_{u+3}) + V_{u+3} \right] & \text{for } P_v < P < P_{v+1},\ T_w < T < T_{w+1} \\ \frac{(P - P_v)}{(P_{v+3} - P_v)} (V_{u+3} - V_u) + V_u & \text{for } P_v < P < P_{v+1},\ T = T_w \\ \frac{(T - T_w)}{(T_{w+1} - T_w)} (V_{u+1} - V_u) + V_u & \text{for } P = P_v,\ T_w < T < T_{w+1} \end{cases} \tag{14}$$

Line	V	P	T
1	V_1	P_1	T_1
2	V_2	P_1	T_2
3	V_3	P_1	T_3
4	V_4	P_2	T_1
5	V_5	P_2	T_2
6	V_6	P_2	T_3
7	V_7	P_3	T_1
8	V_8	P_3	T_2
9	V_9	P_3	T_3

NETWORK VALUE TABLE ARRANGED SYSTEMATICALLY
Table 3

When data is arranged as shown in the order of Table 3, the subscripts are related by

$$u = 3(v - 1) + w. \tag{15}$$

Once V has been calculated, the project return, R, can be found using equation (9).

The problem now becomes one of maximizing R subject to the constraints imposed upon it. Since V and M of equation (9) are both functions of P and T as well as m_i, p_i, t_i then

$$R_{max}(m_i, p_i, t_i) = \underset{i=1,n;u(v,w)\leq 8}{\text{maximum}} \left| V(P, T) - M(P, T) \right| \tag{16}$$

subject to the restraining equations listed below.

$$M = \sum_{i=1}^{n} m_i \qquad 0 < M \leq M_{max}, \tag{17}$$

$$T = \sum_{all\ j} t_{cp_j}, \qquad 0 < T \leq T_{max}, \tag{18}$$

$$P = g(p_i), \qquad P_{min} \leq P \leq 1. \tag{19}$$

Equations (16) through (19), used to describe a diagram like the one shown in Figure 1, constitute the optimality criterion for a mathematical model of a business network problem where the purpose is to find the best combination of resources, time and performance. A method of using the model to solve such an optimality problem is described in the next section.

An Optimal Mix Solution Method

The problem can be solved quite naturally by taking all possible combinations of time, t_i, resource costs, m_i, and reliability, p_i, and comparing them to find the optimal mix. However, this composes a staggering time problem even for a high speed digital computer. If nine lines of data are used for each of the n activity cost tables, then 9^n combinations must be considered. Once n exceeds 5, 9^n becomes a number that commands a certain amount of respect even for a digital computer. For example, a sample problem having 10,000 iterations was run on an IBM 1130 digital computer, and the computation time was 11.5 minutes. To run a 5-activity problem would require days and beyond that the computational time becomes totally unfeasible. Most network problems having more than 100 activities cause the programmer to necessarily move on to more attractive means of problem solving.

A means that enables the programmer to circumvent the problem of considering all possible combinations is provided by Bellman's dynamic programming technique[8]. To visualize the use of dynamic programming in calculating the best activity cost, time and reliability to maximize profit, one must first consider the array given in Figure 2. In this matrix array, α_{ik} represents the cost-time-reliability mix of the i^{th} line associated with the cost table for the k^{th} activity. If each α_{ik} is replaced by a dot which will be called a node and if every combination of dots or activity lines is connected by a line which will be called an arc, then Figure 3 results.

The following variables are defined:

$N = 1, 2, \ldots, n-1$ - stages,

$X_N = A, B, \ldots, I$ - the nine nodes associated with stage N. In terms of the matrix of Figure 2 it can be seen that $(X_1 = A)$ is α_{12}, $(X_1 = B)$ is α_{22}, ..., $(X_N = I)$ is α_{9n},

$D_N = 1, 2, \ldots, 81$ - the 81 arcs associated with all the combinations of connecting the nine X_N nodes with the nine X_{N-1} nodes,

$r_N(X_N, D_N)$ - return from X_N, D_N node-arc combination,

$r_{cp_{N-1}}(X_{N-1})$ - function giving the optimal return from each of the input nodes at stage N-1 where X_{N-1} is the node to which the X_N, D_N combination leads.

The cp subscript is used to indicate critical path returns. It should be pointed out that the critical profit path has meaning only for the network display of Figure 3 and should not be confused with the critical time path of Figure 1. The critical profit path is defined as a direct path through the entire network of Figure 3 which links the nodes of that network in such a way that an optimum profit mix solution is obtained.

Using Figure 3 and the variables associated with that figure, it is possible to derive a recursion formula:

$$r_{cp_N}(X_N) = \max_{D_N} \left\{ r_N(X_N, D_N) + r_{cp_{N-1}}\left[D_N - 9(X_N - 1) \right] \right\} \quad (20)$$

In order to prove this dynamic programming equation, it is necessary to take into account the fact that Figure 3 has nine initial-condition nodes X_o which are labeled as A, B, ..., I. For a given initial-condition node, r_{cp_1} is defined as the return derived by going from that particular initial-condition node, X_o, to the node X_1. For example, $X_1 = A$. The proof by construction is as follows:

stage one

$$r_{cp_1}(X_1 = A) = r_1(X_1 = A, D_1)$$

$$\vdots$$

$$r_{cp_1}(X_1 = I) = r_1(X_1 = I, D_1)$$

where D_1 is the arc associated with the given initial condition X_o.

$$r_{cp_2}(X_2 = A) = \max_{D_2=1,2,3,\ldots,9} \Big\{ [r_2(X_2 = A, D_2 = 1) + r_{cp_1}(X_1 = A)], [r_2(X_2 = A, D_2 = 2) + r_{cp_1}(X_1 = B)], \ldots, [r_2(X_2 = A, D_2 = 9) + r_{cp_1}(X_1 = I)] \Big\},$$

stage two

$$r_{cp_2}(X_2 = B) = \max_{D_2=10,11,12,\ldots,18} \Big\{ [r_2(X_2 = B, D_2 = 10) + r_{cp_1}(X_1 = A)], [r_2(X_2 = B, D_2 = 11) + r_{cp_1}(X_1 = B)], \ldots, [r_2(X_2 = B, D_2 = 18) + r_{cp_1}(X_1 = I)] \Big\},$$

$$\vdots$$

$$r_{cp_2}(X_2 = I) = \max_{D_2=73,74,75,\ldots,81} \Big\{ [r_2(X_2 = I, D_2 = 73) + r_{cp_1}(X_1 = A)], [r_2(X_2 = I, D_2 = 74) + r_{cp_1}(X_1 = B)], \ldots, [r_2(X_2 = I, D_2 = 81) + r_{cp_1}(X_1 = I)] \Big\},$$

---

stage three

$$r_{cp_3}(X_3 = A) = \max_{D_3=1,2,3,\ldots,9} \Big\{ [r_3(X_3 = A, D_3 = 1) + r_{cp_2}(X_2 = A)], [r_3(X_3 = A, D_3 = 2) + r_{cp_2}(X_2 = B)], \ldots, [r_3(X_3 = A, D_3 = 9) + r_{cp_2}(X_2 = I)] \Big\},$$

$$r_{cp_3}(X_3 = B) = \max_{D_3=10,11,12,\ldots,18} \Big\{ [r_3(X_3 = B, D_3 = 10) + r_{cp_2}(X_2 = A)], [r_3(X_3 = B, D_3 = 11) + r_{cp_2}(X_2 = B)], \ldots, [r_3(X_3 = B, D_3 = 18) + r_{cp_2}(X_2 = I)] \Big\},$$

$$\vdots$$

$$r_{cp_3}(X_3 = I) = \max_{D_3=73,74,75,\ldots,81} \Big\{ [r_3(X_3 = I, D_3 = 73)$$

$$+ r_{cp_2}(X_2 = A) \Big], \Big[r_3(X_3 = I, D_3 = 74)$$

$$+ r_{cp_2}(X_2 = B) \Big], \ldots, \Big[r_3(X_3 = I, D_3 = 81)$$

$$+ r_{cp_2}(X_2 = I) \Big] \Big\},$$

$$r_{cp_N}(X_N) = \max_{D_N} \Big[r_N(X_N, D_N) + f_{N-1}(X_{N-1}) \Big]. \quad (21)$$

Let $\alpha = r_N(X_N, D_N) + r_{cp_{N-1}}(X_{N-1}),$

where $X_N = 1, 2, \ldots, 9 \equiv A, B, \ldots, I$

$D_N = 1, 2, \ldots, 81,$

but

$$D_N = \begin{cases} 1, 2, \ldots, 9 & \text{when } X_{N=1} \\ 10, 11, \ldots, 18 & \text{when } X_{N=2} \\ \vdots & \\ (9i-8), (9i-7), \ldots, 9i & \text{when } X_{N=i} \\ \vdots & \\ 73, 74, \ldots, 81 & \text{when } X_{N=9} \end{cases}$$

and

$$X_{N-1} = \begin{cases} 1 & \text{when } D_N = 1, 10, \ldots, (9i-8), \ldots, 73 \\ & \text{and } X_{N=1}, 2, \ldots, i, \ldots, 9 \\ 2 & \text{when } D_N = 2, 11, \ldots, (9i-7), \ldots, 74 \\ & \text{and } X_{N=1}, 2, \ldots, i, \ldots, 9 \\ \vdots & \\ 9 & \text{when } D_N = 9, 18, \ldots, 9i, \ldots, 81 \\ & \text{and } X_{N=1}, 2, \ldots, i, \ldots, 9; \end{cases}$$

therefore $X_{N-1} = D_N - 9(X_N - 1);$ (23)

and $$\alpha = r_N(X_N, D_N) + r_{cp_{N-1}}\Big[D_N - 9(X_N - 1) \Big], \quad (24)$$

or $$r_{cp_N}(X_N) = \max_{D_N} \Big\{ r_{cp_{N-1}}(X_N, D_N) + r_{cp_{N-1}}\big[D_N - 9(X_N - 1)\big]\Big\}. \quad (25)$$

Equation (25) is the recursion formula for the network decision model shown in Figure 3. This recursion formula can be applied to equation (16) of the last section where the function to be maximized is total return (i.e., $r_{cp_N} = R_{max}$, the maximum return associated with the optimum combination of activity-cost table lines). However, in order to use equation (25), $r_{cp_N}(X_N, D_N)$ must be available. The mathematical model describing the network diagram shown in Figure 1 does not show a relationship between r_i and m_i, p_i or t_i in any of its corresponding equations. In order to write r_i as a function of m_i, p_i and t_i, some basic assumptions must be made.[8] They are as follows:

1. The returns, r_i, from different activities can be measured in a common unit of dollars.

2. The return from any activity is independent of the performance-time-resource allocations to the other activities.

3. The total return, R, can be obtained as the sum of the individual returns (i.e., $R = r_1 + r_2 + \ldots + r_i + \ldots + r_n$).

Fundamentally, Bellman's dynamic programming technique is founded on the statement, "Do the best you can in terms of where you are."[9] The determination of r_i is arrived at by considering the relationship between the above statement and the assumptions just made about r_i in the last paragraph. The approach used is to determine the return of the overall project if it is completed with the same degree of progress as it has experienced up to the i^{th} activity. For example, the cost of completing the first three activities is given by the equation

$$\text{Cost} = m_1 + m_2 + m_3. \tag{26}$$

If there are n activities, then the overall network cost, as it can be linearly predicted after the completion of activity 3, is estimated as

$$\mathcal{M}_3 = \frac{n}{3}(m_1 + m_2 + m_3). \tag{27}$$

Essentially this is a projection to the n^{th} stage based on what is known about stage 3. The script letter is used to indicate that $\mathcal{M}_3$ is an approximation and not the actual total network cost M. The subscript 3 on $\mathcal{M}_3$ means that the prediction about total project cost was projected from activity 3. Likewise, $\mathcal{P}$, $\mathcal{T}$, $\mathcal{V}$ and $\mathcal{R}$ can be predicted using the same type of reasoning that was used to develop equation (27). This procedure allows a method for determining r_i in the following manner:

$$
\begin{aligned}
1)\quad \mathcal{P}_0 &= p_1^n, \\
\mathcal{P}_1 &= p_1 p_2^{n/2}, \\
\mathcal{P}_2 &= p_1 p_2 p_3^{n/3}, \\
&\vdots \\
\mathcal{P}_N &= p_1 p_2 p_3 \cdots p_n.
\end{aligned} \tag{28}
$$

2) $\mathcal{M}_0 = nm_1$,

$\mathcal{M}_1 = n[\frac{1}{2}(m_1 + m_2)]$,

$\mathcal{M}_2 = n[\frac{1}{3}(m_1 + m_2 + m_3)]$,

$\vdots$

$$\mathcal{M}_N = m_1 + m_2 + \ldots + m_n. \tag{29}$$

3) $\mathcal{T}_0 = mt_1$ where m is the number of stages on the critical time path,

$\mathcal{T}_1 = \max\{ mt_1, m[\frac{1}{2}(t_1 + t_2)], mt_2 \}$,

$\vdots$

$$\mathcal{T}_N = m(t_{cp})_{avg}. \tag{30}$$

4) $\mathcal{V}_i = h(\mathcal{P}_i, \mathcal{T}_i)$ where h denotes the same function that is given by Table 1 where V = h(P, T). (31)

$$\mathcal{R}_i = \mathcal{V}_i - \mathcal{M}_i. \tag{32}$$

5) (see equation 32 above)

$$r_i = \frac{1}{N}\mathcal{R}_i. \tag{33}$$

6) (see equation 33 above)

The r_i of equation (33) is used as $r_N(X_N, D_N)$ in equation (25). All of the variables in the recursion formula of equation (20) are now defined and equation (20) is ready for computer programming.

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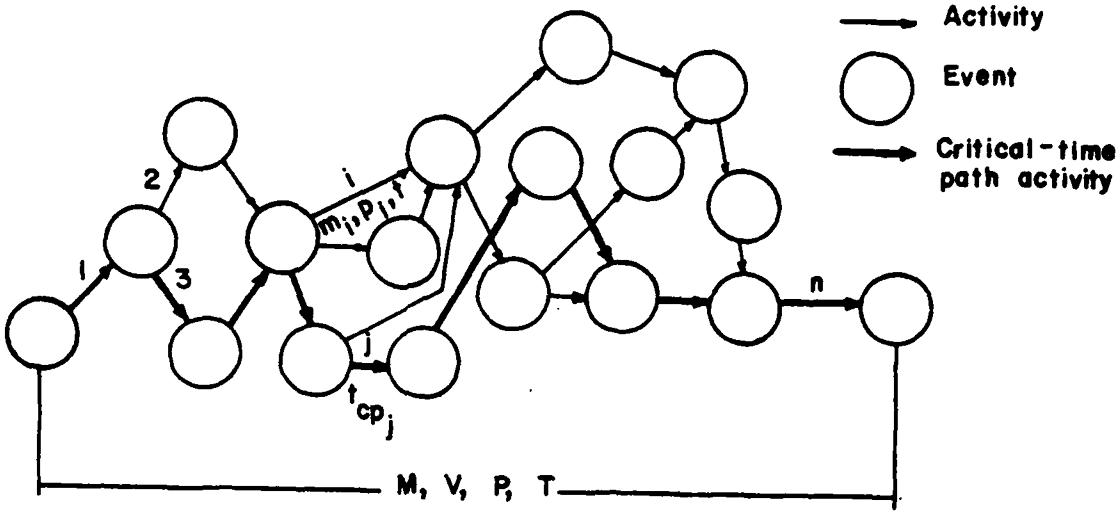


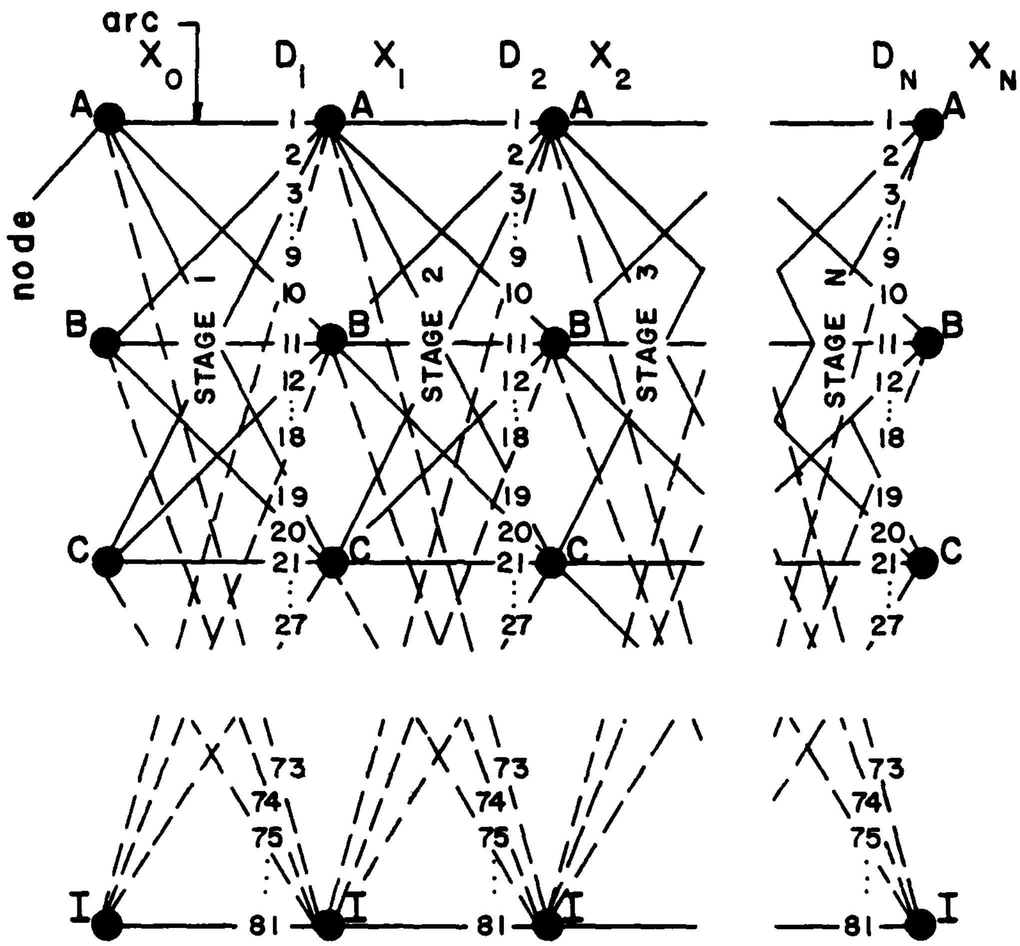
TYPICAL BUSINESS NETWORK

Figure 1

$$\begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1k} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2k} & \cdots & a_{2n} \\ \vdots & \vdots & & & & \\ a_{i1} & a_{i2} & \cdots & a_{ik} & \cdots & a_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{91} & a_{92} & & a_{9k} & & a_{9n} \end{vmatrix}$$

ACTIVITY COST TIME RELIABILITY MATRIX

Figure 2



ACTIVITY COST-TIME-RELIABILITY NODE-ARC ARRAY

Figure 3

PATTERN RECOGNITION ANALYSIS OF SHOCK TRAUMA DATA AND ITS APPLICATION TO ARMY PROBLEMS

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ABSTRACT

Physiological and biochemical measurements taken from severely injured patients treated at the Maryland Institute for Emergency Medicine*, have been analyzed by Army mathematicians, with medical expertise provided by physicians at the Institute as well as Army physicians. The initial objectives of the study were:

- to refine a set of physiological and biochemical parameters (profile) which would characterize the state of severely injured patients;

- to delineate good and poor prognosis regions in the state space; and

- to evaluate the change in patient state over time (trajectory).

This paper describes a measure of "patient distance" from normality or homeostasis. This measure can be used for prognosis purposes, for evaluating the effect of therapies and for estimating the level of care provided by various institutions.

Application of these analyses to Army problems are also discussed.

INTRODUCTION

A systematic study of the effects of shock and trauma on humans has been undertaken by clinicians from the Maryland Institute of Emergency Medicine, MIEM, assisted by systems analysts from the Army. The methodology developed should be able to assist in the evaluation of injury due to blunt and penetrating trauma and burns. Previous papers in this series[1,2] have described pattern recognition techniques used in the study of patients. The goals of the previous studies were to determine compact physiological and biochemical profiles (sets of measurements) which reflect post-traumatic states, and to compute probabilities of survival for different regions of "profile space."

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Pattern analyses[1,2] were performed on body subsystems. Trajectories (time-sequences) of a patient's state were computed and reviewed in various discriminant spaces. In this paper we introduce the concept of Euclidean distance to evaluate patient state and as a refinement of the above "trajectory" analyses. The notion of derangement or distance from normality has long been a qualitative guide of clinicians for evaluating patient state. Here we will formalize this concept and illustrate its use as an index of severity of injury. (We have used the concept previously[3,4] to suggest a methodology for patient triage and for the evaluation of quality of care.)

Suppose one assumes that the state of a seriously injured patient can be represented by a small number of core variables, which may be termed the "monitor profile." The collection of all states in the monitor space which are the result of measurements drawn from "healthy" persons constitutes the "region of normality." If this region (which may consist of several disjoint subregions) is known, then a measure of the distance of any state from normality can be calculated.

The method for quantifying patient distance from normality will now be discussed.

PATIENT DISTANCE FROM NORMALITY

Let $S_t = (S_1, S_2, \ldots, S_N)$ represent the state vector of a patient at time t. The components of S_t represent the values of the various physiological and biochemical parameters which comprise the profile, at time t. For this study the following profile parameters were chosen by clinicians at the MIEM: systolic blood pressure (S_1), hematocrit (S_2), fibrinogen (S_3), potassium (S_4), osmolality (S_5) and creatinine (S_6).

Let $D = (D_1, \ldots, D_6)$ be composed of "normal" values of the six parameters (in this case we have reduced the region of normality to a point.) These normal values were computed in the following way:

a. 350 cases of patients who were treated and ultimately released from the Institute were retrieved from the data bank.

b. The final reading from each of these cases, for each of the six variables was recorded.

c. The final average value (taken over the 350 patients) for each variable was used as the "normal" value in vector D.

Using this method the components of D were computed to be:

D_1 = 127.3 (systolic blood pressure)

D_2 = 36.86 (hematocrit)

D_3 = 429.50 (fibrinogen)

D_4 = 4.212 (potassium)

D_5 = 291.6 (serum osmolality)

D_6 = 1.0003 (serum creatinine)

There are a large number of measures which could be used to determine the "distance" between S_t and D. One commonly used is Euclidean distance. In general, if two points x and y in N-dimensional space are defined as:

$$x = (x_1, x_2, \ldots, x_n); \text{ and}$$

$$y = (y_1, y_2, \ldots, y_n), \text{ then}$$

the Euclidean distance, E(x,y), between these two points is defined to be:

$$E(x,y) = [(x_1-y_1)^2 + (x_2-y_2)^2 + \ldots + (x_n-y_n)^2]^{1/2}$$

As an example, suppose we wish to calculate the Euclidean distance between S_t and D when

$$S_t = (155.3,\ 36.86,\ 552.5,\ 3.50,\ 261.6,\ 3.000).$$

Then $E(S_t, D)$ is easily calculated to be 129.66.

There is an obvious disadvantage to calculating Euclidean distance between D and S_t as they are now defined. Although there may be no medical justification, those variables which take on large values, and have large variances usually dominate the contributions to distance. Indeed, although the value of creatinine of 3.000 (S_6) is probably clinically the most significant measurement in the example, its contribution to the distance is negligible. Obviously, direct use of the Euclidean distance is pointless. Normalization of the measurements is a necessity. To accomplish normalization we chose to record each measurement S_i in standard deviation units from the mean value D_i.

The standard deviation σ_i of each of the six components was also calculated from the final measurements on the 350 surviving patients, with the following results:

Standard Deviation	Variable
21.11	Systolic Blood Pressure
5.96	Hematocrit
177.10	Fibrinogen
.6723	Potassium
14.99	Serum Osmolality
.4929	Serum Creatinine

This normalization procedure transforms the original S_t vector to a normalized vector $N_t = (N_1, \ldots, N_6)$ according to the rule:

$$N_i = \frac{S_i - D_i}{\sigma_i} \quad \text{for } i = 1, \ldots, 6.$$

For example (from the previous section), the vector S_t = (155.3, 36.86, 552.5, 3.50, 261.6, 3.000) is transformed to N_t = (1.32, 0.00, .69, -1.06, -2.00, 4.052). Similarly the vector D is transformed to the zero vector $\underline{O} = (o,\ldots,o)$. Now the Euclidean distance between N_t and $\underline{O}$ is $E(N_t,\underline{O}) = [(1.32)^2, + (0.00)^2 + (.69)^2 + (-1.06)^2 + (-2.00)^2 + (4.052)^2]^{1/2}$ and the creatinine value (4.052) becomes very significant.

This normalization equally weights the contribution of each variable to the total distance measure. It should be emphasized that this preliminary normalization will be altered ultimately (variables weighted according to their predictive capability) to more accurately reflect clinical judgment and research findings.

RESULTS

Retrospective Study. A retrospective study was performed on 80 randomly selected patients. The patients incurred various serious injuries and of these patients 65 had survived and 15 had died. Daily Euclidean distances of patient states from normality were computed for each patient based on the 8:00 A.M. values of the six parameters mentioned in the previous section. For example, in Figure 1 we portray a five-day distance trajectory of a 65-year old male patient who died. Listed below the plot are the raw and normalized measurements for each variable for each day.

Below are listed the means and standard deviations for the distance values and also for the maximum values of each of the 80 patients. Both mean differences are statistically highly significant ("Students t" values of 6.7 and 5.1). Note also the relatively large variation among the distances for those patients who died as compared with those who lived.

MEANS AND STANDARD DEVIATIONS OF EUCLIDEAN DISTANCES

Mean	Standard Deviation	
2.36	.685	Based on 333 measurements on 65 patients who lived
6.20	3.43	Based on 92 measurements of 15 patients who died
2.69	.79	Based on 65 maximum distances (one for each patient who lived)
8.38	45	Based on 15 maximum distances (one for each patient who died)

Examination of patient maximum distances from normality indicated that 14 of the 15 patients who died had, on at least one day, a distance exceeding five units. Collectively these patients spent 92 days in the Unit. On 43 days the distances exceeded five units.

Only one of the patients that lived had a distance exceeding five units (5.41 units). The major contributors to this patient's distance were serum osmolality and creatinine. It appears that any distance over five units was accompanied by a bad prognosis. This may define or indicate a tendency toward an "irreversible" or "refractory" condition.

If one were tentatively to "define" a refractory state as being associated with a distance exceeding five units, then for this retrospective data two of eighty patients would have been misclassified.

Prospective Study. To test this index and threshold value of five units on prospective data, distance trajectories were computed for all patients in the MIEM for several months. During this period 89 patients treated survived their injuries and 16 patients succumbed. The maximum distance threshold of five units led to four misclassifications: three patients who ultimately recovered exceeded five distance units and one patient who died did not exceed five units. Lumping retrospective and prospective results there have been seven misclassifications in 185 cases. The maximum distance experienced by any patient who survived was 5.7 units. The 154 survivors collectively spent 1,116 days in the Shock-Trauma Unit. The four survivors who exceeded five units did so a total of 19 days (or for $\frac{19}{1116}$ = 1.6% of the measurements); one patient for 14 days, one for three days and each of the two other patients for one day. The 31 patients who died collectively spent 251 days in the Unit. On 95 days ($\frac{95}{251}$ = 38% of the measurements) the distances exceeded a value of five units. Table I is a detailed breakdown of the findings for the patients who died, including the first day at which the patient exceeded five units.

The measurements which contributed most to the large distance values were creatinine, osmolality and systolic blood pressure. These three variables alone would have accounted for distances greater than five units in 90 of the 95 cases detected by all six variables.

CLINICAL CORRELATIONS

Daily clinical prognoses were available for the 105 patients studied prospectively. During morning rounds a clinical prognosis was indicated for each patient based on the following code:

Value	Prognosis
1	Good
2	Fair
3	Poor
4	Critical
5	Terminal

Each day prognosis values of 1 to 5 were also assigned using the maximum Euclidean distance experienced by the patient up to that day using the rule:

Maximum Distance Experienced	Assigned Value	Interpretation
>2	1	Good
2 to 3	2	Fair
3 to 4	3	Poor
4 to 5	4	Critical
>5	5	Terminal

No values of 5 were ever assigned by clinicians before death had occurred. As a result, it is not possible to determine misclassifications with respect to death using the clinical prognoses. Clinical prognoses of "critical" were assigned on most days for the three surviving patients misclassified as terminal according to the distance prognosis.

As expected, good agreement was observed between clinical and distance prognoses for the patients who survived.

Table I is a breakdown of clinical and distance prognoses for the 16 patients who died. For patients numbered 1451, 1482, 1512, 1564, 1657, 1975, 2063 and 2007 the prognoses are essentially the same. For the remaining patients, 1460, 1465, 1476, 1504, 2033, 1900, 1924 and 1895 the distance prognosis gives an earlier indication of impending death.

The object of this paper is to present a method of analyzing data in terms of a patient's Euclidean distance. Limitations of the method, as well as possible uses will be enumerated in order to develop a more accurate assessment technique.

Limitations Requiring Refinement:

a. The clinicians with regard to the prospective group never assigned a patient to the terminal class. The worst category that a living patient was assigned to was critical. This clinical classification points out the difficulty in determining the difference between a critical and terminal case, especially when the patient initially arrives in a hospital. In addition, the distance measure gave an earlier indication of death in 10 out of 16 "prospective" cases that eventually died. In the remaining seven cases there was agreement. It should be noted, however, that clinical prognoses might have reflected the optimism of the physicians caring for the patient. With the inclusion of additional measurements it may be possible to make even more accurate and earlier prognoses.

b. No attempt was made to weight each measurement so its contribution to the distance value would depend on its clinical significance. For example, if in one patient the systolic blood pressure falls from 127 to 63 (a distance of three standard deviation units) and in another patient the creatinine rises from 1 to 2.5 (also a distance of three standard deviation units), there may be a marked difference in immediate survival which should be reflected in a statistical assessment. In another approach planned, the variables will be weighted based on clinical judgment. Then, for example, a systolic blood pressure of 63 might have a "clinical" distance of seven instead of three, and a creatinine of six could have a "clinical" distance of seven instead of ten.

Possible Uses:

Assuming there are improvements in both selection of criteria and their weighted reflection of patient illness, in addition to more frequent measurements, what are the possible uses of this distance measurement?

(1) Characterization of Specific Injury or Disease. The profile described in this paper has indicated its usefulness in predicting final patient outcome, for those suffering from a wide variety of diseases and injuries. Of course, the concept could be used to characterize a particular disease, injury type or body subsystem. In this case a candidate parameter may be inserted into a profile, and data collected to determine its use as a prognosticator. An "information gain" analysis would indicate the value of the new parameter.

(2) Patient Monitoring. Using a distance measurement in an intensive care unit setting could be an aid to patient monitoring. One could imagine computing distances based on pulse, systolic blood pressure, respirations, urine output, central venous pressure, arterial blood gases and pH. If the distance is "small," all of the contributing measurements would be small. If the distance measurement is large, the contributing values would be printed by the computer. In this setting, normal values for each patient could be pre-set on the computer rather than depending on group data normals.

(3) Wound Ballistics.

A major goal of the Army's Wound Ballistics Program is to provide criteria which are used to assess the effectiveness of current and proposed antipersonnel weapon systems. These same criteria are used to evaluate the protection offered by helmets and body armor against various types of fragmenting munitions.

The current "incapacitation criteria" for fragments and flechettes are based upon a combination of animal experimentation and the subjective evaluation of surgeons. These criteria have provided effectiveness analysts with a set of equations which estimate the "probability of incapacitation"* as a function of tactical role, post wounding time and the mass and velocity of the striking fragment or flechette.

The subjectivity in assessing the effects of specific wounds when evaluating the effectiveness of munitions and/or protective

*Probability of incapacitation is a misnomer, actually percent incapacitation is estimated.

materiel would be reduced by incorporating a physiological and biochemical characterization of casualty state into the assessment criteria. This characterization may relate to the casualties "probability of incapacitation" and to estimates of the probability that a wound would be classified as serious or lethal. Results presented in this paper describe one way in which the physiological and biochemical characterization of patient state can be used to predict lethality.

(4) Triage.

During combat, the rate of patient arrivals to medical care facilities is anything but uniform. In those periods with the greatest influx of patients, because of limited resources, the order in which patients are to be treated must be determined. This, so-called, triage procedure is currently accomplished by a visual inspection of casualties by surgeons, and depends upon estimates of the probability of survival, with and without immediate treatment, for each casualty. A goal of the procedure might be to maximize the expected number of survivors.

The distance measure described earlier has been accurate in predicting patient final disposition (with respect to life or death), when expert care is being administered. Such an "integrated score," composed of easily obtainable physiological and biochemical parameters which respond soon after trauma, could be used to supplement the physicians initial triage. This procedure would be useful in following the state of patients given delayed treatment, so that succeeding triages could be based upon the latest information.

(5) Evaluation of Acute Care. A method has been proposed for quantitatively comparing the patient populations treated and the level of care provided by various institutions.[3] By comparing patient data from different time periods, the method also provides a means for estimating the improvement in the level of care which a facility has provided over some period of time.

(6) Teaching Aid.

The relationship between the patient's distance and course of therapy serve as an excellent teaching tool. Although "computerization" of care may hint that the physician will be removed from the bedside and medical care will be depersonalized, this of course is not the case. At this point the computer finds it difficult enough to define those criteria that should be incorporated into a distance measurement, let alone determine the necessary therapy.

Clinicians are continuing to test the reliability of this index on current patients in the MIEM. Also, similar analyses are being done on other profiles most of which include systolic blood pressure, serum creatinine and osmolality.

CONCLUSIONS

This paper has described some applications of pattern recognition techniques in evaluating the severity of injury to traumatized individuals.

Methods for analyzing patient state, estimating the probability of survival or death, evaluating administered therapies and the level of care provided by various institutions were discussed, along with possible applications of the work to problems faced specifically by the military community.

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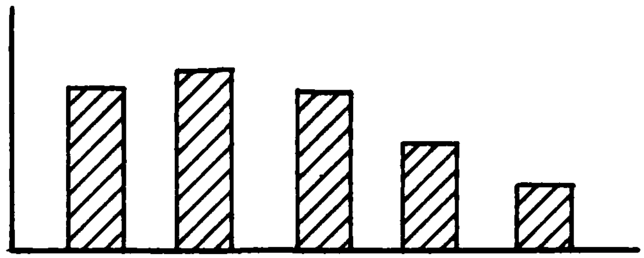
FIGURE 1

DISTANCE TRAJECTORY OF A 65-YEAR OLD MALE PATIENT WHO DIED



DAY		SBP	HCT	FIB	POTAS	CREAT	OSMOL	EUC DIST
1	Actual Value	88.0	32.5	676	2.70	1.30	380	
	Norm. Value	-1.86	-.731	1.39	-2.25	.603	5.90	6.79
2	Actual Value	80.0	34.0	669	5.20	1.60	396	
	Norm. Value	-2.24	-.480	1.35	1.47	1.21	6.96	7.69
3	Actual Value	72.0	34.5	509	5.30	1.80	375	
	Norm. Value	-2.62	-.396	.449	1.62	1.62	5.56	6.59
4	Actual Value	102	34.0	571	4.20	1.10	353	
	Norm. Value	-1.20	-.480	.799	-.0179	.197	4.10	4.37
5	Actual Value	116	33.0	575	3.50	1.00	312	
	Norm. Value	-.535	-.648	.822	-1.06	-.00609	1.36	2.09

TABLE I

BREAKOUT OF RESULTS FOR PATIENTS WHO DIED

NUMBER OF DAYS SPENT IN UNIT	NUMBER OF PATIENTS	NUMBER OF DAYS FOR WHICH DISTANCE EXCEEDED 5 UNITS (FOR EACH PATIENT)	EARLIEST DAY FOR WHICH DISTANCE EXCEEDED 5 UNITS (FOR EACH PATIENT)
1	1	1	1
2	2	2,2	2,2
3	4	2,1,1,1	2,3,3,3
4	3	3,0,4	2,-,1
5	3	4,5,0	1,1,-
6	3	4,4,0	2,2,-
7	1	2	1
8	2	1,8	8,1
9	2	3,1	1,7
10	1	10	1
11	1	9	3
12	1	7	3
14	2	14,5	1,10
18	1	6	10
21	1	8	14
26	1	0	-
28	1	28	1

TABLE II

BREAKOUT OF CLINICAL AND DISTANCE PROGNOSES FOR PATIENTS WHO DIED

Patient Number	Number of Days in Unit	C: Clinical Prognosis by Day D: Distance Prognosis by Day
1451	3	C: 4 4 4 D: 4 4 5
1460	11	C: 4 3 3 3 3 3 3 3 3 3 3 D: 3 4 5 5 5 5 5 5 5 5 5
1465	14	C: 4 4 4 3 4 3 3 4 4 3 4 D: 5 5 5 5 5 5 5 5 5 5 5
1476	7	C: 3 2 2 2 3 4 D: 5 5 5 5 5 5
1482	5	C: 4 4 4 4 4 D: 4 4 4 4 4
1504	4	C: 4 3 3 3 D: 5 5 5 5
1512	6	C: 4 4 4 3 4 5 D: 4 4 4 4 4 4
1564	2	C: 4 4 D: 4 5
1657	10	C: 4 4 4 4 4 4 4 4 4 4 D: 5 5 5 5 5 5 5 5 5 5
1975	26	C: 4 ... 4 26 days D: 4 ... 4 26 days
2033	9	C: 4 4 4 4 4 4 4 4 5 D: 4 4 4 4 4 4 5 5 5
2063	3	C: 4 4 4 D: 3 4 5
1900	28	C: 3 3 3 4 4 ... 4 D: 5 ... 5
1924	21	C: 4 ... 4 D: 4 ... 4 5 (14th day) ... 5
1985	5	C: 4 4 4 4 4 D: 5 5 5 5 5
2007	3	C: 4 4 5 D: 4 4 5
1395	14	C: 2 2 2 2 2 2 2 2 2 2 3 4 4 4 D: 3 3 3 3 3 3 3 3 3 3 5 5 5 5

SUBJECTIVE EVALUATIONS IN ARMY OPERATIONS RESEARCH

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BACKGROUND

Traditionally there has been much controversy in the scientific community regarding subjective versus objective approaches to various problems. In statistics for example, one has the arguments involving subjective probabilities and classical probabilities, fiducial intervals and confidence limits; as well as the debates for and against the application of Bayesian procedures. Although there are some problems for which the operations research analyst may prefer an objective approach to a solution, there are clearly other situations where he may have a choice between a subjective and objective approach or situations such as: the determination of individual preferences for items based on taste, color, odor, touch and sound which can best be analyzed by subjective means.

In the Army the OR analyst is often faced with the problem of rating various alternatives or systems of interest. The complexity of this problem is increased when, for example: the number of systems is large, or when the systems are closely related, or if the attributes of each system are multidimensional or qualitative. Thus, in some situations it may be impossible, intractable or otherwise undesirable to formulate an objective basis for this rating; that is, it may be difficult to derive an analytical model without simplistic assumptions which detract from the crediability of the method. In these situations the analyst generally decides to take a subjective approach. He first forms a panel or an evaluation team whose members constitute a random sample from an appropriate population of experts in the particular field. He then asks each of the panel members to compare by some prescribed procedure a subset of the systems of interest. These individual ratings are then tabulated and analyzed in order to obtain an overall composite rating of the systems or alternatives.

Consider some examples where this approach may be applied:

(1) Ranking various competing weapon systems.

(2) Estimating the wound ballistics of small arms systems.

(3) Assessing the advantages/disadvantages of various product improvements.

(4) Rating various alternative strategies for combat actions.

(5) Assessing intelligence information.

(6) Ranking employees for promotions or awards.

EXPERIMENTAL PROCEDURES

A preliminary question to be addressed prior to the conduct of a subjective evaluation is: Which experimental procedure should one use to collect the required data? Some procedures are described as follows:

(1) Paired Comparisons: The subject is asked to state a preference for one of two items presented to him at a time. The

advantage of this procedure is its freedom from dependence on scoring systems, memory and previous subjective responses. The disadvantage is that it may be time consuming to obtain the amount of data required by a specific design.

(2) Triple Comparisons: The subject is asked to rank the items when presented to him three at a time. When the number of items is small, ranking in groups of three reduces the time and effort required for evaluation; but when the number of items is large, there is no advantage for triples over paired comparisons.

(3) Ranking: This represents an extension of the paired comparison and triple comparison techniques. The subject is simply presented with a subset M of the N items and asked to rank them according to his preference. It should be noted that given a set of data in which subjects have ranked M items, one could transform these data into $\binom{M}{2}$ paired comparisons.

(4) Method of Choices: The subject is asked to indicate the item for which he has the greatest preference; that is, his first choice. In many instances this procedure would be the easiest task for the subject to perform. Guilford in [1] suggested that subjects also specify their last choice to circumvent the problem that some items are never judged most preferred.

(5) Delphi Method: The Delphi method dates back to the early days of the Rand Corporation, although it has only been since 1953 that the method has existed in its present form. The name "Delphi" was derived from the Greek location of the Oracle. There

are three features which characterize this procedure: anonymity of the subjects' responses, iteration with controlled feedback, and statistical index of the subjects' response. An important advantage of the Delphi method is that the role of the dominant individual participating in a group decision-making process is considerably less significant.

MATHEMATICAL MODELS

There have been many models developed for obtaining rankings from experimental data, most all of which assume data in the form of paired comparisons. Since data obtained by any of the experimental procedures previously discussed may be transformed into paired comparison data, it is appropriate to consider these models. Brunk in [2] classifies these models into two categories: type 1 models - where "worth" of an item may be defined in terms of its expected scores in comparisons with others; and type 2 models - where each item is assumed to have an intrinsic worth. Consider the following notation to facilitate a discussion of some mathematical models:

(1) Let I_1, $I_2 \ldots I_N$ represent N items under consideration; let I^1, $I^2 \ldots I^N$ be a specific ranking of these objects.

(2) Let E be the N x N matrix of the expected scores in which the element in the i^{th} row and j^{th} column is e_{ij}

(3) Let e^{ij} be the expected score of the i^{th} ranked item when compared with the j^{th} ranked item.

(4) Let w_i be the worth of the i^{th} item; let w^i be the i^{th} largest of the set $\{w_i / i = 1, 2 \ldots N\}$.

Type 1 Models

(1) Brunk Model A:

$I^1 \ldots I^N$ is determined as the ranking which yields the maximum overall possible permutations, $P_{N,N}$, of the sum

$$\sum_{i=1}^{N} \sum_{j=i+1}^{N} e^{ij}.$$

This model is most appropriate in a situation in which the whole ranking is, say, of uniform interest.

(2) Kendall Model (Row Sums Model):

$$w_i = \sum_{j=1}^{N} e_{ij}$$

$$I^i = w^i \qquad i = 1, 2 \ldots N$$

The Kendall model is appropriate in the very common situation in which it is of prime importance to choose the highest ranked item correctly. Then of secondary importance to choose the second, etc. An application of this method is found in the determination of major league baseball standings.

(3) Kendall-Wei Model (Powering Model):

$$\lambda w_i = \sum_{j=1}^{N} e_{ij} w_j$$

$$I^i = w^i \qquad i = 1, 2 \ldots N;$$

where λ is a characteristic value and $w = (w_1, w_2 \ldots w_N)$ a corresponding characteristic vector of the expected scores matrix, E. In the Kendall-Wei model a high expected score, when compared with a worthy item, contributes more to worth than a high expected score when compared with a less worthy item.

(4) (Thompson) Dominance Ranking Model (Weighted Powering Model):

Let D be a matrix identical with E except that 0's appear on the main diagonal.

Let $\underline{1}$ be a vector each of whose components is 1.

Let $0 < z < \frac{1}{\lambda}$, where λ is the principal characteristic value of E.

Let $\underline{w} = (w_1, w_2 \ldots w_N)$ define a worth vector.

Then $\underline{w} = (D + zD^2 + z^2 D^3 + \ldots)\underline{1}$

$$I^i = w^i \qquad i = 1, 2 \ldots N \quad .$$

When $z = 1/\lambda$, the dominance ranking method coincides with the Kendall-Wei method.

(5) Doehlert Triad Reduction Model [3]:

This technique consists of an examination of the raw data in order to determine the pair of items, say, I_i and I_j, appearing most frequently in a circular triad list (e.g., i preferred to j, j preferred to k, but k preferred to i). The observed scores for these items are then interchanged and the data are again examined. This procedure is repeated until there is no pair appearing more frequently in a circular triad list than any other pair. A ranking $I^1 \ldots I^N$ of the N items is then obtained from these modified data using the method of Row Sums.

Type 2 (Intrinsic Worth) Models

In the intrinsic worth models one assumes apriori estimates of the elements $\{e_{ij}/i,\ j = 1, 2 \ldots N\}$ of the expected scores matrix E.

(1) Scheffe´ Model:

$$w_i = \frac{1}{N} \sum_{j=1}^{N} e_{ij}$$

$$I^i = w^i \qquad i = 1, 2 \ldots N$$

(2) Bradley-Terry Model:

Assumes $\frac{e_{ij}}{e_{ji}} = \frac{w_i}{w_j}$; or equivalently, $e_{ij} = \frac{w_j}{w_i + w_j}$

The estimates of the worths, w_i, are found by the solution of the following N nonlinear equations:

$$w_i = \sum_j e_{ij} \left[\sum_{\substack{k=1 \\ k \neq 1}}^{N} \frac{1}{w_i + w_k} \right]^{-1} \qquad i = 1, 2, 3 \ldots N$$

$$I^i = w^i \qquad i = 1, 2 \ldots N$$

where $\sum_j e_{ij}$ are row sums of the expected scores matrix E. A starting approximation to an iterative solution for w_i was proposed by Dykstra [3]. This starting approximation for w_i is given as:

$$w_i = \sum_j e_{ij} / \left[(N-1)^2 - (N-2) \sum_j e_{ij} \right].$$

This model is no different from the Row Sums Model when used to estimate rank order.

(3) Thurstone-Mosteller Model (Normal Distribution Model):

It is assumed that the worths (interpreted as the responses of subjects to items) w_i for each of the N items to be compared are independent, have equal variances and are each normally distributed about a mean value. Hence, the difference between two responses is also normally distributed and the following relation is obtained:

$$e_{ij} = \frac{1}{\sqrt{2\pi}\sigma} \int_{-(w_i - w_j)}^{\infty} \exp \left[-x^2 / 2\sigma^2 \right] dx$$

(4) Brunk Basic No-interaction Model:

This model assumes that the expected score of an item of worth u when compared with an item of worth v is a function e(u, v) which is non-decreasing in u, non-increasing in v. Therefore, given N items, there exists a ranking $I^1, I^2 \ldots I^N$ such that $e^{ij} \leq e^{ik}$, $e^{jk} \leq e^{ik}$ for $1 \leq i \leq j \leq k \leq N$; namely, ranking by worth. In order to obtain this ranking the following procedure is employed.

A distribution function is assumed for each score; and then, every possible ranking of the items is assumed in turn while the maximum likelihood function is computed for each of these rankings. The final ranking is then selected as the ranking for which the maximum likelihood function assumes its largest value.

In conclusion, it seems that there are many methods both to collect the experimental data and to analyze it. Several studies seem to indicate that, in general, there is little difference in the resultant rankings obtained by any of these methods.

EXAMPLES OF THE RELIABILITY OF SUBJECTIVE EVALUATIONS

Reference [4] demonstrates the reliability of subjective estimates in a high incentive situation. The data used comprised the results of all thoroughbred horse races run at Acqueduct and Belmont Park in 1970 (a total of 1825 races). Table 1 presents a comparison of subjective probabilities of winning and actual frequencies of wins as a function of odds rank for races with 5-12 entries. The subjective probabilities were computed as the normalized reciprocal of the odds to a dollar that a horse wins plus one. Also shown in Table 1 are computed chi-square values with the appropriate values of the chi-square statistic for the .95 confidence level.

TABLE 1 COMPARISON OF SUBJECTIVE PROBABILITIES OF WINNING AND ACTUAL FREQUENCIES OF WINS AS A FUNCTION OF ODDS RANK OF HORSE

No. of Entries	No. of Races		Ranking by Odds 1	2	3	4	5	6	7	8	9	10	11	12	Computed Chi-Sq	$\psi^2_{.95}$
5	69	Subj Prob	.42	.25	.17	.11	.06								3.2	9.5
		Obs Freq	.41	.30	.20	.07	.03									
6	181	Subj Prob	.36	.23	.17	.12	.08	.04							10.5	11.1
		Obs Freq	.43	.21	.20	.11	.03	.02								
7	312	Subj Prob	.33	.22	.16	.12	.09	.06	.03						5.7	12.6
		Obs Freq	.34	.21	.16	.12	.08	.08	.02							
8	352	Subj Prob	.31	.20	.15	.12	.09	.06	.04	.03					7.1	14.1
		Obs Freq	.33	.25	.13	.09	.07	.06	.04	.02						
9	283	Subj Prob	.30	.20	.15	.11	.09	.06	.05	.03	.02				13.1	15.5
		Obs Freq	.35	.15	.17	.13	.08	.06	.02	.01	.02					
10	241	Subj Prob	.29	.19	.14	.11	.08	.06	.05	.03	.02	.02			5.0	16.9
		Obs Freq	.31	.17	.16	.10	.07	.07	.06	.04	.02	.01				
11	154	Subj Prob	.27	.18	.14	.11	.08	.07	.05	.04	.03	.02	.01		11.8	18.3
		Obs Freq	.27	.18	.19	.08	.05	.05	.05	.05	.04	.04	.01	-		
12	233	Subj Prob	.26	.17	.13	.10	.08	.07	.05	.04	.03	.02	.02	.01	3.2	19.7
		Obs Freq	.28	.14	.17	.12	.10	.06	.02	.05	.03	.03	.01	.00		

The results indicate good agreement between the expected and actual values. In no case is the null hypothesis that the subjective probabilities are the correct theoretical frequencies rejected.

CURRENT APPLICATIONS OF SUBJECTIVE EVALUATIONS

Some problems where Army OR analysts have recently applied subjective techniques or are planning to utilize them in the near future are discussed below:

(1) The Delphi technique has been applied by Edgewood Arsenal, Aberdeen Proving Ground, Maryland, in an effort to obtain estimates of human lethality following impact over the liver area by a "low lethality" riot control weapon which fires a round bean-bag like projectile. The problem was one of extrapolation from animal trauma to human physiologic equivalents.

(2) Subjective evaluations have been suggested as a vehicle to obtain improved mission profile and target array data. In addition some insight may be obtained on Army weapon requirements.

(3) More than 1000 questionnaires have recently been distributed to the infantry community by the US Army Materiel Command, Infantry Research and Development Liaison Office with regard to various product improvements presently being considered for the M16 rifle. The improvements are:

(a) A 2 or 3 round burst control device to limit the number of rounds per trigger pull in automatic fire.

(b) A muzzle device which would compensate the weapons natural inclination to go upward and to the right (or left). It is intended to analyze the results and correlate the responses of about 50 questions concerning various aspects of the proposed improvements with individual personal history data. These data should be very helpful and complementary to the results of the military potential test conducted by the Infantry Board, Fort Benning, Georgia.

(4) Questionnaires administered by analysts to acknowledged "experts" are considered a valuable source for obtaining input data useful in the performance of system analysis studies.

(5) The Delphi procedure is presently being utilized in conjunction with a decision risk analysis on a biodetector. The biodetector is a mechanism for detecting biological agents.

CONCLUSIONS

Subjective evaluations have been demonstrated to be reliable and useful to the decision maker either as a separate analysis or as a complementary analysis to some analytical study. The value of the results are enhanced when valid experimental procedures are used for collecting the data and valid statistical techniques are used to analyze the results.

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