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THE TANK EXCHANGE MODEL

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INTRODUCTION

The Tank Exchange Model (TXM) was developed by the Institute for Defense Analyses (IDA) for the Office of the Deputy Director for Defense Research and Engineering (Tactical Warfare Programs). This paper is abridged from IDA Paper P-916, Tank Exchange Model, November 1973 (AD 771-296 and AD 771-297). Paper P-916 is a more detailed description of the model with definitions of the inputs and output, and running instructions.

MODEL SCOPE

The primary purpose of the Tank Exchange Model (TXM) is to provide a methodology to compare two or more tanks in terms of vulnerability and lethality in engagements with other tanks and antitank weapons. The TXM does not make this comparison directly, but permits the user to separately determine the effectiveness of both tanks in a range of situations. Although the range of situations is limited it is believed to be sufficient to provide realistic comparisons.

The TXM simulates an engagement between two opposing forces of tanks and direct fire antitank weapons. The major output is the loss to both sides during the engagement. The model does not optimize any factors (i.e., tactics, tank characteristics, etc., are input by the user and are played as input). To analyze the change in total system effectiveness due to some modification in the tank design, several model runs would be required. For example, suppose it is desired to estimate the change in tank performance as a result of replacing the current rangefinder on the M-60A1 with a laser rangefinder. Several typical situations would be selected for analysis. These would include using the M-60A1 in the assault role and defensive role, the selection of typical enemy units and a range of environments. Each of these cases would be analyzed using the TXM and the current M-60A1 performance estimates. The cases would then be analyzed a second time using the M-60A1 with the laser rangefinder. The resulting exchange ratios would be compared for each case to determine the overall change in system effectiveness.

Examples of other factors that might be analyzed to measure their effect on a tank's vulnerability or lethality are

- Profile of the tank.
- Increased rate of fire.
- Improved sensing for second round capability.
- Change in the armor.
- Stabilized gun permitting accurate fire while moving or decreased time to the first shot after stopping.
- Improved acquisition capability.
- Improved aiming accuracy.

In many instances, when a modification has not been tested, reliable input data are not available. In these cases the model may still be useful by making parametric runs to generate a curve of system performance as a function of the effectiveness of the modification.

To achieve the purpose of the TXM a relatively simple basic scenario has been simulated. In this scenario, only one of the two opposing forces is mobile (called the "assault" force). The second or "defensive" force is not permitted to move. Each defensive unit remains in a fixed position throughout the simulation. All of the units of the assault force are of the same type, while the defensive force may consist of one or two unit types. Unit characteristics are completely defined by inputs. Either tanks or antitank weapons may be simulated; however, simulating lightweight, infantry antitank weapons in the defensive role would not be very realistic since their positions would normally be changed during an engagement. The model has been developed to simulate up to ten weapons of each of the three possible types.

The selection of the basic scenario represents a tradeoff between realism and model simplicity. How frequently a tank assault would occur without supporting arms has not been estimated. Furthermore, it is not likely that one of the forces would remain in a fixed position throughout a long engagement. Certainly if the purpose of the model were to ascertain the number and mix of weapons required to assault or defend a given position, mixes of tanks, aircraft, artillery, infantry and mines would have to be simulated. However, such a model might obscure the relative effectiveness of different tank designs. The TXM in turn may overemphasize shortcomings of different designs. The user should consider that other weapons in an engagement could compensate for weaknesses in the tank's performance.

MODEL DESIGN

The TXM is a Monte Carlo simulation engagement written in FORTRAN IV for the CDC 6400. It is a combination of time-step and event store. During periods of the simulation in which there are no detections or weapon firings the assault unit positions are updated at equal increments of time. As detections and weapon firings occur, events are played in the order and at the time they are to occur.

Modifying the TXM for other computers may be a difficult task. The model currently uses overlays with one main overlay and two primaries. Extensive use of masking (mainly in the input scheme) may also complicate modifications.

The program consists of approximately 70 routines. Of these, seven are major routines; the remainder are subroutines to the seven or are used for input and output operations. The seven major routines are as follows:

(1) MOVE--updates position of assault units.
(2) DETECT--determines acquisition of opposing forces.
(3) TACAD--makes tactical decisions for assault and defensive units.
(4) SELECT--selects target and makes decision to fire.
(5) FIRE--fires round and determines aim errors.
(6) IMPACT--determines round effectiveness and changes status of target.
(7) BKDOWN--determines random equipment failures and repairs.

Except for mobility and those tactical decisions related to mobility the assault and defensive forces are simulated in each routine in the same level of detail.

Terrain is simulated in all of those aspects of the problem in which it is critical, with the exception of mobility. Soil types and obstacles to movement are not explicitly simulated. The model user must consider and evaluate these factors in preparing inputs, and adjust speeds and assault paths accordingly.

To the maximum extent possible, all unit characteristics and capabilities are established by inputs. In many areas of the model the user may decide to simulate detailed or simplistic versions of the same interaction. For example, a series of rounds fired by the same weapon may be played so that the probability of hit of each round is influenced by the information gathered from the previous miss or hit against the same target. This scheme may be bypassed with one input switch and each round treated as an independent event. Although less realistic, the latter approach may be sufficient for the problem being analyzed.

Some features of the model have been incorporated despite the knowledge that at this time there are no valid input data. For example, assault units have the option to fire while moving. To simulate this, the user must input the aiming errors associated with firing from a moving platform. There are two advantages for incorporating features of this sort in the model even though valid field data are lacking. First, it is easier to incorporate such features during model development than later as a modification to the model. Thus, the model is ready to simulate these factors if and when data become available. Second, it is possible to analyze these capabilities through a parametric analysis. In the above example, the model might be used to determine how accurate the fire must be from a moving platform to make it advantageous to have this capability. Of course, the user may bypass these inputs by not permitting units to fire while moving.

MODEL CONTROL

Since the model is Monte Carlo, it must be run a number of times to obtain meaningful results. After each complete pass through the engagement (called an iteration) the results are tabulated and stored. Upon completion of the required number of iterations, the results are averaged and printed. The major results of each iteration may also be printed individually, if desired.

The MAIN routine controls the operation of the model. After the input data are read, routine INITER is called to initialize the engagement. All units are placed at their initial positions and time is set to zero. Initially there are no detections of opposing forces.

The simulation commences with a call to MOVE, which starts the assault units on their paths. After the first call to MOVE, the next routine to be played depends upon whether any events have been stored. Five types of events may be stored, each with a time at which it is to be played. These are

(1) SELECT: This event is played for an individual unit; up to 30 may be stored at one time.
(2) FIRE: Like SELECT this event is played for individual units.
(3) IMPACT: This event is stored for each projectile that is fired.
(4) BKDOWN: This event is played for the individual system that is scheduled to fail or be repaired.
(5) MOVE: This event is played for all assault units and is stored in two different ways. It is stored to be played at input time intervals, and may also be stored to cause position updates that are required between the time steps. Regardless of the way in which it is stored the same MOVE routine is played.

The other two major routines, DETECT and TACAD, are called at the end of the MOVE, so they are played at least once for each assault position update.

After the initial call to MOVE the event store list is checked. At least one event (the next time step MOVE) is always stored. Of these events in store, the one with the least time is played next. It is not possible in the TXM for time to move backwards, although several events may be stored and played at the same time.

After the assault unit positions are updated, DETECT is called. Each possible pair, consisting of one assault and one defensive unit, is checked for detection by either opponent. Detections may occur either through the normal search process or by detecting a firing weapon's signature. If any unit detects an enemy, a SELECT event is stored. The time to play the SELECT is randomly set over the next increment of time, thus preventing an unrealistic synchronization of events.

After all detections are checked, TACAD is called to make tactical decisions. For assault units the possible decisions are to continue the advance, to go to defilade positions and halt, to withdraw, and to open fire (if permission to open fire has not been previously granted). For defensive units the possible decisions are to withdraw or to change the fire control index. The fire control index controls the type of targets that will be fired upon and the number of rapid fire rounds in a burst.

All decisions made by TACAD apply to all active units on either side. For instance, it is not possible to make a decision to send one or two assault units to defilade and continue the advance with the others.

If SELECT is played for a unit and a suitable target is found, a FIRE event is stored for the unit. The time for fire depends primarily upon the times required to aim and to load the weapon. The FIRE routine counts the ammunition expenditure, determines the aim errors of the round (if required) and stores an IMPACT event for the round at the end of its flight time to the target.

If rapid fire rounds are to be played the FIRE event is stored again for the next round. Otherwise, a SELECT event is stored at the IMPACT time and the same or a new target may be selected.

The BKDOWN event simulates the random failure and repair of firepower for assault and defensive units. Random failure and repair of mobility is simulated for assault units only. Partial failures are not simulated. A unit is either completely immobile or fully mobile, and its main weapon is either unable to fire or fires at full effectiveness. When a random failure (or repair) occurs, the BKDOWN routine stores the next BKDOWN event for the system in the event store table.

In addition to the calling of the events, the MAIN program also determines when an iteration should end. The conditions that cause the iteration to terminate are

(1) The input maximum iteration time is exceeded.
(2) All assault or defensive units have been lost due to enemy hits.
(3) The assault forces have been withdrawn and are out of effective weapon range.
(4) The defensive forces have been withdrawn.

When the iteration is terminated, MAIN calls OPRINT if an iteration report is requested. The routine RUNTAB is called to tabulate the run averages that have been compiled so far. If all iterations have been completed, OPRINT is called again to report the run results. If there are more data decks, the next deck is read and the simulation starts again. Otherwise, the program terminates.

The following sections describe each of the major routines briefly.

MOVE Routine

The general movement of the assault tanks is controlled by a list of input go-to points, specified by their X and Y coordinates. Each assault tank is initially assigned to a path consisting of a list of these points. The tank moves from each point to the next on a straight line. The maximum number of go-to points for all of the assault units is 60, but there is no limit on the number of these assigned to one unit. For each go-to point, there are inputs that control the actions of the tank as it approaches that point. The first of these is a designator giving the type of point. Three types may be played: (1) normal, (2) adjust formation, and (3) hold.

For a normal point, the tank approaches at a given input speed; except for stopping to fire, this speed is maintained constantly. Since each point has a separate input for speed, it is possible to reflect the effects of terrain, soil conditions, and obstacles along the path.

For an adjust formation point, all of the assault tanks that are active and in formation adjust their speed to arrive at their respective points at the same time.

Tanks approach a hold point as they do a normal point, but no tank is allowed to progress beyond the hold point until all other tanks in formation have arrived at their respective hold points. Hold points may be used to simulate maneuvers in which one or more tanks advance while the remainder stop to cover the advance. With each hold point, an input is available to give the fraction of cover at the point. Thus, the covering tanks may be stopped at defilade positions.

Several events may occur in the simulation that cause the tanks to alter their normal speed or direction. An individual assault tank may be ordered to stop to fire--either immediately or after making an attempt to locate a defilade position. The availability of suitable cover is probabilistic and a function of the terrain type. Also, a tank that has lost its firepower system may be ordered to stop at a defilade position.

The selection of terrain characteristics is probabilistic; it is made at the end of the MOVE routine. The area in which the engagement occurs is divided into rectangles, the dimensions of which are input. For each rectangle, there are inputs for cover and concealment codes.[1] These codes are integers from 1 to 5 and indicate the probability distribution of cover and of concealment type. For each of the five cover codes, a probability distribution is input. This distribution gives the probability of the tank being behind cover (expressed in the fraction of the unit that is behind cover) from zero up to an input maximum value. As a new terrain square is entered, the cover code is determined from the inputs, and a random number is selected to determine the fraction of the tanks covered. A second random number, together with the average distance to the next cover change for this code, is used to determine the distance at which a new cover level will be selected. The fraction of a unit covered affects both its detectability and vulnerability.

The concealment code operates in approximately the same manner. However, instead of a fraction as in the case of cover, a concealment type is maintained for each tank. This is an integer from 1 to 5. The probability of each type is input for each concealment code. The concealment type affects only the detectability of the unit.

Since defensive units do not move, the fraction covered and the concealment type are input directly for each position.

TACAD Routine

This routine is called every time the assault units are moved. Tactical decisions that affect all of the assault or defensive force are made by this routine; decisions for individual units are not. Five decisions may be made in TACAD:

(1) To expand or contract the assault paths.
(2) To order the assault tanks to defilade or to leave defilade and continue the assault.
(3) To order the assault or defensive units to withdraw.
(4) To permit the assault or defensive units to fire at targets of opportunity after initially withholding their fire.
(5) To change the level of the defensive fire control index.

The user has freedom to exercise any of these decisions. The decisions are made by reference to an input matrix, each row of which is designated to apply to a particular decision. This decision is implemented if the current status of the forces in the simulation satisfies all of the inputs in one of the designated rows. For example, row 3 may be designated "assault forces to defilade positions." Elements 1 and 2 in each row are input as the lower and upper limits on the number of defensive units detected and active. Other

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[1] Cover defines the amount of the unit that is behind a solid barrier and is invulnerable. Concealment defines the type of vegetation in the vicinity of the target and only alters the detectability of the unit. If detected, the unit is still vulnerable even if the concealment level is high.

elements in the row pertain to the limits on the number of assault tanks remaining active, the number of active assault tanks minus the number of defensive weapons detected and active, the average distance between the assault formation and the defensive units, and the current tactics of the assault and defensive units. If all of the elements in this row are satisfied, the assault units leave their assault paths and seek defilade positions.

DETECT Routine

The scheme used in DETECT is closely patterned after the DYNTACS model detection scheme. The possibility of detection is checked after each position update and after the firing of any weapon. The same scheme is used for assault and defensive units, but different inputs are provided for each weapon type. Thus, the detection capability of each type may be different.

Line of sight is simulated by providing one input that indicates whether line of sight exists for each "terrain square-defensive position" pair. For each defensive position, either all or none of each terrain square is in line of sight. When an assault unit enters a new terrain square, an indication is made of which defensive positions are visible, and only these are checked for detection.

Detection may occur in one of two ways: by normal searching of an area or by sighting the signature of a firing weapon. In the case of a weapon firing, the user specifies a maximum possible range of detection for each type of ammunition and each type of observer. For each observer within this range, a random number is selected and compared to an input probability to determine if the flash is sighted. If the flash is detected, a second Monte Carlo check is made to determine if the target itself is detected. This probability depends on the observer type, target type, and level of concealment at the target.

Detection by normal searching of an area is probabilistic and determined by Monte Carlo methods. The probability of detection for a given situation is of the form

$$P_D = 1 - \exp(-A),$$

where A is a function of the range to the target, target cover and concealment, crossing velocity of the target, terrain complexity, the fraction of time that the sector containing the target is searched, and the time since the last check for detection.

SELECT Routine

The SELECT routine is stored for a unit whenever it has detected one or more potential targets for a given weapon and when it has permission to fire. It is also called for a unit when its status changes and it might decide to fire at targets that were previously bypassed. For instance, it is called whenever a unit stops, under the assumption that the requirements for firing may be less stringent for a stopped vehicle than for a moving one. When SELECT is stored by DETECT the time to SELECT is random and is slightly greater than the DETECT time. This prevents an unrealistic synchronization of events.

SELECT has several functions. It computes a target weight for each detected target that is classified "active." If more than one target is available, the one with the highest computed target weight is selected. The next determination is whether the selected target should be fired upon. If not, a SELECT event is stored for a later time for this unit. If it should be fired upon, an ammunition type is selected, the time to fire is computed, and a FIRE event is stored for the unit.

Seven factors may be used in weighting the targets:

(1) Range from firing unit, together with target type.
(2) Number of detected enemy units within some critical range.
(3) Whether a potential target is in the assigned sector of responsibility of firing unit (the width of the sector is input, and it is centered on the principal observation bearing used in DETECT).
(4) Aspect of target relative to firing unit.
(5) Condition of target--moving or stationary; fraction of cover; detected or pinpointed.
(6) Number of other friendly units currently firing at target.
(7) Results of last round fired by unit--if potential target was fired upon last, was round a hit or miss? If a miss, was it sensed or not?

After selecting a target, the decision of whether to fire is made. In the case of defensive units, the decision to fire is based on the type of defensive unit, the calculated weight of the selected target and the defensive fire control index. For assault units, the decision to fire is more complicated. For moving assault tanks, a determination of whether they should fire without stopping depends on the range to the target, the type and cover condition of the target, and the calculated target weight. If the unit may not fire while moving, or if it is currently stopped, inputs are checked to see if the target weight is sufficient to fire. Depending on the terrain conditions and the target weight, the moving assault unit may stop to fire immediately or may delay its stop to locate a defilade position.

If the decision is made to fire, the ammunition type is selected. This is a function of the type and range of the target. A count of ammunition expended is maintained for each unit, but no limitations are placed on the amount of ammunition that can be used. Assault units may have up to three types of ammunition, while defensive units may have up to two.

The final computation in SELECT is the time at which the round will be fired. The time to fire depends on the time required to load and aim the weapon, and in the case of moving assault tanks, the time required to stop. Both load and aim times are computed randomly using log-normal distributions. The user inputs the minimum times, mean times, and standard deviations. For load times, the inputs depend on weapon and ammunition type; for weapon aim times, the inputs depend on whether or not the target was fired upon with the previous round. In the case of the assault unit, different values may be input for moving and stationary tanks, thus simulating the effect of being able to aim the weapon while moving. Finally, the aim times may be altered as a function of the target range, to simulate the observed effect of requiring more time to aim the weapon against more difficult targets.

The user may, if desired, simulate the effect of misfires. Inputs are available for each ammunition type, together with a time required to clear the misfire.

Finally, the maximum of the load and aim time (including the time to stop the assault tank) is determined. A FIRE event is stored to be played at this time.

FIRE Routine

Given that a round is to be fired, the FIRE routine determines the hit location information for the round (if required). There are essentially two FIRE and IMPACT routines that may be selected for each combination of ammunition and target type. In the simpler of these, the probabilities of hit and kill used in IMPACT are directly functions of target type, ammunition and weapon type, target range, aspect, cover and whether the assault unit is moving. In this scheme, FIRE does not determine impact points.

In the second scheme, kill probabilities are a function of the impact location on the target (described further under IMPACT routine). For this scheme, FIRE predicts impact points for each round based on aiming error distributions.

The inputs controlling the impact points are the desired aim point, fixed bias, variable bias, and random error. All four are input separately for the X and Y coordinates. Independent X and Y impact points are determined from these inputs by selecting a normal random variable with the fixed bias as the mean and the variable bias as the standard deviation. A second random variable is selected from a normal distribution with mean zero and the random error as the standard deviation. The X aim point and the two X random variables are added together to determine the X impact point. The Y impact point is computed in the same manner. The input aim points are functions of target type and exposure, ammunition type, and whether the target is moving. Aiming errors are input for various conditions of ammunition and weapon type, stationary or moving platforms (for the assault tanks), target range and aspect, target exposure, and target velocity (for defensive units).

This impact calculation scheme applies to the first shot at a new target from a fixed location and to any shot from a moving platform. If a weapon continues to fire at the same target from a fixed location, a different scheme of impact calculation may be used. This scheme depends on whether the previous shot was a hit or miss and, in the case of a miss, whether the impact was sensed. The probability of sensing the impact is input for each ammunition type, concealment level of the target, and over and under shots.

If firing continues at the same target and the previous round was sensed, the aim point may be corrected. The miss distance that would be estimated by the firing unit is obtained by adding a random error to the actual miss distance (in both the X and Y coordinates). The aim point of the previous round is corrected by the estimated miss distance. The new round has the same variable bias as the last, but a new random error is selected to obtain the impact point.

If the previous round was not sensed, standard fixed correction factors may be applied to the previous aim point. Whether or not the fixed correction is applied is a probabilistic decision. If applied, there is also a probability that it will be in the wrong direction. As in the sensed case, the corrected aim point, the previous variable bias, and a new random error are used to determine the new impact point. After computing and storing the impact point for the projectile, the impact time is computed and an IMPACT event stored.

Finally, FIRE determines the next action for the firing unit. Depending on the fire control selection and the ammunition type, the firing unit may fire one or more rapid fire rounds at the target. These are rounds fired in a burst at the same target with no aiming of the weapon between rounds. In this case SELECT is not stored; rather, another FIRE event is stored for the proper time. A second possibility is that an assault tank may be limited to the number of rounds it may fire from one fixed position. When this number of rounds is fired the tank is required to move for a period of time before it is allowed to stop and fire again. If rapid-fire rounds are not required, and the tank need not move, a new SELECT event is stored to be played immediately after the IMPACT event.

IMPACT Routine

This routine is played for each round fired at a target. The user may specify the type of kill probability inputs to be used for each combination of ammunition and target.

For the first type, the input probability includes the probability that the round hits the target and the probability of loss given impact. The input probability is the average kill over the exposure of the target, given that a round is fired. In the second type, the probabilities that are input are the probability of loss given that the round impacts on a particular one foot square of the target. The impact square is determined from the impact points given by the FIRE routine.

When the first scheme is used it is not possible to simulate the effect of aiming improvement that is possible with successive rounds. Each round fired at a target is played as a first round.

Both kill probabilities are functions of target range and aspect, target and ammunition types. In addition to these parameters, the first type of kill probability depends upon the target cover and whether the assault unit is moving at the time of fire. For the one foot square probabilities, a calculated impact that is below the target cover is a miss.

In both cases the input probabilities give the probability of loss of mobility, loss of firepower, or total loss. For the purposes of this model, total loss is defined as the loss of mobility and firepower and thus includes more than the commonly accepted K-kill criterion. If, for example, on successive shots a tank loses firepower and then mobility, it is considered a total loss and is out of action for the engagement, even though it may not be K-killed.

If an assault tank loses mobility, it is stopped but remains in the engagement both as a possible target and as a firing platform. If firepower is lost but not mobility, the user has the option of sending the assault tank to defilade or of keeping it with the formation. Since the loss of firepower refers only to the tank's main armament, it may remain with the formation.

If any unit is a total loss, there is an input probability to determine if the enemy units continue to classify it as active and fire upon it. This probability is played after every hit that causes it to be a loss.

BKDOWN Routine

For assault units, random failures may be simulated both for firepower and mobility; for defensive units, only firepower failures are simulated. The effect on the tank's actions as the result of a random failure is the same as a loss due to enemy action. However, for random failures, it is possible to play random repair times. If the tank is not put out of action by enemy fire in the interim, the tank may be repaired and returned to action.

The mean time to fail and mean time to repair are input for each system. The time to the next change is selected from an exponential distribution with the appropriate mean value.

TITLE: AN ANALYSIS OF FACTORS AFFECTING A TANK COMMANDER'S FIRING DECISION PROCESS[1]

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The general situation of interest in this paper is a land combat armored engagement between two opposing forces consisting of armored vehicles. The focal point of the system is the individual tank commander. The problem is to describe the functional relationships which exist between the tank commander's expressed appraisal of and subsequent decisions relative to the current combat situation and the state variables which describe it. In particular the individual tank commander's firing decisions are related to both friendly and enemy environmental state variables describing the combat situation.

It is hypothesized that two basic factors influence the tank commander's firing decision process:

1. "threat" - the tank commander's estimate of his current vulnerability to enemy tanks; and

2. "destruction" - the tank commander's estimate of his capability to inflict damage on enemy tanks.

We define:

TI = threat index; $0 \leq TI \leq 1$

DI = destruction index; $0 \leq DI \leq 1$

such that increasing values of TI and DI indicate increasing threat and increasing destruction capability, respectively, as seen by the individual tank commander. We define TDI as the threat-destruction index such that[2]

$$TDI = f\,(TI, DI) \tag{1}$$

An example of the function, f, describing TDI is given in Figure 1.

The value of TDI is an indicator of the engagement situation relative to the red tank as seen by the blue tank commander and, conceptually, could be used to describe the fire-no fire decision for the blue tank commander, as well as to describe the current battle situation as seen by the blue tank commander.

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[1] A portion of the research for this paper was conducted under the Foundation Research Program of the Naval Postgraduate School.

[2] In this paper TDI is expressed relative to the red force as observed by the blue force.

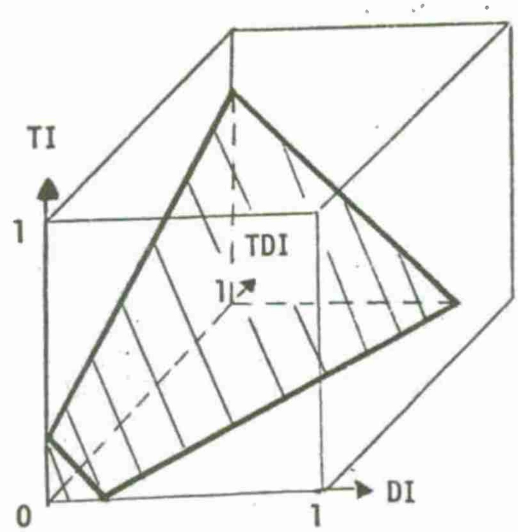

FIGURE 1. -- THREAT-DESTRUCTION INDEX

The threat index, TI , and the destruction index, DI , are each quantitatively described by the product of two subjective probabilities as follows:

$$TI_{ij}(t) = PH^{i}_{ji}(t) \cdot PD^{i}_{ji}(t) \tag{2}$$

$$DI_{ij}(t) = PH^{i}_{ij}(t) \cdot PD^{i}_{ij}(t) \tag{3}$$

where[1]

$PH^{i}_{ji}(t)$ = the subjective probability that element j can effectively hit element i as observed by element i, at time t, given that element j has detected element i at t.

$PD^{i}_{ji}(t)$ = the subjective probability that element j has detected element i, as observed by element i, at time t.

$PH^{i}_{ij}(t)$ and $PD^{i}_{ij}(t)$ are similarly defined.

Recall that the goal of the general system model is to functionally relate the system state variables to TI and DI , and to ultimately relate the tank commander's firing decisions to TDI. Considering equations (2) and (3), the problem becomes that of relating the system state variables to the defined probabilities. In the remainder of this

[1]The superscript notation indicates the element which is making the estimate of the specified subjective probability.

paper, the conduct and analysis of an experiment utilizing actual tank commanders to investigate the firing decision process is presented.

The goal of the experiment was to determine the relative importance of the various system state variables in an experienced tank commander's estimate of the following factors relative to an enemy tank:

1. Whether the tank commander would act as if he is currently detected by the enemy tank;

2. The percent chance of getting a solid hit on the enemy tank at the current time;

3. Whether the tank commander would engage the enemy tank at the current time; and

4. The percent chance of the enemy tank getting a solid hit on your tank, given the enemy is detecting you, at the current time.

Because of the large number of state variables required to define the situation, and because very little prior knowledge regarding the importance of state variable interactions was available, it was decided that no more than two levels of each state variable factor would be considered.

After careful consideration of the total set of state variables which would be used to describe the situations for which responses were to be given, eight basic factors were selected for inclusion in the experiment. Five of these factors (enemy tank speed, turret position, and fire history, and observer tank fire history and cover) were represented at two value levels. Three of the factors (enemy tank aspect dynamics, cover dynamics, and range) were represented at four value levels. The resulting experimental design was a 2^{11} design. Each factor and their respective treatment levels are defined in Table II. The assumptions concerning factors not specifically included as independent variables in the model are given in Table I. Four dependent variables, which were measured by subject responses to the following questions, were considered:

Q1. Is the enemy tank crew currently detecting your tank?

Q2. What is your percent chance of hitting the target?

Q3. Would you fire on the enemy tank at this time?

Q4. What is the enemy tank's percent chance of hitting your tank, given that he fires at your tank?

For purposes of model structure and analysis, each of the dependent variables in conjunction with the eleven independent variables, constitute a separate experimental design model.

The experiment was conducted in an environment in which experienced tank commanders were shown sequences of color slides depicting enemy tank activities over a time period of from ten to thirty seconds for each sequence. The subjects gave written responses to the dependent variables defined above based on the viewed sequence and verbal input information on fire histories, enemy turret position, and observer cover.

TABLE I: ASSUMPTIONS CONCERNING FACTORS NOT SPECIFICALLY INCLUDED AS INDEPENDENT VARIABLES IN THE MODEL

Variable	Assumptions
Force Size	Situations considered are limited to the case of one observer tank versus one enemy tank
Observer Speed	The observer's tank is always stationary
Observer Aspect	The observer's tank is always headed in the direction of attack (i.e., the principal observation direction)
Vehicle and Weapon Type	Both the observer's tank and the enemy tank are standard M-60 tanks for which only the conventional tank main gun is considered
Ammunition	Both the observer's tank and the enemy tank have available only high explosive (HEAT) ammunition and have a sufficient supply of HEAT rounds
General Battle Situation	The observer's tank is part of the attacking force; the enemy tank is part of a delaying force.

TABLE II: INDEPENDENT VARIABLES IN THE MODEL

Variable Designation	Treatment Level	Description
A	---	Enemy tank's change in direction of travel from initial direction relative to the observer-to-enemy tank range.
A	Low	Incoming or no change.
A	High	Outgoing.
B	---	Enemy tank's change in direction of travel from initial direction relative to the line describing the observer's principal observation direction.
B	Low	Incoming or no change.
B	High	Outgoing.
C	---	Portion of the enemy tank covered at the decision point.
C	Low	Completely uncovered.
C	High	Hull defilade (only the enemy tank turret is visible to the observer.

TABLE II. --- Continued

Variable Designation	Treatment Level	Description
D	---	Change in cover of the enemy tank from the initial position to the final position.
D	Low	No change.
D	High	Change (either uncovered to hull defilade or visa-versa.
E	---	Range to enemy tank at the decision point (lower levels).
E	Low	500 meters.
E	High	1500 meters.
F	---	Change in range from the defined level of E.
F	Low	No change from the level of E.
F	High	Increment level of E by + 2000 meters.
G	---	Enemy tank speed (assumed constant over the presented activity sequence duration).
G	Low	Slow (5 miles/hour).
G	High	Fast (20 miles/hour).
H	---	Enemy tank turret position (assumed constant over the presented activity sequence duration).
H	Low	Turret <u>is</u> <u>not</u> pointed at observer's position.
H	High	Turret <u>is</u> pointed at observer's position.
J	---	Fire history of the observer during the sequence of enemy tank activities.
J	Low	Observer does not fire during the sequence.
J	High	Observer fires one round during sequence.
K	---	Fire history of the enemy tank during the sequence.
K	Low	Enemy tank does not fire during the sequence.
K	High	Enemy tank fires one round during the sequence.
L	---	Observer's cover relative to the enemy tank (assumed constant over the duration of the presented activity sequence).
L	Low	Observer uncovered relative to the enemy tank.
L	High	Observer is in hull defilade relative to the enemy tank.

After investigating various design configurations, a fractional factorial scheme was selected. A full factorial scheme for a 2^{11} design would require 2048 observations for one replication. Because of physical limitations on resources, it was determined that 128 unique sequences of enemy tank activities would be presented, and that 32 experienced tank commanders would be utilized as subjects. The total experiment was divided into eight experimental sessions (runs). Within each run, sixteen sequences of enemy tank activities were presented to four subjects. Each subject responded to two of the dependent variable questions for each run.

The design employed was a 1/16 replicate of a 2^{11} factorial scheme requiring 2^7 (128) observations per replication. An additional feature of the design was that two full replications of the fractional scheme were obtained, since responses to each presented sequence were obtained from two subjects for each dependent variable.

The fractional experimental design consisted of sixteen blocks of eight units each, since a specified pair of subjects responded to alternating treatment combinations for a particular dependent variable question. A completely randomized design of a 1/16 fractional replicate of a 2^{11} factorial experiment would have 128 orthogonal contrasts (including the mean), provided the arrangement of treatment combinations is properly constructed. Fifteen defining contrasts (factorial effects) required to produce the 1/16 fractional replicate were selected to assure that all main effects and two-factor interactions were aliased only with third order and higher interactions. In addition, fifteen contrasts were utilized to block the design and therefore were completely confounded with the block effects. Thus, there were 112 contrasts which remained orthogonal to the blocks.

The model on which the analysis is based is given by

$$Y_{ijkl} = M + F_i + S_j + G_{k(j)} + R_{l(kj)} + \epsilon_{(ijkl)} \qquad (4)$$

where

M = the experimental mean.

F_i = factorial effects (orthogonal contrasts) not confounded in block ($i = 1, \ldots, 112$).

S_j = session effects ($j = 1, \ldots, 8$).

$G_{k(j)}$ = group effect nested in session ($k = 1, 2$).

$R_{l(kj)}$ = replication (or subject-within-group) effect nested in groups and sessions ($l = 1, 2$).

$\epsilon_{(ijkl)}$ = residual error.

Note that the combination of the session and group effects make up the block effect as described above.

The analysis of concern in this paper is related to tests of significance of the difference between treatment effects. That is, comparisons of treatment means as opposed to treatment variances are of primary interest. Davies (1960) states that the F-test in an analysis of variance is really an extension of the t-test for the comparison of treatment means, and that such a test is not very sensitive to departures from normality.

The responses to Q2 and Q4 previously described are subjective probabilities. These data were transformed prior to analyzing the factorial effects in order to make the mean and standard deviation of the transformed variate approximately independent.[1] The transformation used on the original data for Q2 and Q4 is given by

$$x(\text{radians}) = \arcsin \sqrt{p} \qquad (5)$$

where

p = original subjective probability response.

x = value of the transformed variate.

The transformation of (5) also tends to result in the observations being distributed more normally.

The responses to Q1 and Q3 are in the form of Bernoulli trials in that they are yes-no responses. The data was coded using +1 for a "yes" response and 0 for a "no" response. This scale was selected for convenience, since the mean value difference analysis is not affected by the choice of scale.[2]

The sum of squares for the analysis of variance utilizing the model given by (4) is presented in Table III. Note that the session and group effects given in (4) are combined as the block effect in Table III.

TABLE III: ANOVA RESULTS FOR ALL QUESTIONS

Source	Question (Sum of Squares) Q1	Q2	Q3	Q4
Mean (1df)	81.000	190.090	165.770	122.350
Factors (112df)	27.125	22.947	21.250	20.430
Block (15df)	11.875	3.526	4.984	5.989
Subject (16df)	6.125	6.140	3.250	6.284
Residual (112df)	17.875	6.626	10.750	8.596
Total (256df)	144.000	229.330	206.004	63.650

[1] See Davies (1960), Bartlett (1947), and Curtis (1943).

[2] Extensive data is required for statistical tests on variance for non-numerical data, since departures from normality are critical. For mean value differential analysis, however, the quantification scheme is not critical (Fisher (1944)).

Note that the largest block effect occurs for Q1, with the block effect for Q2, Q3, and Q4 being from one-half to one-third that for Q1. The subject-within-group effect is about one-half of that amount for Q3. In general, it is obvious that the differences between individual subjects, as well as the difference between subject pairs (blocks) are both very significant. This fact indicates that, even though the subjects were all Army officers with previous experience as tank commanders, a rather large variation due to such factors as training and currency of experience existed between these officers.

A complete analysis of variance was conducted for the 112 orthogonal contrasts for each question. Only those contrasts which contributed most significantly to the total factor sum of squares will be discussed in this paper. The analysis of the mean value differentials for a particular contrast provide information regarding response variation resulting from various "high" and "low" value levels of the contrast. This analysis is valid, even though the factorial effect total for that contrast may be attributable to a combination of the contrast <u>and</u> its aliases. Also, the mean value differentials may be analyzed for those contrasts which are confounded with blocks, even though the significance of the factorial effect total is attributable to a combination of the contrast and the block effect.

In order to demonstrate the mean value differential analysis procedures, the contrasts FJ and CFJ (both of which are highly significant factorial effects for Q1) will be discussed. The mean value differentials for the contrasts FJ and CFJ are given in Tables IV and V, respectively.

TABLE IV: ANALYSIS OF THE <u>FJ</u> INTERACTION FOR Q1

Treatment Levels	Mean Value	Differential
(1)	0.4375	-0.1250
f	0.6719	0.1094
j	0.0731	0.1406
fj	0.4375	-0.1250

The experimental mean, M , for Q1 over all treatment levels was 0.5625. The mean value for (1) in Table IV of 0.4375 represents the average of the observations for which factors F and J are at their low levels, but averaged over all treatment levels of the other nine factors. The differential, -0.1250, is the experimental mean minus the treatment level mean. To illustrate, recall that the low levels of F and J represent the near ranges (500 and 1500 meters) and that <u>no</u> observer firing occurred during the sequence. Note from Table IV that a differential value of +0.1406 resulted when the observer did fire during the sequence (given by j). This result indicates that the average observer felt he would be detected about 26 percent of the time more often if he had fired in the immediate past.

To gain further insights into these results, consider Table V in which enemy tank cover at the decision point (termination of the presented sequence) is introduced. Note that the differential of +0.1406 for observer firing at the near ranges (see Table IV) is the average of the differentials for j and cj in Table V. The value of +0.1563 for the enemy tank in hull defilade at the decision point (and for observer firing at the near ranges) indicates that the average observer felt his chances of being detected were greater if the enemy tank was in hull defilade than if it was uncovered.

TABLE V: ANALYSIS OF THE CFJ INTERACTION FOR Q1

Treatment Levels	Mean Value	Differential
(1)	0.5625	0.0000
c	0.3125	-0.2500
f	0.5313	-0.3130
cf	0.8125	0.2500
j	0.6875	0.1250
cj	0.7188	0.1563
fj	0.4375	-0.1250
cfj	0.4375	-0.1250

The situation given above was presented to illustrate the insights which may be gained by mean value differential analysis of experimental data. It is important to note that if further insights into the near range, observer fire history, enemy cover situation is desired, additional factors may be sequentially introduced for analysis. Each newly introduced factor will yield additional differential values indicating the effect of the new factor on the situation being investigated.

Obviously space does not permit an exhaustive analysis of all possible situations in this paper. The conclusions of the analyses of the mean value differentials for each question are summarized below.[1]

Question 1: Is the enemy tank crew currently detecting your tank?

a. The direction of heading of the enemy tank interacts primarily with range, and secondarily with enemy tank cover in the subjects' feeling of being detected.

b. The cover, and change in cover of the enemy tank interacts primarily with range. In particular, the subjects felt more vulnerable to detection by enemy tanks which were initially uncovered at the near ranges, but to those which were in hull defilade at the decision point for the far ranges.

[1]Extensive tables of mean value differentials are available from the author.

c. The effect of range was not significant apart from its interaction with other effects.

d. Enemy tank speed was only moderately important, and then primarily in conjunction with enemy tank cover.

e. Enemy tank turret position was not found to be important.

f. Observer firing during the sequence interacted primarily with range level. In particular, it increased the subjects' feeling of being detected at the near range, but decreased for the far ranges.

g. Target firing during the sequence, as well as observer cover was not significant.

<u>Question 2</u>: What is your percent chance of hitting the target?

a. The subjective hit probabilities were slightly higher for an incoming enemy tank. The direction of heading, however, is of primary importance as it interacts with range.

b. Consideration of cover alone revealed that the <u>initial</u> cover situation of the enemy tank was important. In particular, the estimates were higher for an enemy tank initially uncovered than for one initially in hull defilade. Also, the target's change in cover interacting with target fire history is the most significant factor. In this case, the estimates were substantially higher for the cases when the enemy tank changed cover and did not fire, or when it did not change cover and fired. The large differential here indicates that target fire history in conjunction with target cover should be considered at several treatment levels in future experimentation. This contrast is also very significant in Q4 and is discussed in a subsequent section.

c. As previously stated, range is the most important factor for Q2. It is important to note, however, that the direction of heading and cover of the enemy tank interacting with range produce the largest mean value differentials. Future experimentation should consider this interaction in depth, possibly utilizing the concept of the solid angle subtending the enemy tank relative to the observer.

d. Enemy tank speed did not prove to be a significant factor, possibly because it was verbally specified, and hence not as meaningful as if it had been visually represented.

e. The turret position of the enemy tank had no real effect in Q2.

f. As previously stated, observer fire history did not, in general, increase the subjective probability of hit. Once again, the fact that fire histories were specified verbally instead of visually may have contributed to this result.

g. Target fire history was very important in its interaction with target cover changes, and to a lesser extent with observer fire history.

h. The observer's cover situation had no appreciable significance in the results.

<u>Question 3</u>: Would you fire on the enemy tank at this time?

a. The direction of heading of the enemy tank interacts with range, enemy tank cover, and speed. The subjects would tend to fire more at incoming, initially uncovered tanks at the near ranges. Also, the tendency was to fire more often at incoming, fast or outgoing, slow enemy tanks.

b. The cover situation, and particularly the change in cover, of the enemy tank during the sequence had a substantial effect on the subjects' decisions to fire. In general, the tendency was to fire at enemy tanks which changed cover during the sequence. The cover factor, however, is also dependent on range.

c. The range to the enemy tank had a great influence on the subjects' firing decisions. The interaction of range with observer fire history, target cover, and target speed are also important in the decisions.

d. The speed of the enemy tank was found to be significant only in its interaction with the range level. In particular, the tendency to fire was less for a fast-moving tank at the far range level than for a slow tank. At the low range levels, however, the effect of enemy tank speed was small.

e. The turret position of the enemy tank during the sequence had essentially no effect in the firing decision.

f. Observer firing during the sequence increased the tendency to fire a second round at the near range levels, but decreased this tendency at the far range levels. Also, the fact that the observer was covered and fired, in conjunction with the enemy tank not firing during the sequence, substantially increased the subjects' tendency to fire.

g. Target fire history interacts primarily with observer fire history and observer position as described in (f) above.

h. The observer's cover situation is important only as it interacts with the target's cover, range, and fire history.

<u>Question</u> 4: What is the enemy tank's percent chance of hitting your tank, given that he fires at your tank?

a. The effect of direction of heading of the enemy tank was more pronounced than for Q2. In particular, an incoming enemy tank led to higher subjective probabilities of being hit than outgoing tanks. Also, the interaction of direction of heading and target cover was significant.

b. The cover of the enemy tank was important, particularly in conjunction with range. In particular, the "being hit" estimates were higher for defiladed enemy tanks than for uncovered ones, especially at the near ranges.

c. As previously stated, range was the predominant factor in Q4. In addition to the range interaction with cover, a significant interaction with turret position of the enemy tank was noted.

d. The speed of the enemy tank was found to be important in conjunction with target fire history. In particular, a slow moving and firing enemy tank increased the subjects' subjective probabilities of being hit.

e. The turret position of the enemy tank was highly significant, both as a main effect and its interaction with range, target fire history, and target cover.

f. The observer fire history was not found to be a significant effect.

g. The target fire history was significant in its interaction with target turret position and speed.

h. The observer position did not have a significant effect in the analysis of Q4.

Regression Analysis

It has been proposed that TDI represents a measure of the "intensity" of a combat situation and is related to the tank commander's feeling of enemy threat and his destruction capability. In other words, TDI is taken to be a monotone increasing function of combat intensity. It is hypothesized that a measure of TDI is the frequency with which tank commanders would fire in a given situation.

A model describing the relationship between tank commanders' subjective probabilities of hitting, being detected, and being hit, and the associated frequency with which they would engage the enemy is valuable for several applications. First, it is useful for fire control models in land combat simulations. Second, it can be employed in the training of potential tank commanders in the area of tactical firing doctrine. Third, it can be used to evaluate engagement decisions based on field trial data as compared with sampled responses of tank commanders in the same situations.

Several multiple regression models were investigated utilizing averaged response data for various treatment combinations of the system state variables. In order to demonstrate the procedures, two quadratic response surface representations of the dependent variables given by (6) and (7) are discussed.

Model I: $$Y = \beta_0 + \beta_1 \cdot DI + \beta_2 \cdot TI + \beta_3 \cdot DI \cdot TI + \beta_4 \cdot (DI)^2 + \beta_5 (TI)^2 \quad (6)$$

Model II: $$Y = \beta_0 + \beta_1 \cdot DI + \beta_2 \cdot TI + \beta_3 \cdot DI \cdot TI + \beta_4 \cdot (DI)^{1/2} + \beta_5 \cdot (TI)^{1/2} \quad (7)$$

where

Y = average of responses to Q3 (i.e., the frequency with which observers would fire);

DI = the destruction index, given by the average of responses to Q2, the frequency with which observers felt they could hit the target;

TI = the threat index, given by the product of average responses to Q4 (the frequency of being hit) and Q1 (the frequency of being detected).

Average response data for the various treatment levels of C, D, E, F, CD, CE, CF, DE, DF, and EF were utilized for this analysis. These factors were chosen because of the significance of enemy tank cover and range in responses to the questions.

The fit obtained by Model I was slightly better (i.e., Multiple R of 0.741) than by Model II (i.e., Multiple R of 0.696). The regression coefficients for each model are given in Table VI.

TABLE VI: REGRESSION COEFFICIENTS

	β_0	β_1	β_2	β_3	β_4	β_5
Model I	-2.428	14.712	-10.911	0.0	-11.987	23.571
Model II	0.853	0.0	4.375	0.0	1.105	-3.956

The ability of the regression models to predict the frequency with which tank commanders would fire was investigated. The actual firing frequency responses were compared to the regression models' predictions over 32 treatment level combinations of average response data. The mean absolute deviation between predicted and actual responses was 0.0324 for Model I and 0.0328 for Model II. In other words, the average of the absolute deviations in the prediction of firing frequency was slightly greater than three percent for the subset of data investigated.

These results are encouraging, but by no means conclusive, in regard to the realization of a valid model for describing a tank commander's firing decision process. It is hoped that this paper will stimulate further study and analysis to gain additional insights into this very complex process.

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The Interface Between DYNTACS-X and Bonder-IUA

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The Dynamic Tactical Simulator, DYNTACS-X, and the Battalion Level Differential Model, BLDM, widely known as the Bonder-IUA model, are two models that simulate battalion level mid-intensity armored combat.

DYNTACS is an event sequenced stochastic model that simulates the interactions between an individual weapon and the environment, tactics, and other weapons in great detail. DYNTACS was written by the Systems Analysis Group at Ohio State University in 1965 and extended in 1970. The Rock Island Arsenal acquired DYNTACS in 1969 and used it to evaluate proposed mobility improvements to the M-60 tank and the Family of Scatterable Mines Concept. Currently, this model is being used to evaluate cannon launched guided projectiles and additional mobility improvements to the M-60 tank. Soon, Rock Island Arsenal will use DYNTACS to evaluate remotely piloted vehicles and the XM1 tank.

BLDM is an expected value model that uses an extension of the Lanchester method to determine the expected attrition during a short time interval, usually ten seconds. The BLDM model was developed by Dr. Seth Bonder of the University of Michigan. The Rock Island Arsenal acquired BLDM in 1972 and used it to support the MBT70 study. Since that time, BLDM has been extensively modified in order to evaluate several Anti-Armor Automatic Cannon Concepts. This version is currently being used in the Low Dispersion Automatic Cannon Study. Because of these extensive modifications, this model has been renamed The Firepower Analysis Sequenced by Time (FAST) Model.

Rock Island Arsenal intends to use both models to the fullest advantage. The detailed data for a DYNTACS scenario will be gathered and a DYNTACS run will serve as a preprocessor for FAST. Then FAST will be used to study variations in weapon system parameters in order to eliminate the less effective conceptual candidates. The weapon systems showing the highest combat effectiveness payoff will then be studied in greater detail using DYNTACS. This is a report of the modifications made to both models at Rock Island Arsenal in order to achieve the capability for using these two models in this way. A preliminary comparison of the two models is also presented.

The basic flow of logic in DYNTACS is represented by the circular flow chart in Fig. 1.

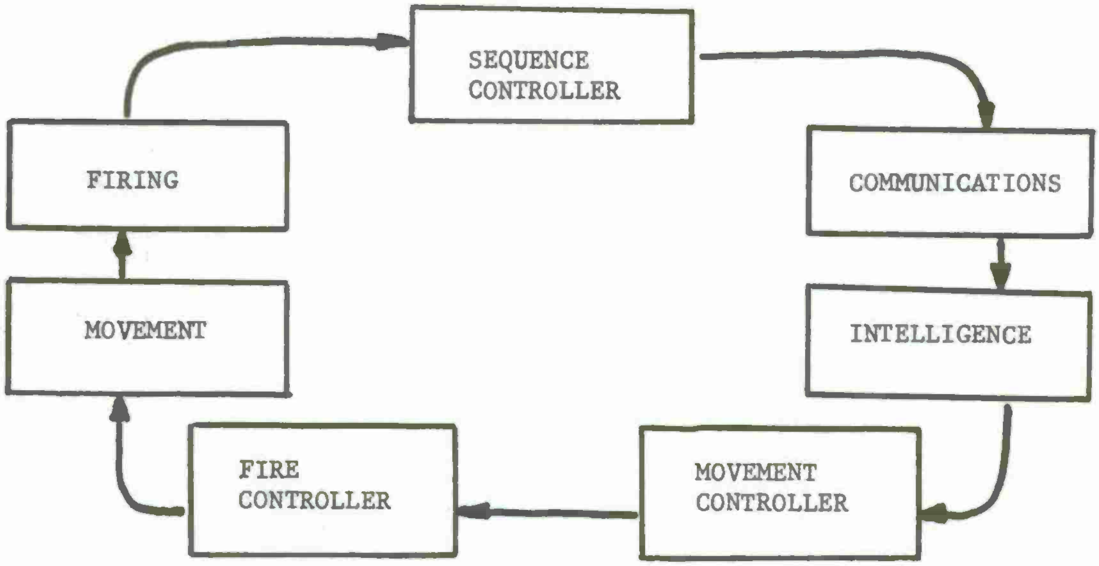

Figure 1 Basic DYNTACS Logic Flow for a Tank

Each element, be it a tank, an APC, a missile launcher, a forward observer, an artillery fire direction center, an artillery battery, a helicopter, or an air defense system, has a clock. This clock is set to the time of the next event for that element. The sequence controller selects that element with the smallest clock time and gathers basic data about that element. If the selected element is a tank, then the logic in Fig. 1 is followed. Very similar logic is followed for each of the other types of elements simulated in DYNTACS. Only the logic shown in Fig. 1 is outlined here.

In the communications routine, all messages sent to the current element are processed. These messages contain information about the battlefield. In the intelligence routines, tables of the information that the current element has on the entire battle are updated. During this process, the actual terrain is used to determine which, if any, of the enemy elements are covered. Vegetation overlays are used to determine which, if any, of the enemy elements are concealed. For each uncovered, unconcealed enemy element, a stochastic detection process is used to determine if that enemy element is actually detected.

The movement controller routines provide for dynamic formation and route selection. Only the maneuver unit leader selects formations and routes, the other elements in the maneuver unit attempt to stay in formation. In DYNTACS, the attackers are given desired routes but, while attempting to stay near these routes, are not constrained to remain on these routes. Under a variety of circumstances - start of the battle, completion of last route selection path, encountering a minefield, a new maneuver unit leader, or a significant change in the maneuver unit's knowledge of the enemy - the maneuver unit leader will select a best route to cover the next kilometer. This best route is determined by a dynamic programming algorithm to minimize travel time. Also considered are exposure time and barriers such as known minefields and forests. This dynamic route selection logic makes DYNTACS uniquely qualified to determine the effects of mines since each encounter of a minefield will cause a new route to be selected. This new route may involve a retrograde maneuver in an attempt to circumvent the minefield.

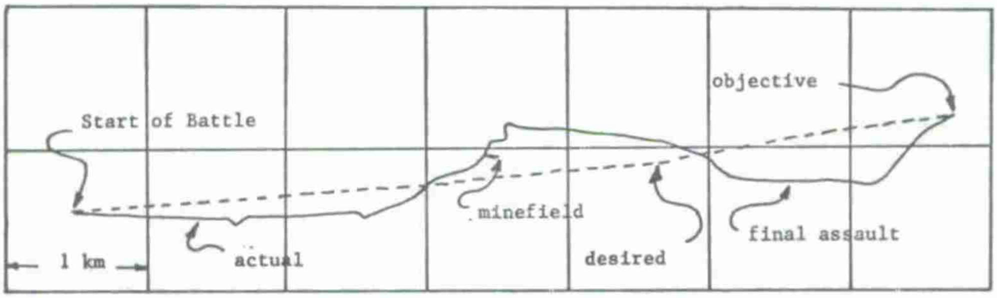

Figure 2 Desired vs Actual Route for One DYNTACS Element

Fig. 2 shows how, in DYNTACS, the actual route of an element can vary from the desired route. In this case, the element gets more than 400 meters off the desired route.

In the fire controller routines, the intelligence tables and tactical doctrine are used to select a target to fire at, the round to use, and whether to stop-to-fire or fire-on-the-move. The decisions made in the fire controller are passed to the fire routines, but movement is made first. The movement routines use standard mobility equations to determine how far the tank will move along the selected path for its next event. The interaction between the vehicle and the terrain is modeled in some detail.

The fire routines determine the time of fire, the dispersions associated with a fire, and accesses damage to the target if there is a hit. The calculations for probability of hit involve range to the target, speed of the target, portion of the target that is covered, and dispersion of the firing weapon. The calculations for the probability of the various types of kill - mobility, firepower, firepower and mobility, and total - involve the round type, the target type, range to the target, speed of the target, and the direction of the incoming round.

The clock for this tank is reset to the time of the next event and control is passed to the sequence controller, where the whole process is repeated.

The data requirements for DYNTACS are extensive and comprehensive. This data is broken into three general categories: environment, tactical, and engineering. The environment data consists of such things as a reasonably detailed continuous representation of terrain with vegetation, cover, trafficability, and obstacles. The tactical data consists of such things as organizational structure, communication channels, target priorities, dessired attack or withdrawal routes, and objectives. The engineering data consists of such things as vehicle dimensions and engine torque versus rpm curves.

Since DYNTACS is stochastic, its output depends on the random number seed used. DYNTACS battles must be replicated in order to obtain meaningful results.

In FAST, several weapon systems of the same type and in the same general location are collected into groups and each group is treated as an entity. The basic statistic for each group is the expected number of survivors in that group as a function of time. The location, velocity cover codes, and concealment codes for each group are read from a "mobility file" at each time step. This file must be generated by a model, other than FAST, that simulates the effects of terrain and the environment on motion, cover, and concealment. Until recently, all existing mobility files were generated by the terrain and mobility preprocessors for the Individual Unit Action (IUA) model, thus explaining the old title of Bonder-IUA for the FAST model.

The attrition rate for each group is computed as the sum of the attrition rates on that group by each enemy group. These latter rates are computed as a function of the number in the firing group, the percent of firepower allocated to the target group, the cover, concealment, and range between the two groups, load and lay times, and extensive dispersion and vulnerability data. After the total attrition has been computed, it is assumed to be constant over that time interval and the expected number of survivors in the group at the end of the time interval is computed. After the attrition has been computed for each group, the mobility data for the next time interval is read in and the process repeated.

Since BLDM is deterministic, one run will determine the expected number of survivors at the end of the battle and provide other meaningful results. However, there is no way to measure the statistical significance of any differences that may appear in two runs.

Both models require extensive firepower data. This data includes: firing rates (load and lay times); firing bias and dispersion as functions of the firing weapon, the range to the target, the speed of the firer, the speed of the target, various aspect angles, and the covered portion of the target; and vulnerability data in the form of probability of kill as a function of kill type, round fired, target, range to the target, speed of the target, and various aspect angles. As acquired by Rock Island Arsenal, FAST used the IUA format for firepower data. This format varied considerably from the DYNTACS format for the same type of data, and the volume of firepower data required by either model was very large. Accurate representations for firepower data were developed at Rock Island Arsenal in the form of functions with coefficients that are determined by use of regression techniques. Both DYNTACS and FAST are being modified to use these functions and the same coefficient tables. Consequently, both models will use the same firepower data in the same format. This modification will reduce the DYNTACS firepower data base to approximately one-tenth the present volume.

FAST requires a "mobility file" containing the location, velocity, cover codes, and concealment codes for every group at each ten second interval during the battle. DYNTACS selects routes and moves elements as the battle progresses. A version of DYNTACS that produces a "mobility file" in a format suitable for use by FAST was developed at Rock Island Arsenal. Four mappings are used in this preprocessor, each mapping some DYNTACS concept into its FAST equivalent. One mapping from DYNTACS into FAST takes the elements on the DYNTACS battlefield and their organization to produce the equivalent groups in FAST. The simple mapping of making each DYNTACS element be a FAST group was rejected because this negates the advantages of the group concept. In addition, there is logic in FAST that would provide unrealistic results if such a simple mapping were used. The basic idea behind the mapping used is to consider each DYNTACS maneuver unit as a FAST group.

Two other mappings used take DYNTACS cover and concealment into FAST cover and concealment codes. In DYNTACS, cover is computed as the portion of a vehicle that is covered. In FAST, cover is a code with three values representing completely exposed, hull defilade, and completely covered. The same disparity exists between DYNTACS concealed portion and FAST concealment code. The same mapping is used in both cases: a portion less than some threshold is completely exposed, a portion greater than some other threshold is completely covered or concealed, and a portion between the two thresholds is hull defilade or partially concealed. The cover thresholds and the concealment thresholds may be different.

In DYNTACS, each element has the option of fire-on-the-move or stop-to-fire. A leapfrogging effect is attained by some elements stopping to fire while other elements are moving between firing events. The mapping between DYNTACS stop-to-fire tactics and FAST leapfrogging tactics was handled by modifying FAST to simulate leapfrog tactics or stop-to-fire using the mobility data from a DYNTACS run where all the elements used fire-on-the-move tactics. This was done by modifying the attrition rate computations to reflect the fact that some of the elements in each group would be stopped.

Running both DYNTACS and FAST on the same data base compels a comparison of the two models. Fig. 3 outlines some of the differences that are due to the contrasting methodologies. The chief advantages of DYNTACS are its detailed representation of the battlefield and its dynamic route selection. The chief advantages of FAST are that no replications are needed and each run is relatively inexpensive.

DYNTACS	BLDM/Bonder/FAST
DETAILED	AGGREGATED
DYNAMIC ROUTES	FIXED ROUTES
STOCHASTIC	DETERMINISTIC
COSTLY	INEXPENSIVE

Figure 3 Differences in the Two Methodologies

In order to obtain a better feel for the comparison of the two models, the scenario used in the Family of Scatterable Mines study was used with DYNTACS to prepare the mobility file for FAST. Ten replications of DYNTACS were made using this same scenario. Fig. 4 tabulates some end-of-battle statistics for all these runs. These results indicate a reasonably good agreement since the casualties in FAST are within one-half standard error for the mean of the DYNTACS runs. The FAST casualty ratio is within 1.1 standard errors of the mean of the DYNTACS runs.

RUN #	1	2	3	4	5	6	7	8	9	10	MEAN	STD. ERROR	FAST
BLUE CAS.	13	12	11	12	13	11	11	10	12	10	11.5	.34	11.7
RED CAS.	11	20	21	10	12	8	11	13	13	18	13.7	1.40	14.2
BLUE/RED	1.18	.60	.52	1.20	1.08	1.38	1.00	.77	.92	.56	.92	.09	.82

Figure 4 End-of-Battle Statistics

Another way to compare the two models is to study the trajectory of Red Survivors vs Blue Survivors. The graphs in Fig. 5 shows the FAST trajectory and the average of the DYNTACS trajectories. The attrition ratio in FAST remains nearly a constant whereas it varies widely in DYNTACS. Fig. 6 shows the FAST trajectory and the trajectories from two DYNTACS runs. This figure demonstrates how DYNTACS can indicate the variability in the results whereas FAST/BLDM/Bonder cannot.

A greater disparity between FAST and DYNTACS appears in the survivors versus time plots. Fig. 7 shows the Red Survivors for the FAST run and the average of the ten DYNTACS runs versus time. The attrition rate for FAST is much more nearly constant than for DYNTACS. In DYNTACS, the attrition starts later but reaches a peak rate during the hottest part of the battle before leveling off as the battle comes to its conclusion. The same disparity appears in the Blue Survivors versus time plots and in the survivor plots for each of the DYNTACS runs.

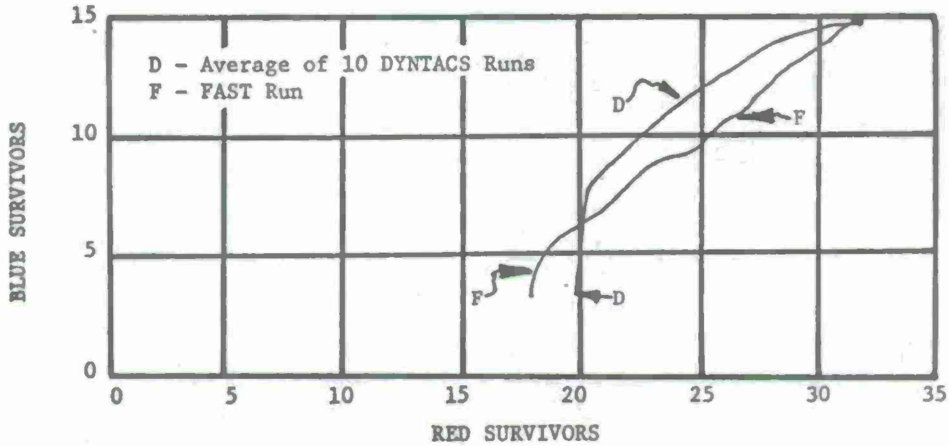

Figure 5 Average Survivor Trajectories

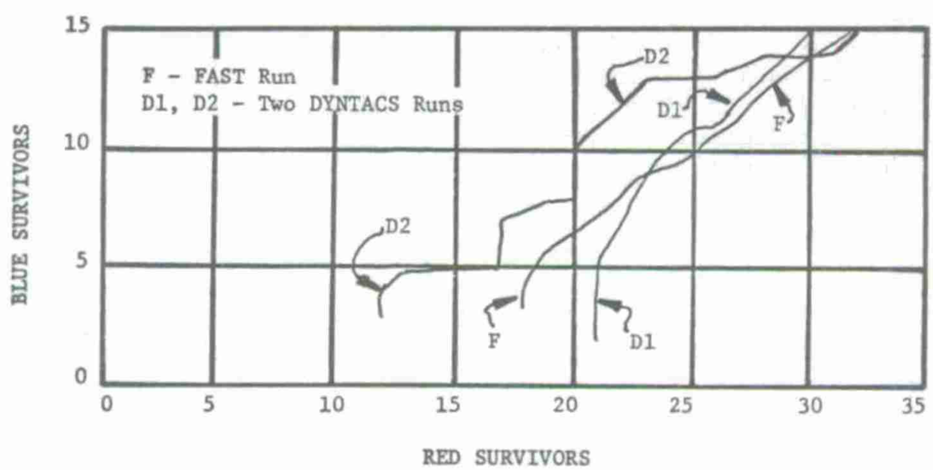

Figure 6 Specific Survivor Trajectories

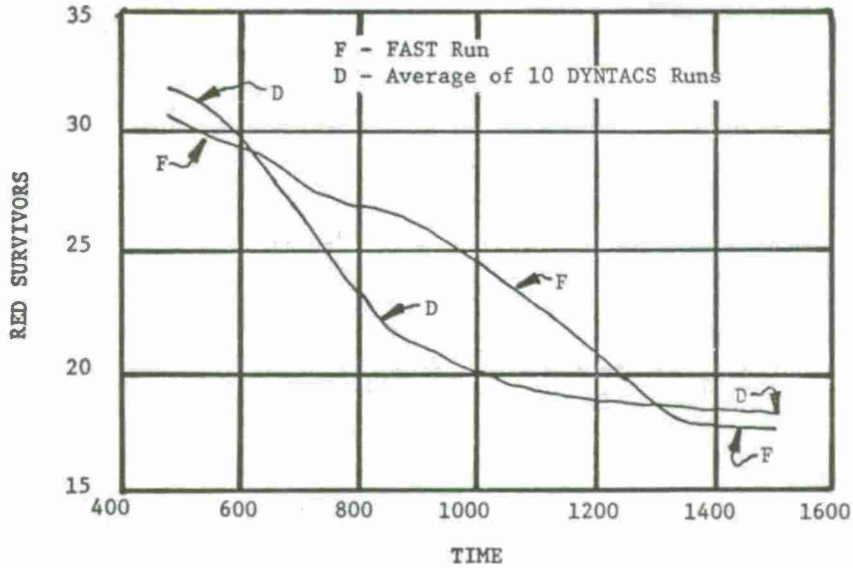

Figure 7 Red Survivors vs Time

These results compare the absolute results for one case and not, as both models are used, the relative changes due to a change in fire-power, mobility, etc. The negative aspects of these comparisons should not be construed as a rejection of either model. Additional analysis of both models is clearly indicated.

In summary, both DYNTACS and FAST have certain advantages. The chief advantages for FAST is that the model is inexpensive to run and results for certain parameter variations can be quickly obtained. The chief advantages of DYNTACS are its detailed representation of Battlefield elements, its dynamic route selection, its replications give data on the variability of the results, and it serves as a preprocessor to FAST.

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WEAPONS EFFECTIVENESS AND SUPPRESSIVE FIRE

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PURPOSE:

The purpose of this presentation is four fold:

First, to summarize previous research in the area of suppressive fire as a component of weapons effectiveness.

Second, to discuss several attempts to develop valid models which would define the relationship between weapons characteristics and effectiveness in suppression.

Third, to identify some of the contributions of suppressive fire studies to weapon systems design and procurement decisions.

Fourth, to clarify the primary issues relating to proposed research in the suppressive fire area.

The primary emphasis will be on small arms weapons systems. The phenomena of suppression is complex; all too often those who would perform research in this area have committed the error of oversimplification, failing to realize that suppression is a function of literally hundreds of different variables, of which weapons characteristics represent only a small number.

The effectiveness of any weapons systems is a function of its performance in each of the roles that it will be expected to fulfill. The primary function of weapons is to decrease the effectiveness of the enemy. This may be done by eliminating these enemy forces or by preventing them in other ways from accomplishing their objectives. Weapons may be effective by physically incapacitating the enemy or by psychologically reducing his effectiveness. Any research program to improve weapons effectiveness must, therefore, concern itself with first identifying a set of measures of effectiveness, and second, with identifying objective relationships between these effectiveness measures and weapons characteristics.

Previous studies have been consistent in identifying five major interdependent measures of effectiveness for most weapons systems:

Hit capability
Suppression capability
Lethality
Reliability
Sustainability

All are time related, and each is a function of the others. Thus, the weapon with a high single round hit probability may not have as great a hit capability in combat as a less accurate weapon which can put out a much greater volume of fire within the same time span.

In this respect, Combat Developments Command Experimentation Command (USACDEC) tests showed that soldiers equipped with 7.62mm M14 rifles consistently hit more long range targets per round of ammunition fired than did M16 firers. However, M16 firers (firing 5.56 mm rounds that weighed only half as much) scored significantly more hits at all ranges per pound of ammunition fired. M16 hits were also secured more quickly than M14 hits, which means that M16 firers would have been subjected to a shortened duration of return fire from the enemy.

The M16 firers were also able to sustain their fire effects for a longer period of time due to the lightness of the weapon and ammunition which permitted more rounds of ammunition to be carried. Within the basic weapon system weight of 17 pounds prescribed for the rifleman, the M14 soldier carries only 100 rounds as opposed to 300 for the soldier armed with the M16. If time intervals of fire were equated, and rates of fire were identical, the M16 firers would have been able to sustain their effects for three times as long as the M14 rifleman.

On the other hand, a weapon with an extremely high single round hit probability may be relatively ineffective because of low lethality or because its reliability is so low that it is unable to fire many rounds because of malfunctions. In like manner, the suppressive effects that a weapon produces may be diminished by high malfunction rates or by inability to transport the quantities of ammunition necessary for sustaining fire. The suppressive value of small arms weapons systems is also diminished when the weapon's projectiles are not perceived as being very lethal; and when projectiles are not perceived as being threatening, suppression will not be effected.

Mobility of weapons is a component of sustainability in that the amount of ammunition a soldier can carry is diminished as the weight of the weapon increases. As sustainability of a weapon is increased through increasing the ammunition load, mobility is correspondingly made more difficult and decreased.

THE NATURE OF SMALL ARMS SUPPRESSION RESEARCH

Although all of these five measures of effectiveness are components of an integrated system of effectiveness, each may be considered and examined as a subsystem. In this respect, hit probabilities, lethality, reliability and sustainability have been the subject of far more detailed research than suppression. This is attributed to the fact that each of the first four is more easily studied quantitatively from the point of view of the physical sciences.

For example, rifle hit probabilities may be physically measured in terms of hits on targets as a function of specific measurable ranges and number of rounds fired, while reliability is basically a matter of compiling numbers, types and causes of malfunctions over a period of the weapon life cycle. Sustainability of a weapon system may be studied as a function of rates of fire, basic loads of ammunition, logistics and similar numerical factors. Lethality is a more complex measure but extensive data have been made available from gelatin block experiments, penetration studies, animal studies, and studies of human wounds in combat to include extensive medically based classification schema.

On the other hand, suppression deals with numerous psychological factors. There is, of course, "permanent suppression" from physical factors -- the soldier who is severely wounded or killed becomes "permanently suppressed" -- but studies in this area fall under the "hit capability" and "lethality" categories previously mentioned. Psychological suppression from small arms fire is a more complex phenomenon. Unlike hit capability and other effectiveness measures, suppression or its causes cannot be measured directly in most cases. Since phenomena within the human mind are of concern, casualty must sometimes be inferred or indirectly established.

Furthermore, it is not possible to study suppression primarily as a system of discrete numbers. In researching hit capability (to include hit probabilities), a target is either hit or it is not. When considering lethality, the reaction of a gelatin block to the penetration of the bullet may be recorded and measured by high speed photography. But such finite physical measurements are usually not possible when one examines suppression.

A period of slightly reduced effectiveness which lasts only several seconds may constitute suppression in one instance while in another case suppression may consist of an immobilizing terror and shock that results in a prolonged total incapacitation requiring psychiatric treatment. Furthermore, the reaction in the same soldier to the same stimuli and cues may be vastly different from one time to the next. Suppression is also influenced by a much greater variety of extraneous factors than the other measures of small arms effectiveness. Training, leadership, morale - even religious beliefs - are only a few of the many factors that determine the degree of suppression that may be effected on any one individual at any given time. Suppression, therefore, become the most complex component of weapon systems combat effectiveness studies.

DEFINITION OF SUPPRESSION

Most previous suppression research has been concerned only with suppression by small arms fire. On the other hand, small arms fire is usually only one of many types of weapons fire contributing to suppression at any given time. Even in the final stages of an assault when only small arms are being used, the suppression that occurs may be, in reality, only a continuation of the suppression <u>effects</u> that occurred as a result of heavy preparatory tank, mortar, and/or artillery fire. Although there are many and varied definitions, suppression is operationally defined here as:

> "A state of relative ineffectiveness or incapacitation of the individual soldier which is a function of psychological factors, and which is either initiated or maintained by a perceived threat from weapons fire."

Within a psychological framework and in the language of the psychologist, suppression is defined as:

> "The resolution of an approach-avoidance conflict in an individual by taking the avoidance response."

DIMENSIONS OF SUPPRESSION

Previous research studies indicate that there are five primary dimensions of suppression and that it is important to understand these dimensions prior to conducting any investigation of suppression for the weapons characteristics most desirable in one case may not be applicable in another. These five dimensions are:

- Reasoned (Rational) Suppression versus Unreasoned (Irrational) Suppression.

In reasoned suppression the soldier rationally analyzes the situation and mentally calculates the probabilities for mission success and survival. The soldier who keeps his head down and cooly waits until the enemy has exhausted much of his ammunition before resuming the assault has had his effectiveness temporarily reduced and, therefore, has been suppressed. This constitutes reasoned suppression. On the other hand, the soldier who reacts out of panic or psychological fear without consciously thinking or considering the real nature of the threat or long term effects is reacting without reason, which constitutes unreasoned (irrational) suppression.

- Area Suppression versus Point Suppression.

The suppression resulting from mortar fire or from the classic distribution of machine gun fire between two reference points is an example of area suppression. The soldier who has been suppressed as an individual by sniper fire or by an enemy machinegun specifically aimed at his location has been incapacitated by point suppression. The weapon which is best for area suppression may be relatively unsatisfactory in a point suppression role.

- Defensive Suppression versus Offensive Suppression.

Some of the weapons characteristics which make the greatest contributions to effectiveness of suppression in offensive situations may be different from those most desired in the average defensive engagement. One study, for example, indicates that the infantry weapon with the greatest suppressive effect against assaulting enemy troops is the machinegun, whereas the weapon providing the greatest suppression against emplaced defending enemy troops is the mortar. The recoilless rifle is perceived as more effective than the automatic rifle against defending troops whereas the reverse is true against assaulting troops.

- Lethal Suppression versus Denial Suppression.

Suppressive fires may be used against an area or positions that the enemy is known to occupy. In these instances, the objective is to neutralize the enemy by preventing him from moving or using his weapons or by killing him if he attempts to. This is known as lethal suppression, whether the "suppression" occurs by physically killing and disabling the enemy, or whether it occurs as a result of a psychological fear which causes the enemy to remain immobile and not use his weapons. Denial suppression is used against areas unoccupied by the enemy and is used to deny them access to that area or position. Continuous bursts of machinegun fire fired down a stretch of road or across the entrance to a bridge are examples of denial suppression. The same psychological factors that prevent a soldier from sticking his head out of his foxhole to fire his weapon also keep him from venturing up the slope of a hill through interlocking machinegun fires or exploding grenades.

- Direct Fire Suppression versus Indirect Fire Suppression.

This dimension, of course, is a classic one. In the case of small arms, grenade launchers and hand grenades are considered to be the only effective weapons for use in the indirect role while rifles, automatic rifles, machineguns and grenade launchers may all be used for direct fire.

DEGREES OF SUPPRESSION

As already discussed briefly, suppression is a state which may last for only a few seconds or it may "permanently" incapacitate a soldier just as effectively as a bullet, to the extent that the soldier must be evacuated for psychiatric care. S. L. A. Marshall's description of suppressed American soldiers on Omaha Beach on the afternoon of D-Day, June 6, 1944, is an excellent example of the latter:

> "They lay there motionless and staring into space. They were so thoroughly shocked that they had no consciousness of what went on. Many had forgotten they had firearms to use. Others who had lost their firearms didn't seem to know that there were weapons lying all around them. Some could not hold a weapon after it was forced into their hands...Their nerves were spent and nothing could be done about them."

At the other end of the continuum would be a hypothetical soldier who is not subject to suppression, who does not duck or in any way adjust his actions as a result of being suddenly brought under fire, and, who, because of his foolishness, dies! The majority of historical instances of suppression lie somewhere between these two extremes.

Many researchers in the past, particularly those who have not experienced infantry combat or who have based their studies solely on after-action interviews, have been unsuccessful because they did not understand the desired objective of suppressive fire or its full psychological implications. The objective of suppressive fires is <u>not</u> just to neutralize or incapacitate the enemy during the time he is being subjected to suppressive fire. Effective suppressive fire (of the "Lethal Suppression" type) is such that the enemy remains incapacitated for a period of time after the fires are lifted. This period of psychological shock should ideally be of sufficient duration to permit friendly forces to fully exploit their advantage, e.g., move onto the enemy position in an assault and capture or kill the stunned enemy in their emplacements without receiving return fire. The length of this post-suppressive fire incapacitation will vary from a few seconds to minutes to hours depending upon many factors, some of which will be discussed later.

It is extremely difficult to collect valid data on these post-suppressive fire investigations through the use of interviews and questionnaire techniques. In most cases there is no stigma attached to having been pinned down or suppressed in a fire fight. In fact, every infantryman who has served in combat for any length of time has been "suppressed" many times. But for a soldier to admit post-suppressive fire incapacitation (that he did not fire his weapon or that he remained temporarily in a state of shock in the bottom of his foxhole after enemy fire was lifted) is something entirely different, for the label and social stigma of cowardice is attached to such conduct. The most feasible approaches for collecting information in this area are interviews where the responder is asked to describe the conduct and actions of his fellow unit members, or when anonymous questionnaires are used in a group setting.

Point Suppressive Fire may also be quite effective. Military history is replete with examples of lone snipers who were able to quite effectively suppress or delay the advance of entire units.

The degree of suppression inflicted upon a unit may be measured in two categories. The first involves the degree of incapacitation suffered by individuals, whereas the second involves the total number of personnel affected within the unit. Theoretically, the same loss of unit effectiveness might result from all unit members being slightly incapacitated, as from a fraction of the members being severely affected.

Suppression, therefore, occurs on a continuum ranging from incapacitation requiring evacuation to no incapacitation at all. It may seriously affect only several members of a unit at any given time, while at other times all members of the unit may be pinned down simultaneously.

FACTORS AFFECTING SUPPRESSION

Although most research projects are primarily concerned with determining objective relationships between weapon systems fire characteristics and effectiveness in suppressive fire, we cannot ignore all of the other factors that contribute to suppression in any given situation. We have already discussed the five primary dimensions of suppression and emphasized that those factors which most influence suppression in one situation may have relatively little effect in another.

Litton's Defense Sciences Laboratories, during the course of extensive work in the small arms area, has obtained and researched more than 1200 documents and combat films which initial research indicated were related to suppression. As a result, much of the background research work required to effectively initiate a detailed study of suppression has already been accomplished, and many of the hypothesized factors and weapons characteristics related to suppression have already been identified. In addition, literally thousands of combat veterans (Viet Cong, NVA, Australian, Korean, South Vietnamese and U.S.) have been interviewed in depth and administered questionnaires relating to suppression. Field tests have also been conducted.

These research efforts and analyses of previous research reports, after action reports, combat films, questionnaire results, and other related material, have identified literally hundreds of factors affecting suppression. Some make substantial contributions while the effects of others are negligible in most situations. Many are specific subsets of a larger more general factor. A sample of some of these factors that have been identified are listed below. Weapons fire characteristics (often overlapping) are listed first, followed by a short list of other factors which interact to determine the degree of suppression.

SAMPLE OF WEAPONS FIRE CHARACTERISTICS

Volume of fire per unit time
Cyclic rate per burst
Acoustic signature (volume)
Acoustic tone
Accuracy of fire
Perceived lethality of projectiles
Distance of passing or impacting projectiles from the soldier
Manner of distribution of fire
Coordination of fire with suppressive fire from other types of weapons
Weapon's basic load
Visual cues
Uniqueness of sound (e.g., ability of enemy to consistently identify the sound with a particular weapon)
Actual lethality of projectiles
Signature cues at the weapon (e.g., muzzle blast)
Inflight visibility of projectiles (e.g., tracer)
Impact signature (e.g., debris or dust thrown up by impacting rounds)
Time to reload
Reliability

SAMPLE OF OTHER FACTORS

Experience under fire
Leadership of the unit
Fatigue
Availability of cover and concealment
Religious beliefs
Mission type
Distance from enemy
Proximity of soldier to automatic weapon (those close to friendly machineguns fire more and are suppressed less)

Reaction time of target
Previous training
Weather
Availability of routes of withdrawal
Time remaining before rotation
Time of day (night)
Morale
Number of casualties being received by unit while under fire
Proximity to unit leader
Ability to see and be seen by other soldiers
Firer/target density

These factors represent only a sample of the total possible factors influencing the initiation, maintenance and post-suppression fire effects of suppression.

ATTEMPTS TO MODEL SUPPRESSION
Work by Kinney, Swann, and others at the Naval Weapons Center at China Lake, California, represents one approach to the modelling of suppresion. Their work has been primarily in the area of fragmentation weapons used by aircraft to suppress infantrymen. They have developed an analytic model for computing suppression effects which uses existing warhead lethality or P_K descriptions. The model has been used for computing quantitative estimates of the suppression capability of the AH-IJ helicopter weapon system. However, these quantitative estimates have no real meaning except in conjunction with comparisons of similar estimates from other weapons systems. One may also not be willing to accept some of their definitions or assumptions. Their model, for example, is based upon the assumption that the higher the lethality of a weapon, the longer it will take to recover from suppression by that weapon. Yet we know of no evidence in the literature to support this. In fact we hypothesize, for example, that the frequency and number of low lethality weapons rounds may be such that longer periods of suppression will result than for fewer rounds of greater lethality. This study does not consider the weight of rounds, which, of course, may be interjected later.

The significance of projected size and weight warrants mention at this time. If we are not careful to consider weight and size we fall into the trap of concluding that because the ammunition of weapons system A is more suppressive than the ammunition of weapons system B, then system A must also be more suppressive than system B! This, of course, is not true. For example, the M14 round makes more noise passing overhead than the M16. It yields a considerably larger visual signature upon impact and under some circumstances is more lethal. According to all rational criteria it may be considered at least as suppressive a round as the M16. But, we have to consider, as mentioned earlier, that the M16 round weighs only half as much as the M14 round, and because of lighter weapon weight, 300 M16 rounds can be carried within the 17 pound M16 weapons system load - as opposed to only 100 M14 rounds within the 17 pound M14 basic weapon system load. Furthermore, most soldiers perceive that if they are hit in the head with an M16 bullet they are going to be just as dead as if hit by an M14.

It is obvious then that the M16, which can put out 3 times as many rounds per unit of time per basic load as the M14, is considerably more suppressive than the M14. In fact, since the hit probabilities and P_K values (at expected ranges of engagement) of the two weapons were not far apart, the suppressive superiority of the M16 over the M14 was one of the primary reasons it was adopted. In like manner, it makes no sense to say that 40mm grenade launcher are better suppressive fire weapons than M16 rifles. Quite the contrary, many feel that 20 M16 rounds spaced out over, say a 1 minute time period, will have far greater suppressive effect during that minute than one 40mm grenade which weighs the same as 20 M16 rounds.

The models presented in the China Lake study are applicable only to weapons with high-explosive fragmenting warheads. Weapons or projectiles with non-explosive warheads such as rifles, and weapons with fuel-air explosive and flame warheads cannot be analyzed with these models. The study itself, points out that there is still much that needs to be done. For example, major modeling concepts and input parameters have not been validated, and the model does not provide for anticipatory suppressive behavior which, of course, is one of the primary reasons for attempting to effect suppression.

As mentioned earlier, Litton's Defense Sciences Laboratory conducted extensive literature surveys, interviews, and questionnaire administration and conducted five field experiments in an attempt to quantify relationships between small arms characteristics and suppression. The principle findings of this research in which hundreds of variables were considered were, first, that the major factors producing suppression were loudness of passing rounds, the proximity and number of passing rounds and the signatures associated with rounds impacting. Within the limits of the distances employed in the study, suppression was shown to decrease in a linear fashion with increasing lateral miss distances of incoming projectiles. Within the limits of number of rounds employed in this study, suppression was shown to increase linearly with increase in volume of fire. Within the limits of the projectiles employed, suppression was shown to increase in a linear fashion with increase in the perceived loudness of passing projectiles. It was also found, as would be expected, that a combination of both auditory and visual signatures from near misses was more suppressive than auditory signature alone. Finally, a set of recommendations for design considerations to enhance the suppressive capability of small arms weapons was developed. The study also concluded that a multiple regression model can be employed to predict the degree to which a soldier would be suppressed by a given weapon under various circumstances. To predict suppression in combat, the model must include such factors as the characteristics of the weapon and situational variables, and must take into consideration the experience and psychological make up of the individual. Perceived dangerousness of projectiles was an important factor among those leading to an individuals' being suppressed. The actual P_K value of a round was not shown to be directly related to its perceived dangerousness, an assumption that other studies often make. We cannot discuss details or specific examples because this information is classified, but we can say that some of the highest lethality projectiles had the lowest suppression effects. Some of the loudest noise projectiles (40mm) also have relatively low lethality while other have high lethality. Where the impact of rounds was visible, the visual signature had more suppressive effect than the acoustic signature. The major weapon characteristics which should be entered into the model are class of weapon, projectile caliber, projectile velocity, cyclic rate of fire and the weapons dispersion. In another Litton study, this time of suppressive effects of supporting weapons, no quantitative data on suppressive effects was found. Probably the most important finding of this research was, and I quote, "The combat suppression phenomenon is too complex to be amenable to references that rely on laboratory or experimental findings...suppressive behavior is high variable." Litton, however, did develop a model (to be used in conjunction with other research) that requires expected fraction of casualties and a human factors coefficient as inputs, but recommends again that the void in quantitative data on suppressive effects should be filled by analysis of combat after-action reports that include an orientation towards suppressive behavior rather than any experimentation. A method for calculating suppression level and a probabilistic model of suppression are provided in the Litton report. The model allows for Monte Carlo runs, expected value determination, parametric studies, and sensitivity analyses.

As of this time little direct use has been made of the results of suppression research. The Litton support fire model has been used in conjunction with the Bonder Independent Unit Action Model in an evaluation of the Bushmaster. At Fort Benning suppression has been incorporated into the Army Small Arms Requirements Study Small Unit Engagement Model. A Litton model was used here and the Delphi technique was used to collect input data. One of the first real uses of suppression research data was in the Small Arms Weapons System (or SAWS) study of 1965 and 1966 which resulted in the junking of the M14 rifle and adoption of the M16. The M14 was a larger caliber rifle with higher hit probabilities per round, especially at long ranges. However, it was determined by CDEC that suppression must also be measured. The other agencies involved in SAWS did not consider suppression and all recommended that the then TOE M14 be retained. CDEC, however, on the basis of the superior suppressive fire and sustainability characteristics of the M16 recommended it be adopted and the M14 discontinued. DA reviewed all of the SAWS reports and recommendations, accepted CDEC's, rejected the others, and the M16 became the new US Army rifle. In this case, CDEC's research consisted primarily of setting up acoustic miss distance indicators at the center of realistically deployed and camouflaged targets in six different tactical situations. Squads of troops equipped with different small arms systems attacked or defended against these operational arrays. The data was collected by computer and later incorporated into a simplistic model which gave suppressive capabilities of the weapons one-third of the total effectiveness weight. It was found in the field tests that soldiers consistently were able to put significantly more M16 rounds within given distances of the target per unit of time and per equivalent weight basic load than were M14 firers, even at longer ranges.

SUMMARY

Today, we have attempted to detail the necessity of considering suppressive fire characteristics in weapons system design and evaluation. We have summarized previous research in the area and have discussed contributions of past suppression research and have looked at attempts to model suppression.

Suppression research is a complex area of study requiring multidisciplinary talents to include primarily those of the soldier and the psychologist. A considerable body of literature relating to the subject is currently available, however, some of the most pressing questions in the area have not been answered. Indeed, some experienced suppression researchers maintain that some of these questions may be unanswerable.

TITLE: Comparison of the Effectiveness of Scout Vehicles on Reconnaissance Missions in Terms of Visibility and Mobility

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Introduction

The need for a quantitative comparison of Armored Reconnaissance Scout Vehicle (ARSV) candidates on the basis of effectiveness on missions was identified early in the ARSV Program.[1] A reconnaissance mission involves an interplay of tactics, vehicle characteristics, and terrain characteristics. The effectiveness of an ARSV in performing a mission is, in addition to many other important factors such as vehicle noise control and armament, a function of the extent of terrain covered and the time required.

The objectives of a study conducted by the U. S. Army Engineer Waterways Experiment Station (WES) were to develop procedures for determining the relative effectiveness of ARSV candidates on reconnaissance missions in terms of terrain coverage and vehicle mobility, and to use those procedures to compare the performance of five ARSV's in temperate-zone terrain.

Approach

Zone reconnaissance missions[2] were computer simulated on five temperate-zone sites by each of the following ARSV's: M113A1, M114A1, and M551 (in present inventory), and XM800W and XM00T (new designs). Three sites are near Stuttgart, West Germany, and the other two on the Fort Knox, Kentucky, reservation. The number of simulated missions on the five sites are tabulated below.

Terrain	Site	Number of Simulated Missions
Federal Republic of Germany	FRG1	48
Bavarian Plateau	FRG2	50
	FRG3	51
Fort Knox	FK1	31
	FK2	31

All missions were run under wet-season conditions, which require maximum use of a vehicle's mobility capabilities. Each mission on the FRG sites involved approximately 10-km penetration of the site forward of the starting point for that mission; the penetration on the FK missions was approximately 6 km. Two vehicles of the same type advancing by successive bounds[3] took part in each mission. The objective of each mission was the attainment of several vantage positions from which scouts could cover possible enemy force staging or concealed movement areas. Vantage positions for each site and paths between vantage positions were chosen by WES personnel in consultation with U. S. Armor School scouts.

The extent of site coverage for each mission was calculated with the WES Terrain Visibility Model,[4,5] which has been used successfully in prior studies. The time for each vehicle to accomplish each mission was calculated with the U. S. Army Materiel Command Ground Mobility Model (AMC-71),[6] developed jointly by WES and the U. S. Army Tank-Automotive Command. These models reflect the state-of-the-art in visibility and mobility analyses, respectively.

Detailed descriptions and discussions of scout tactics, vehicle characteristics, and site data are not given in this paper, since such information is available elsewhere.[2,3,6-11]

General Description of Sites

The three FRG sites are in and contain all the important features of the Bavarian Plateau, which covers most of southern Germany. Approximately 70 percent of the lands within the sites are used for agriculture. The lowlands and gentle slopes are used primarily for pasture or small grain crops. Vineyards are common on the steeper slopes, along with managed and unmanaged mixed deciduous and coniferous forests. Forests occupy all very steep slopes and areas with difficult accessibility. All three sites contain small urban centers, the largest of which is approximately 1.5 sq km in area.

Sites FK1 and FK2 are northeast of the main Fort Knox post area in the Salt River Valley, and southeast of the main post area in rolling upland, respectively. Site FK1 is poorly drained, low-lying, and relatively flat, and has many steep-sloped gullies. It is covered with a heavy, almost totally deciduous, unmanaged forest growth with very few open areas. Site FK2 is well drained and has many very steep sloped ridges and narrow gullies, with soft soils between ridges which hinder vehicle motion. The site is bounded by all-weather roads and contains several major vehicle trails. The almost totally deciduous vegetation is unmanaged and particularly heavy on slopes. Neither Fort Knox site contains any urban centers or cultural features.

Preliminary Selection of Missions

Five scouts engaged in teaching assignments at the U. S. Armor School, with many years' combat experience, a knowledge of the FRG terrain, an intimate knowledge of the Fort Knox area, and combat experience with several types of vehicles used for scouting missions, provided the expertise for selection of ARSV missions on the sites.

The scouts were given 1:50,000-scale topographic maps of seven sites and the surrounding regions. It was understood that this would normally constitute the sole source of terrain intelligence available to them prior to engaging in a mission. Five of the seven sites were those used in this study. Each of the sites was outlined on the maps, together with entrance and egress positions, which the reconnaissance teams were instructed to use entering and leaving the sites, respectively. The scouts were told that they were to perform a zone reconnaissance mission on each of the sites with two identical vehicles moving by successive bounds, and to reconnoiter for enemy vehicles or moderate-sized (company or larger) infantry forces in daylight. The scouts were instructed to pick vantage positions--positions they would seek from which to overview the terrain--and possible paths between the vantage positions. Each scout independently studied each of the seven sites and picked vantage positions and missions paths between them on each site.

Several noteworthy assumptions were made by the scouts in selecting the missions, as discussed in the following paragraphs.

In general, scouts are given short notice of an impending mission; lead time is typically minutes to an hour. The type and limits of the impending mission are defined, and the lead time is used to study topographic maps, arm and supply, and move into position. Topographic maps (1:50,000 scale) are normally available as the sole source of hard terrain intelligence. Although aerial photo coverage may be available to control elements, scouts do not normally have a chance to study and use it.

In the time available, vantage positions and proposed paths to and between those positions are noted for the impending mission. Vantage positions are chosen for a zone reconnaissance mission as those positions from which possible enemy staging areas and the general countryside can be viewed.

The detail (number of locations and extent of scrutiny) and area of coverage (area of the site viewed) on a mission depends on the time available for the mission and on whether the mission is terminated by enemy contact. Total or near total coverage of a site is usually not possible nor desirable because of both time constraints and the presence of regions that enemy forces would or could not use because of obvious tactical or physical constraints.

The scouts' primary purpose is information gathering while attempting to deny knowledge of their presence to the enemy, thereby ensuring maximum surprise in any subsequent action. Weapons are used to reconnoiter by fire, or return fire against enemy forces when necessary. To best accomplish the primary aim, cover and concealment are used whenever possible. Exposed regions are skirted, and reconnaissance patrols stay within the tree line if possible.

Mission paths skirt urban centers and are generally off-road to avoid mines and ambushes. However urban centers and roads are scrutinized.

The mission paths picked prior to the mission are tentative. Adjustments are made as the situation warrants. Linear (e.g. ditches) and areal (e.g. a marsh) obstacles encountered are avoided if possible and crossed if necessary.

The paths chosen are the same for any vehicle types used on the mission, provided the vehicle types do not have radically different mobility characteristics.

Typically, only the one person in the vehicle commander's position has any significant viewing capability while the vehicle is on the move, and that capability is often severely limited, primarily because of viewing angle and vibration. The driver's attention is fixed on the immediate scene. Upon reaching a vantage position, all possible personnel dismount to view. Typically, the vehicle is stopped short of the vantage position, and the last short distance is covered by foot while the second vehicle is moving up from the last cover position.

Selection of Vantage Positions

WES personnel selected proposed vantage positions on each of the sites in accordance with the general "rules" advocated by the scouts. All of the positions chosen were at least equivalent to those chosen by the scouts, insofar as the terrain covered from the positions was that chosen by several scouts as requiring coverage on a mission.

All WES-chosen vantage positions (hereafter called vantage positions) were subsequently adjusted (during the computer runs) in accordance with an assumption that scouts, upon reaching the proposed positions, would shift those positions slightly if necessary to achieve better visibility coverage. The procedure used for adjusting positions is described later in this paper. The adjusted positions were used in all calculations following the adjustments.

Final Selection of Missions

An assumption was made and verified with the scouts that many possible missions would be tentatively chosen on a site, each mission consisting of a set of vantage positions and paths, but the scouts would not necessarily visit all vantage positions on the site. The tentative selection of many possible different missions on a site allows the subjective selection of the mission that offers the greatest area of coverage or coverage of the most probable enemy staging or hiding areas in the allowed time. In this study, all mathematically possible combinations of vantage positions and the order in which they would be visited were calculated for each site. Not all combinations were physically significant, however, and on a first cull, only those positions were retained that had a pattern such that the scouting unit would be generally advancing from site entrance to egress while visiting them. That cull substantially reduced the mathematically possible number of combinations (e.g. from more than 2×10^6 to 255 for site FRG2). Those possible missions were then subjected to a second rigorous culling process in which each possible mission was inspected to determine whether it possessed the proper attributes of a scouting mission and whether it was reasonable with respect to other possible missions. A mission was rejected as unreasonable if the <u>only</u> difference between it and another possible mission was that the other mission contained a single vantage position more than the inspected mission, and the path of the inspected mission would pass in the immediate vicinity of that single vantage position without stopping at that position.

The missions remaining after that final cull were all deemed "missions which a scout would choose." Finally, those remaining missions were sorted into four classes, according to how probable a scout would be to choose them, from Class 1 as most probable to Class 4 as least probable, based on a second critical inspection of each mission as to how well its attributes met a scout's criteria.

Selection of Mission Paths

WES personnel also selected paths for each of the missions on each study site. The path for each mission was positioned on the topographic map for that site according to the general "rules" advocated by the scouts. Roads and urban centers were skirted, and cover and concealment were attained by remaining within tree lines. Vehicle silhouettes were hidden by staying off ridges, where possible, except in crossing. For each mission, a path was tentatively assigned that the vehicle would follow, constrained to pass through the site entrance and egress positions and the final-adjusted vantage positions for that mission. Only one path was chosen for each mission, since it was assumed that both vehicles taking part in the mission would follow the same path, and that sets of different vehicles would take the same path unless subsequent calculations showed that mobility differences between different vehicles would allow one vehicle to proceed while the other was halted.

Even though individual paths were chosen for each of the missions on each site, there were a few drastic variations in mission path locations from one mission to another on the same site. The vegetation-topography structure, in conjunction with the rules for choosing paths, highly constrained ARSV path placement, particularly on the FRG sites. It was discovered that portions of paths for several different missions (on any one site) were almost identical.

The tentative path for each mission was subsequently adjusted laterally, as described later in this paper, in accordance with the additional data available from aerial stereophotographs.

Visibility Coverage Calculations

Assumptions

Visibility is defined as the opportunity for unobstructed viewing. Target detection and recognition are not considered. The view of any one position on the terrain from a vantage position was judged possible if no terrain structure, ground or vegetation, intervened to break line-of-sight, as illustrated in fig. 1. In this study, only the terrain surface and vegetation were considered to significantly affect visibility. Rural man-made structures (e.g. stone-wall-banked terraces on FRG sites) were not considered in the calculations, since occurrences were few and the effects on visibility during a scouting mission negligible at worst. Urban man-made structures (e.g. houses) on FRG sites were ignored, since mission paths skirted them, and the view from any vantage position was down into urban areas from adjacent slopes.

In addition to calculations of visibility from vantage positions, it was assumed that scouts could see an average of 50 m to either side of their path while in motion. It was further assumed that all missions took place in daylight and that the maximum viewing range from any vantage position was 2 km. This visibility range restriction was applied since meterological conditions restrict visibility to approximately this range during a large portion of the year, particularly during the wet season, and since the scouts' vantage positions are generally chosen to cover regions within this range.

Scouts were also judged capable of viewing horizontally out of 25 m or less of vegetation and into a position 25 m or less horizontally within vegetation. That is, both scouts and the object being viewed could be within tree lines and still have line-of-sight. The "visible situation" in fig. 1 portrays a situation in which the vantage position is not in the tree line while the inspected position is. Since it was assumed that scouts were searching for moderate to large concentrations of infantry and any vehicles, an inspected point was deemed visible even if that point was up to 1 m in defilade or in grass or brush up to 1 m tall.

Visibility calculations did not include vehicle-to-vehicle differences in sighting or observation systems, as it was assumed that equivalent systems could be implemented for all vehicles.

Data collection and manipulation

Data for visibility calculations for vantage positions on each site were derived from topographic maps and aerial stereophotography of the area. The data for each site were processed in an identical fashion.

Terrain elevations were retrieved from the contour lines of the topographic maps. The distribution of elevations was transformed into a square grid on elevations at a 25-m horizontal spacing between grid positions across the site by means of a computerized interpolation procedure.

Photo interpreters retrieved vegetation elevation data from available aerial stereophoto coverage of the sites. Ground truth data gathered for prior projects were used as the basis of interpretation. The vegetation data were also digitized and placed in digital computer files with the elevation data.

Adjustment of vantage positions

As previously noted, the areas to be viewed on each site were chosen, and tentative vantage positions from which to view them were also chosen and marked on topographic maps. It was assumed that scouts would attempt to attain the local area of the preselected vantage positions and would attempt to optimize their viewing and concealment capabilities in that local area. Computer print-outs of the elevation and vegetation data were used as the basis for simulating that exercise. Specifically, vantage positions were shifted, typically less than 100 m, so as to be within tree lines (if possible) or hidden in brush or tall grass while affording a good view of the desired area. It was necessary in some cases also to perform visibility calculations and shift the vantage positions accordingly as an additional step in the process of achieving good coverage. The region viewed and the area of that region covered from a vantage position was not normally sensitive to the vantage position. The same region could normally be viewed from many alternative locations separated several hundred meters from each other.

Calculations

Visibility calculations were performed within the 2-km range about each vantage position on each site. The area of the site 50 m to both sides of the mission path was also assumed visible. The total area visible on any mission was achieved by computer overlaying the visibility calculation results for all vantage positions on that mission and the visible region along the path. A graphic presentation of visibility calculation results for all vantage positions on that mission and the visible region along the path. A graphic presentation of visibility coverage from vantage positions for one of the 50 missions on site FRG2 (3- by 10-km site) is shown in fig. 2. In calculating area coverage on a mission, a single position on the ground was considered covered on that mission if it was judged visible from the path or from any of the vantage positions visited on that mission. Any point on the site visible from more than one vantage position was counted only once in calculating visibility coverage.

Mobility Calculations

The length of time for a vehicle to perform each mission was calculated on the basis of the AMC-71 speed predictions for that vehicle. A basic assumption in this study was that missions would be conducted at maximum possible cross-country speed, or at a speed less than, but proportional to, that speed where the proportionality constant was the same for all vehicles. This assumption implies that the vehicle operator drives each different type of vehicle in the same manner. For example, if the driver proceeds at 0.8 maximum speed in one vehicle because he cannot stand the vibration at full speed, he will also drive the other vehicles at 0.8 maximum speed. All calculated mission times are based on maximum possible speeds.

Speed calculations for all vehicles were performed as a function of the terrain conditions on each site. Maps of these terrain conditions were available from prior WES studies.

Several steps were performed to reach the point where the vehicle speed data were in a form amendable for studying the mission paths and calculating times for missions. The maps containing the terrain conditions were digitized and computerized to produce a grid map (25-m resolution) data array. Speed maps were subsequently developed from the computerized factor complex maps by substituting the speed values for the terrain conditions. Finally, speed maps for both vehicles on a mission were computer plotted and overlaid on the computer-plotted vegetation and topographic maps.

As previously noted, an assumption was made that the mission paths tentatively chosen solely on the basis of the 1:50,000-scale topographic map would be adjusted by the scouts while on the mission. Specifically, it was assumed that scouts would avoid disadvantageous mobility situations where possible. Low-speed and no-go areas would be avoided by the scouts where possible and crossed only if avoiding them would require a several-hundred-meter diversion (e.g. a search for a better crossing) from the tentative path or a violation of mission concealment.

On inspection, none of the mission paths crossed no-go areas, and few required adjustment to avoid low-speed areas. No attempt was made to maximize overall vehicle speed by making the paths proceed through high-speed areas. It was assumed that the scouts could and would choose alternative paths a short distance from their tentative prechosen paths to avoid problem areas, but it was unrealistic to assume that they would have the information available to choose optimum speed paths.

Mission time was calculated for all missions in an identical manner. The mission path was digitized and computer overlaid on the speed map grid array data, and the time to follow the path was calculated by summing the times along 25-m segments (the speed map resolution) over the entire path. Since it was assumed that one of the two vehicles on the mission was always in motion, the total mission time was calculated from the time to follow the path by multiplying the calculation value for a single vehicle by 2.

Comparison of Vehicles

The data resulting from the visibility and mobility calculations were the basis for comparing effectiveness of ARSV's on reconnaissance missions. The total information available for each mission by each vehicle on any of the sites consisted of total site area, mission class and vantage positions, calculated mission time, calculated area covered on the mission, and calculated maximum area of the site which could have been covered. With the data above, an expression of vehicle visibility-mobility effectiveness was achieved by calculating values for several parameters that characterize effectiveness and are readily interpretable in terms of reconnaissance mission actions. While the calculated results are too lengthy[12] for inclusion in this paper, the parameters are described and the results are commented on below.

In addition to performing calculations of visibility coverage and time to accomplish missions, the terrain conditions encountered by the vehicles along each mission path was studied. The purpose was to determine the terrain conditions limiting vehicle speed so that the differences in time for different types of vehicles to perform the same missions could be rationally approached by appealing to the design characteristics of the vehicles and their influence on mobility while on the missions. Fig. 3 is a graphic display of reasons for speed limitation for missions on site FRG2.

The percentage of the site and the percentage of visibility range covered were calculated for each mission. The percentage of site covered for a mission is simply the percentage of the total site covered on that mission. The percentage of visibility range covered is the ratio of the area of the site covered to the area within visible range on the mission. Several general cluster patterns were apparent in the results when the site coverage and time data were displayed, which demonstrated the following:

<u>a</u>. The missions on which few vantage position were visited and a small area of the site was covered had shorter mission times. Conversely, the missions on which many vantage positions were visited and a large area of the site was covered had longer mission times.

<u>b</u>. Those missions judged most realistic according to the scouts' criteria tended to group at longer mission times and greater site coverage. Conversely, the less realistic missions tended to group at shorter times and lesser site coverage.

c. The data for the new-design vehicles (XM800W and XM800T) were grouped at shorter mission times than those for the inventory vehicles.

A coarse comparison of vehicles was made on the basis of how frequently one vehicle was faster than another. Each vehicle was compared with the other four vehicles on each site by calculating the number of missions on that site for which that vehicle was faster than each of the other vehicles. In addition, the average visibility range covered was also calculated for those missions when the first vehicle was faster than the second, and again for when the second was faster than the first. The intent was to discover whether, even though one vehicle was faster than another on a majority of missions on a particular site, the second vehicle was faster on "important" missions (i.e. a high-coverage mission). It was discovered that when one vehicle was faster than another vehicle on a majority of the missions on a particular site, it was faster on the "important" missions. The missions on which the "slower" vehicle was faster were almost always found to be low-visibility-coverage missions. The calculational results showed the new-design vehicles to be much more effective than the inventory vehicles. In fact, both the XM800W and XM800T were faster than all three inventory vehicles on every mission (total 212 missions), except one on which the M551 was slightly faster than the XM800T. It was almost impossible, however, to see any difference between the new-design vehicles for this calculation. The arrangement, in effectiveness, of the inventory vehicles consistently showed the M551 to be first, the M113A1 second, and the M114A1 last.

Both the average mission time and a weighted average mission time were calculated for each mission class, most to least probable, for each vehicle on each site. The weighting factor used in the weighted average mission times was the percentage of visible range covered on the mission. The weighting was performed such that missions that had a large percentage of visible area influenced the calculated results more than missions with less coverage. Fig. 4 shows the results of calculating the average weighted vehicle times. The results of the calculations again show that the new-design vehicles were faster on missions than the inventory vehicles studied, and that there was little difference between the new-design vehicles, except on site FK2 where the tracked vehicle (XM800T) performed much better than the wheeled vehicle (XM800W). A study of terrain conditions, such as that shown in fig. 3, showed that the wheeled vehicle suffered greater delays than the tracked vehicle when they encountered low obstacles. The tracked vehicle was capable of overriding many low obstacles which the wheeled vehicle was forced to either maneuver about or decelerate and crawl over.

The percent differences in time between each vehicle and the other four vehicles on the same mission were also studied for each site and class of mission. Both average and weighted percent differences were calculated for each site. The weighting factor used in the weighted average was the percentage of visible range covered on the mission, and was applied so that missions with a large visible area of coverage. The new-design vehicles were found, on the average, to accomplish missions approximately 30-60 percent faster than the inventory vehicles, except when soft, wet soil conditions reduced all vehicle movement practically to a stalled condition. When such terrain conditions occurred, as on site FK1, both new-design vehicles were faster than the inventory vehicles on all missions, but the average time difference was less than 10 percent.

Summary

This study was directed toward a quantitative comparison of two new-design and three inventory armored reconnaissance scout vehicles on the basis of visibility-mobility on zone reconnaissance missions. The results of all calculations performed in this study consistently demonstrated that the two new-design vehicles were more effective than the inventory vehicles. The calculations further demonstrated that the arrangement of vehicles in decreasing order of effectiveness is as follows: XM800T, XM800W, M551, M113A1, M114A1. There was no significant difference between the wheeled and tracked new-design vehicles, except when many small, low obstacles were encountered in the terrain, at which time the tracked vehicle significantly outperformed the wheeled vehicle.

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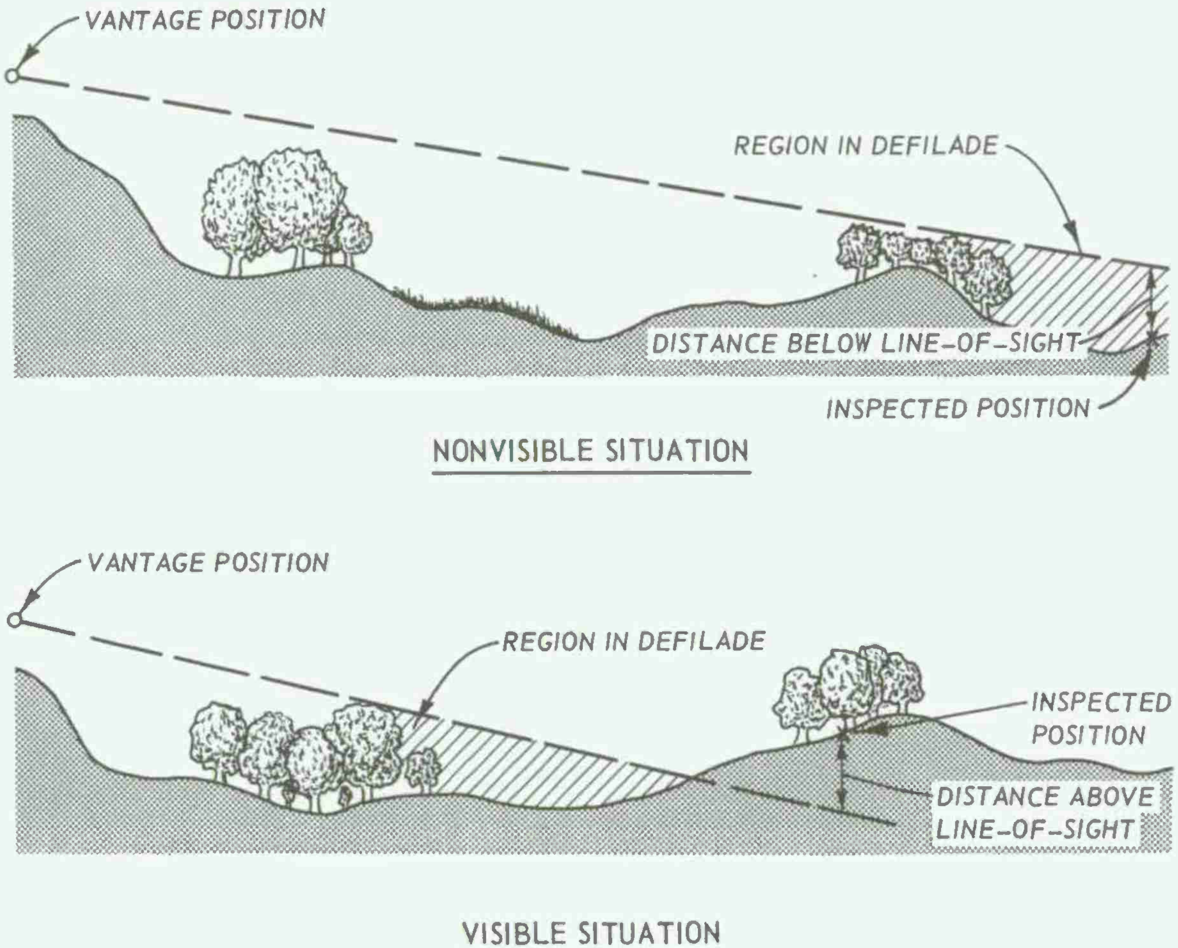

Figure 1. Graphic illustration of nonvisible and visible situations

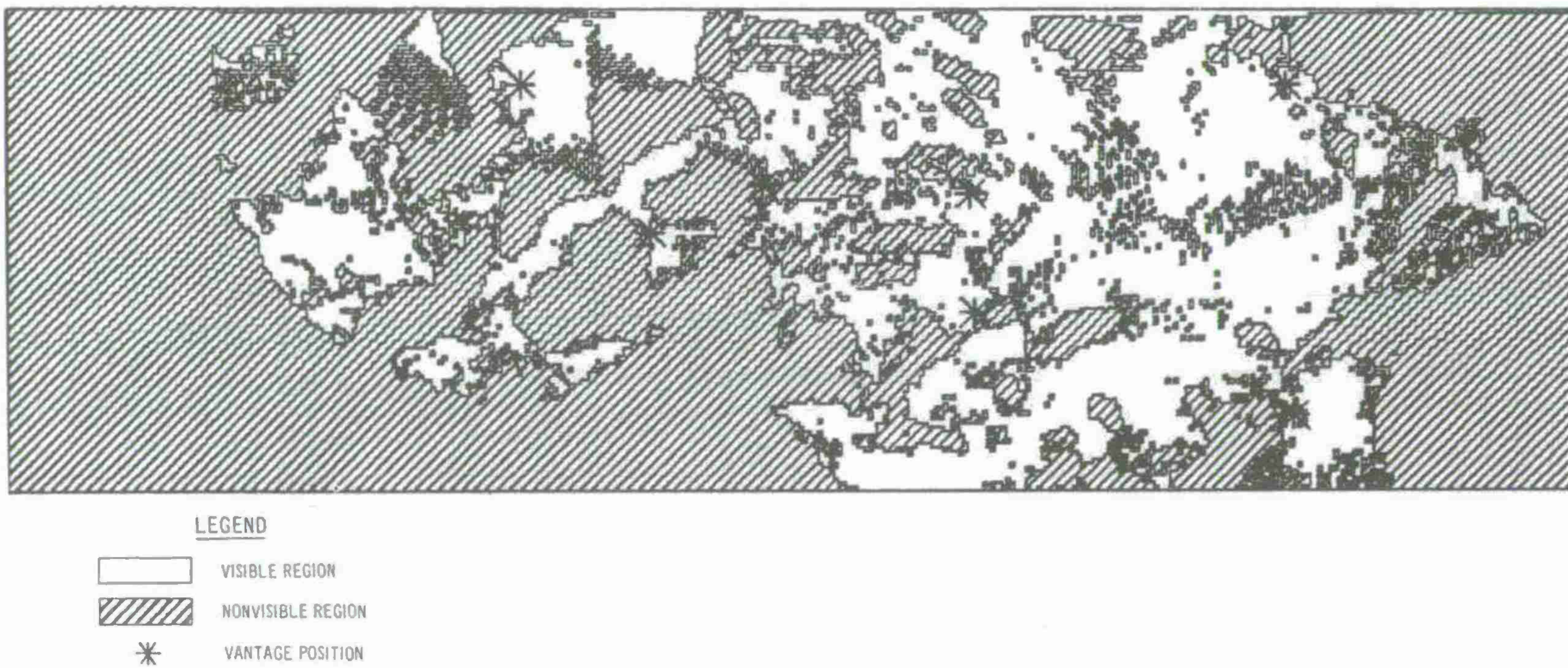

Figure 2. Computer-plotted visibility calculation results of a mission on site FRG2

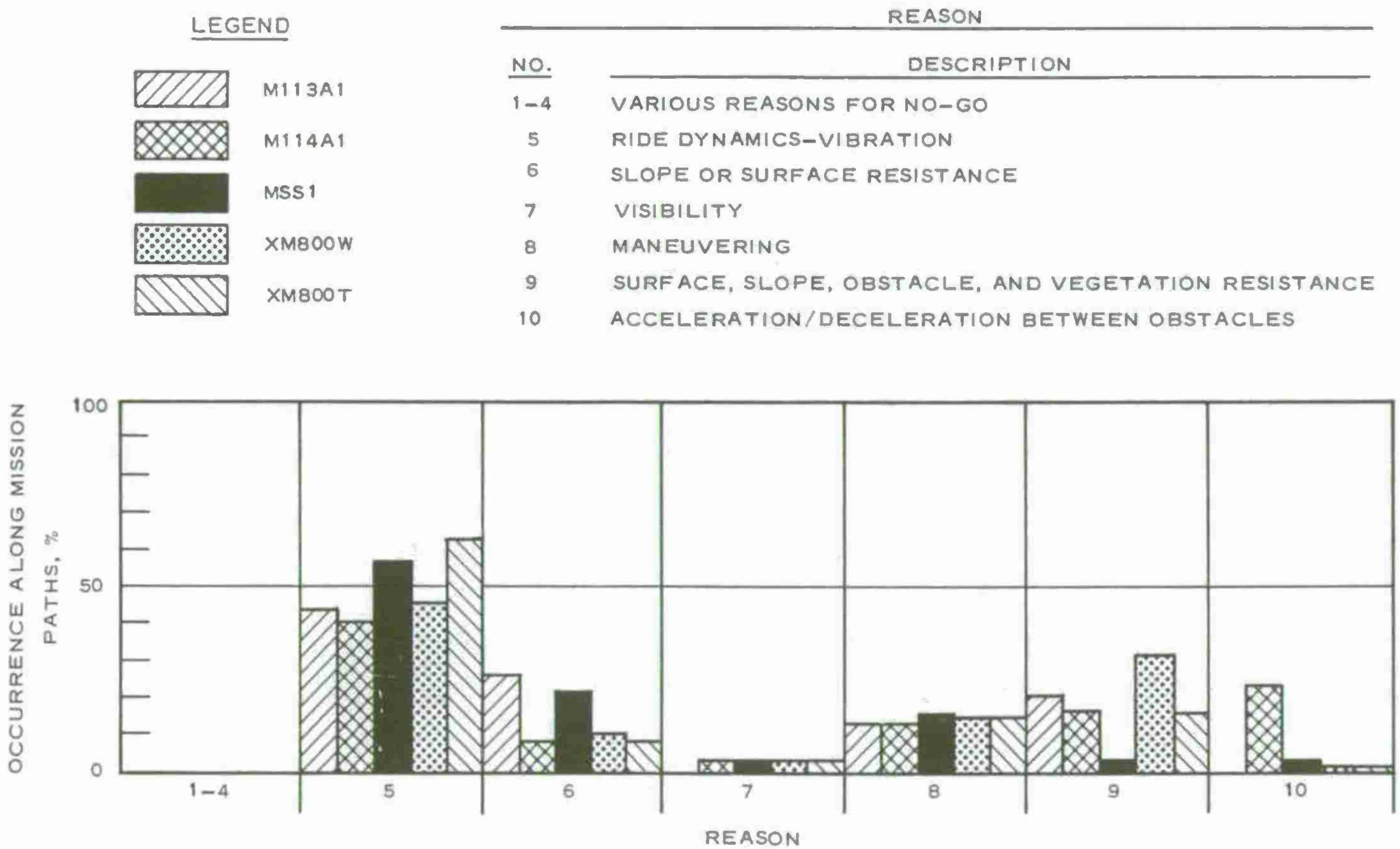

Figure 3. Occurrence of reasons of speed limitations on site FRG2

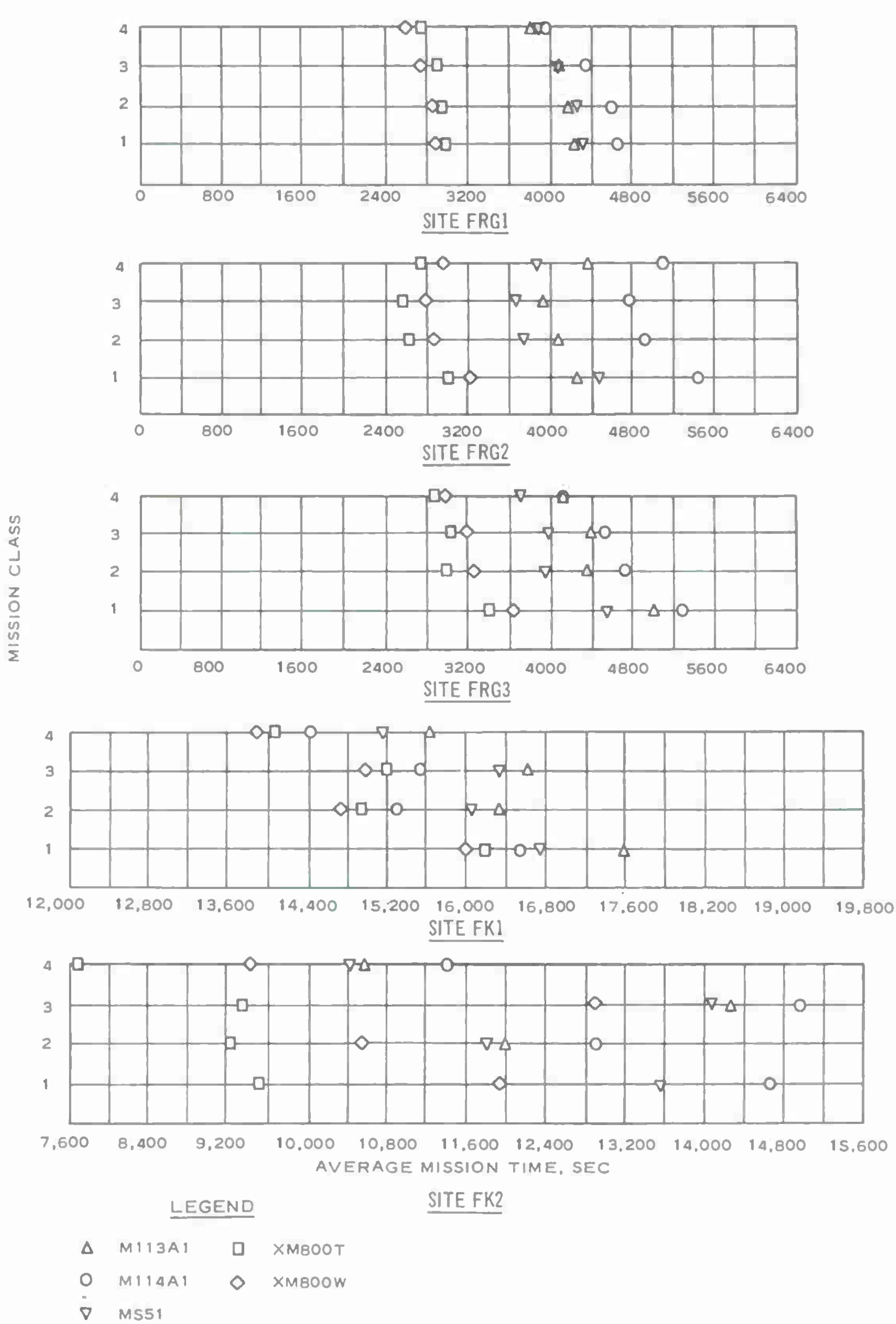

Figure 4. Average weighted vehicle times on missions for all study sites

Preliminary Operational Analysis of Fire-on-the-Move Capabilities for Tank Main Gun

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INTRODUCTION

The Fire-on-the-Move (FOM) doctrine has been a point of controversy in the employment of armored weapon systems for several years. Whether an armored vehicle can fire its main weapon accurately and effectively while reducing its own vulnerability is still an open question.

A stabilized armored weapon system having the capability to employ FOM has several intuitive advantages over a system which must stop to fire. Three of the most obvious advantages are:

1. A moving attacker is difficult to hit.
2. A continually moving attacker is exposed to enemy fire for a shorter period of time.
3. The attacker can fire more rounds.

On the other hand there are several disadvantages as well:

1. A moving attacker fires less accurately.
2. A moving attacker cannot adjust fires, i.e. each round is a first round.
3. A moving attacker is more easily detected and less capable of making detections.

BACKGROUND

The production of add-on stabilization kits for the M60A3 tank, the stabilized M60A2 tank, the XM803 tank, and the MICV-65 personnel carrier indicates a commitment on the part of the Army to exploit the advantages of FOM doctrine. The conceptual development of stabilization systems for future armored systems attempts to advance the state-of-the art in this area. Computer simulation models have been developed to assess the benefit of these stabilization systems. One such model is HITPRO, an armored weapon system performance model, used for evaluating the hit ptobability of an armored weapon system which is firing while traversing rough terrain. A second such model, DYNTACS-X, is capable of assessing the impact of FOM doctrine and stabilized systems in a combat senario.

Two major study efforts have been performed at the Rodman Laboratory, Rock Island Arsenal with the DYNTACS model. The first study was performed for the M60 Project Manager and involved comparing mobility improvements for the M60A1 tank. The second study was performed for the Selected Ammuntion Project Manager and involved the evaluation of the Family of Scatterable Mines (FASCAM) concept. Neither of these studies were specifically designed to investigate FOM doctrine. However, valuable information on FOM can be drawn from their results and their data bases.

During the July 1970 through April 1971 time frame, the DYNTACS model was used to evaluate three alternative mobility packages for the M60A1 tank in support of the Project Manager M60 tanks. The model included routines which provided the capability of simulating FOM. This logic allowed for a FOM opening range and reduced hit probabilities as a function of range and firer speed. As the scenario, tactics and descriptive data base to be used in the M60 study were under development, there was considerable controversy as to how FOM should be employed. Opinions varied from stopping-to-fire to firing at the maximum attainable vehicle velocity. A resolution of the controversy was achieved by judgmentally selecting an opening range of 1500 meters for FOM, and setting the limiting velocity to be the maximum speed at which a .25 hit probability could be realized against a 7.5 X 7.5 foot target.

Each of the three alternative mobility configurations was simulated by varying its acceleration and velocity to reflect differences in system performance. Both test data and results from the HITPRO model indicate that a moving tank that fires at a given range will fire less accurately with increased speed. However, a higher speed tank will close with the enemy more quickly. A moving tank that fires at a given speed will fire more accurately as range decreases. Similar speed and range relationships exist from the defending firer's standpoint. At a given range, a moving attacker is more difficult to hit as his speed increases. However, at a given speed a moving attacker is easier to hit as he closes (range decreases). These relationships are considered in DYNTACS and were reflected in the M60 study data base.

The following trends were noted in the analysis of the M60 study:

1. Examination of the defender casualties as a function of time indicated that the faster moving attacking option inflicted more casualties on the defensive forces than did the slower moving alternative. Also, the slower moving alternative was less accurate because he fired at greater ranges. These results suggest that loss in firing accuracy was compensated by the effect of range to target as a function of battle time.
2. In general, attacker casualties as a function of time were equal for all three alternatives. This fact indicated that an increase in speed offset the fact that he was closing faster and thus receiving fire at shorter ranges.

Due to the high cost of running DYNTACS for the M60 senarios, no further analysis of FOM doctrine was performed. It was concluded that the relationships between speed and FOM accuracy, vulnerability, exposure time and firing range indicated that some optimal speed or combination of speed existed for maximum tank effectiveness.

ANALYSIS

Improvements to the DYNTACS-X model and its implementation on a faster, more versitile computer significantly reduced the expense of one replication.

With this reduced cost and relatively fast running time the previously unanswered questions about FOM could be addressed by simulation in DYNTACS-X. The preliminary analysis of tank FOM presented in this paper is based on an application of the model used in the FASCAM study. The attacking force consisted of 32 elements made up of tanks and vehicular mounted missiles. The 15 defenders were comprised of tanks, APCs, and missiles mounted both on and off vehicles.

The results of any simulation can be no more realistic than the input data it processes. In fact, the tendency of the uninitiated user of simulation results is to forget that input data is required and to think only in terms of the "real world" situation when analyzing the results. This tendency can result in erroneous, if not conflicting conclusions.

At this point a review of the DYNTACS input data is in order. Typical data pertinent to the FOM doctrine and used by the model is presented in Figures 1 through 3. The hit probabilities shown are for the tank systems used in the FASCAM study and represent hit probability at a specific range and attack angle (aspect).

Figure 1 depicts the hit probability of a moving attacker against a stationary defender as a function of attacker velocity. The defender is assumed to be in hull defilade. The attacker is moving over type 1 DYNTACS terrain (Rocky soil, Fort Knox). As expected, the data indicates that the faster the attacker is moving while firing, the lower is his probability of hit.

Figure 2 depicts the hit probability of a stationary defender against a stationary attacker as a function of the fraction of the attacker covered or protected from fire. A hull defilade position is equivalent to a cover of 80-85%.

Figure 3 depicts the hit probability of a stationary defender against a moving attacker as a function of attacker velocity. The attacker is fully exposed and taking evasive action. Clearly, the faster the attacker is moving the harder he is to hit.

By examining the data plotted in Figures 2 and 3 it is apparent that a fully exposed vehicle would require a velocity of approximately 2.7 M/S or more to achieve the same decrease in probability of being hit afforded a stationary vehicle in hull defilade (80-85% covered).

DYNTACS-X was initially replicated using the FASCAM Scenario, for two different attacking tactics.

1. Attacking tanks forced to stop-to-fire.
2. Attacking tanks allowed to FOM at an arbitrary velocity of 3.8 M/S or less.

The results of these two cases are shown in Table 1.

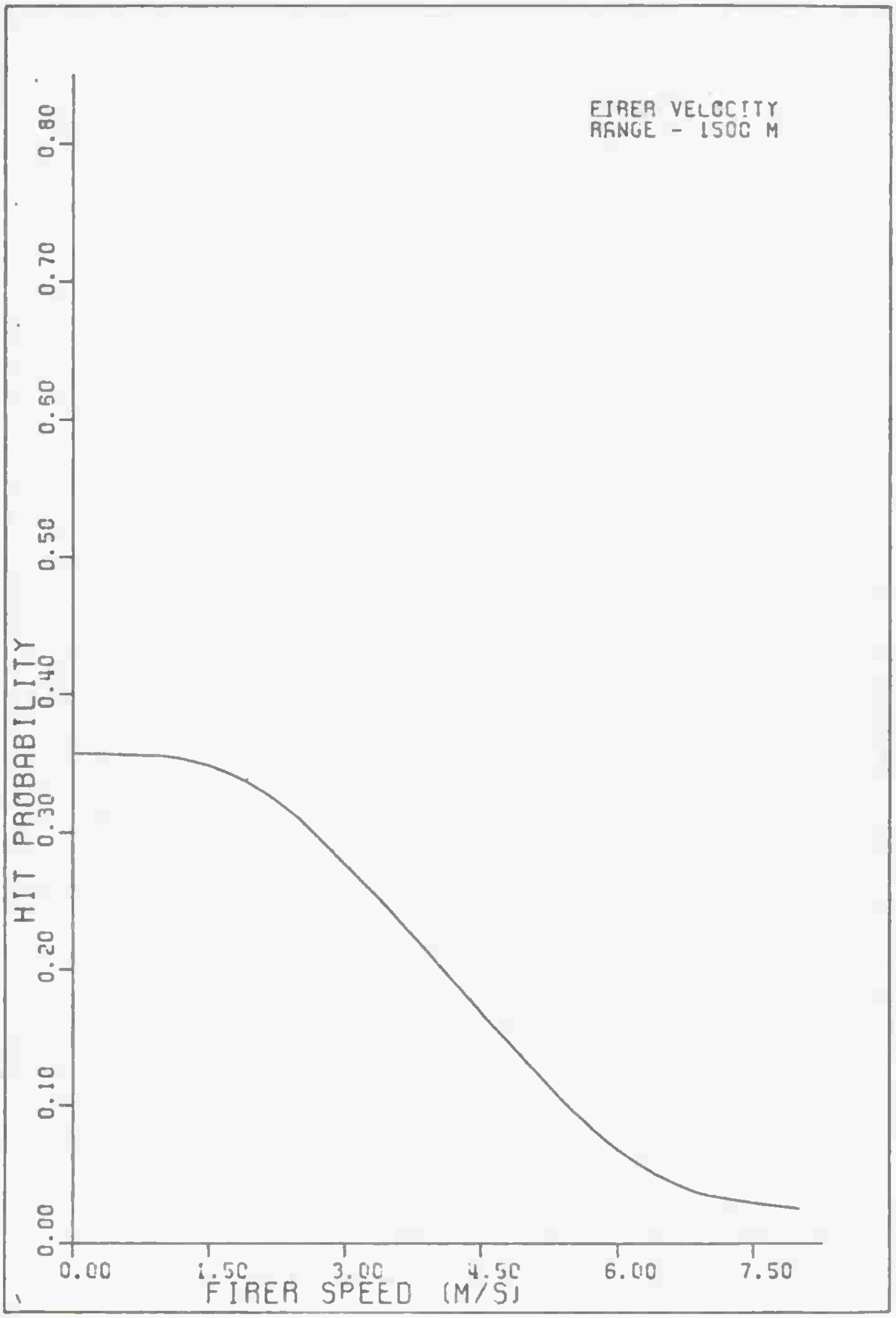

Figure 1 Attacker Hit Probability vs Attacker Velocity

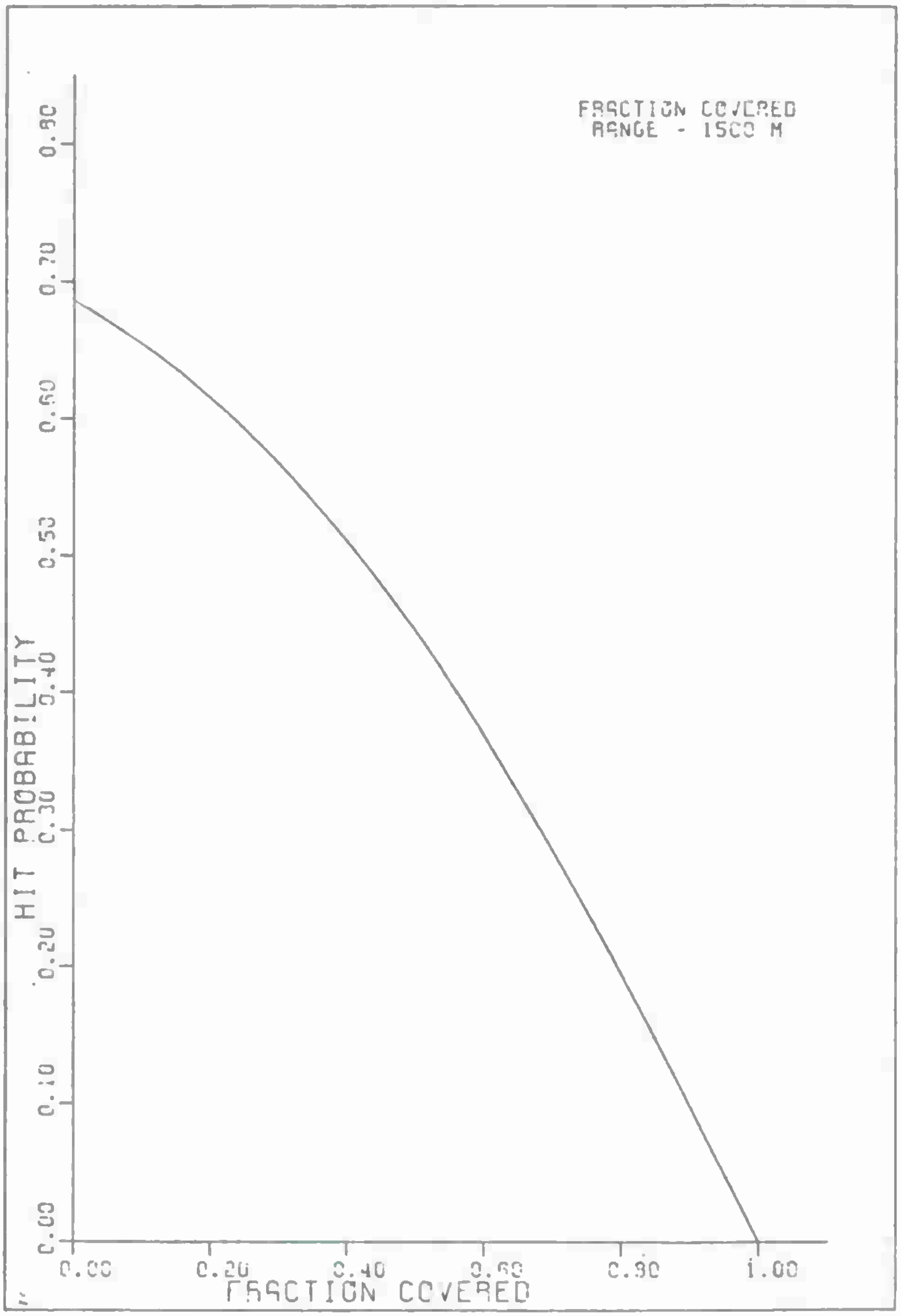

Figure 2 Defender Hit Probability vs Fraction of Attacker Coverage

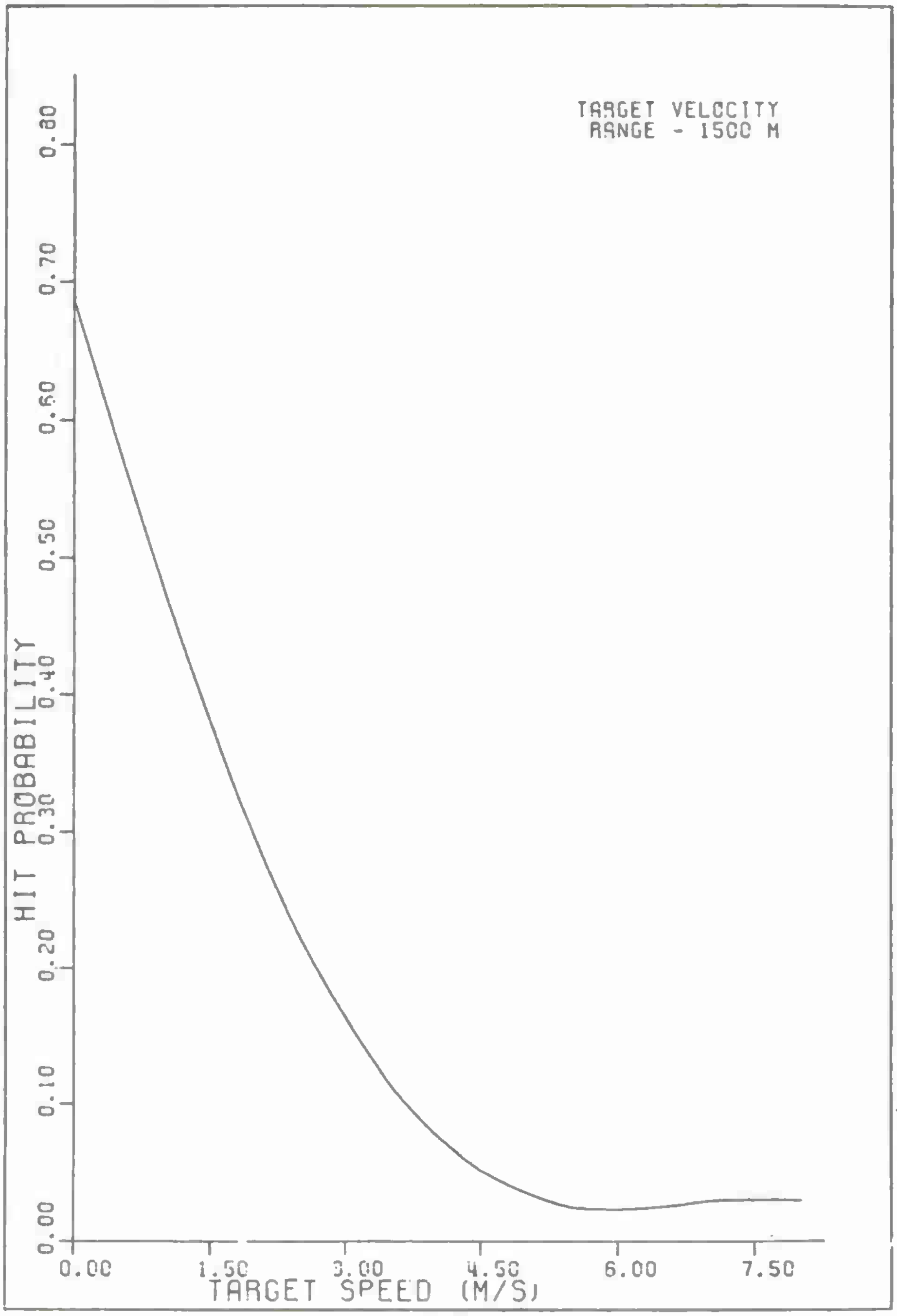

Figure 3 Defender Hit Probability vs Attacker Velocity

TABLE 1 FOM vs. STOP TO FIRE

	WEAPONS DESTROYED		LOSS RATIO	AMMUNITION EXPENDED		BATTLE TIME
	ATTACK	DEFENSE	DEF/ATK	ATTACK	DEFENSE	(SEC)
STOP-TO-FIRE	19.4	11.2	.62	59.6	106.0	1812
FIRE-ON-THE-MOVE	17.0	10.8	.69	55.0	101.8	1791

By use of the Mann-Whitney Test in comparing the results obtained from DYNTACS-X no significant difference could be demonstrated between the FOM and the stop-to-fire cases. However, as stated previously, simulation results should be evaluated in light of the input data and any assumptions made in collecting the data or constructing the model.

Figure 4 is a plot of the difference between Figures 1 and 3, i.e. the difference between the attacker's probability of hitting a hull defilade stationary defender and the fully exposed attacker's probability of being hit by a stationary defender. The curve is for various attacker velocities.

Upon examining the data plotted in Figure 4 it became readily apparent that by reducing the maximum FOM speed for the attacking tanks to 3.2 M/S the difference between their hit probability and their probability of being hit could be maximized.

Based on this analysis of the input data a third case was run - that in which the attacking tanks could FOM, however with a reduced maximum velocity to increase their accuracy, while still maintaining a velocity high enough to be difficult to hit. The results of this case are given in Table 2.

TABLE 2 OPTIMIZED FOM

	WEAPONS DESTROYED		LOSS RATIO	AMMUNITION EXPENDED		BATTLE TIME
	ATTACK	DEFENSE	DEF/ATK	ATTACK	DEFENSE	(SEC)
OPTIMIZED FIRE-ON-THE-MOVE	13.4	12.2	.94	53.4	88.4	1766

By again using the Mann-Whitney Test the following results could be inferred with greater than 90% confidence: The attacking force with tanks capable of FOM suffered fewer losses, destroyed more defender weapons and achieved a higher loss ratio than the force which was compelled to stop-to-fire.

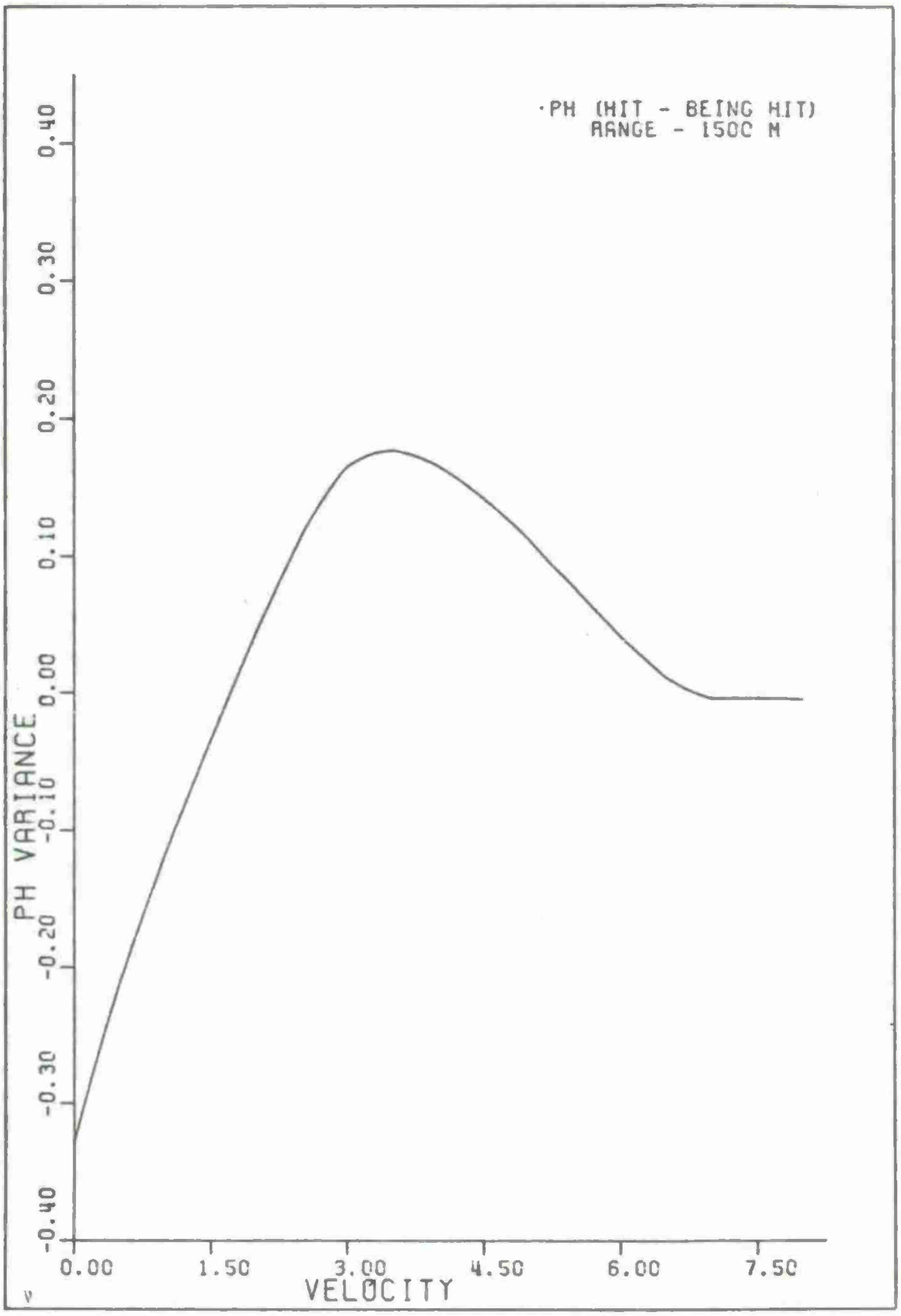

Figure 4 Difference in Hit Probability vs. Attacker Velocity

SUMMARY

In summary it should be noted that the use of simulations such as DYNTACS-X are beneficial in addressing questions such as FOM versus stop-to-fire. However, care must be taken to interpret the simulation results in light of the input data and known restrictions of the model. The analysis presented in this paper indicates that small modifications to the firing thresholds for FOM can make significant differences in the results. Thus, a sensitivity analysis of factors related to FOM is required before the full implications of FOM versus stop-to-fire results can be concluded.

This paper has demonstrated the need for a more complete, in depth analysis of the FOM question. The data base used was that assembled for the FASCAM study which was not directly concerned with evaluation of FOM. A more complete study of FOM would require investigation of the validity and implications of the FOM and stop-to-fire data which have been presented here, and an evaluation of the benefits of stabilization in the stop-to-fire mode with regards to acquisition and lay while moving.

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TITLE: Significant Difference Technique

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Weapons effectiveness analysis is one of the most valuable applications of Operations Research to the US Army. In selecting among various candidate weapons systems, the anticipated performance characteristics are of great importance. Cost and schedule are also vital to the decision process and are related to the performance features for each system. Thus, when comparing alternative weapons systems or even different approaches for a particular system, the decision maker is confronted with a multiple attribute decision situation. The problem is usually confounded by the fact that effectiveness is measured by several characteristics, such as reliability, availability, vulnerability, accuracy, speed, lethality, or any combination of these or dozens of other important weapon attributes. Choosing between various options is obviously a difficult task.

Another complicating factor in this problem is that when the decision must be made, in many cases, the actual hardware does not yet exist and the values for the various attributes are, therefore, somewhat uncertain. Thus, we face a decision in which there are many important system characteristics to consider and some, if not all, of these are estimated. Therefore, the decision maker must look for significant differences on which to base his choice between alternatives. That is, he must account for the possible variability of the values for a particular attribute by requiring a large difference between the values for two alternatives before he will say one is better than the other. This is the basis of the Significant Difference Technique, which was first used in a Decision Risk Analysis in August, 1971, at the Army Logistics Management Center, by John Cockerham and Harold Stafford. There is a direct analogy between this idea of "significant differences" and statistical hypothesis testing, where, in order to minimize the risk of a Type I error, a substantial amount of variation is allowed before rejecting the null hypothesis. This is done to allow for possible sampling error. The Significant Difference Technique encodes decision criteria for each system attribute in terms of what is required at various levels to discriminate between two alternatives. This should take into account the variability present due to the method in which the values are obtained, which in most cases is a risk analysis. This process reduces the chance of reaching an invalid conclusion that one attribute value is appreciably better than another when this is not true. It is possible also to inject into the decision criteria personal value judgements of the decision maker by increasing the required decision difference for attributes of less importance. This has the effect of reducing the influence of these attributes in the decision technique.

The criteria on which conclusions about various alternatives will be made for a specified attribute may not be constant at all levels. It is therefore necessary to consider all possible values for the attribute when encoding this criteria. We may think of the difference which is conclusive as the "required difference" and this will serve to define whether two alternatives have significantly different values or not. This gives rise to the concept of decision difference or, as the original authors referred to them, "indifference" curves. The term "decision difference curves" will be used here to avoid confusion with the economist's indifference curves. These decision difference curves may take on a variety of shapes, depending on the particular attribute under consideration. They may be classified as either constant, constant percentage, or variable percentage difference curves. Where the amount required to make a decision is always constant for any value of the attribute, the decision difference criteria never changes and is equal to that required amount. Thus, the decision difference curve would be termed constant. Displaying this in graphic form (see fig. 1), both axes would be scaled the same, representing the possible range of values for the attribute under consideration. The abscissa would represent the value of the attribute for one alternative (X) and the ordinate the value for the same attribute for another alternative (Y). A straight line with a slope of plus one passing through the origin would represent the locus of all points at which the values for X and Y are equal. Another straight line parallel to this line and a horizontal (and also vertical) distance (d) to the right of (below) this line would serve to define the values for X and Y at which a choice can just be made, where d represents the required difference (see fig. 2). The area to the right or below this second line represents values for X and Y at which there is a definite choice, that is, one alternative is significantly better than the other. The further the point lies from this line, the stronger the choice becomes. Conversely, the area between the two lines represents values for X and Y at which no clear selection can be made, since the actual difference between their values is less than the amount required to make a decision. Referring again to the area below both lines, the determining factor for which of the two alternatives is the better is simply whether the attribute in question is increasing or decreasing in utility. If larger values are preferred, as in the case of reliability, a point in this region would indicate that the alternative whose attribute value is plotted on the horizontal axis is significantly better than the alternative whose value is plotted vertically, and vice-versa. Since there is no specific rationale in assigning one alternative to the vertical or horizontal axis, this situation exists above the equality line as well, giving rise to a symmetric figure (see fig. 3). Thus, when the values for two alternatives are plotted as a point on the graph for this attribute, the point must lie in one of three regions: on or above the upper line, in which case the alternative on the vertical axis is clearly the better one if large values are preferred (the alternative on the horizontal axis if smaller values are preferrable, as in vulnerability), between the top and bottom line, where no choice can be made (the non-discriminatory area), or on or below the lower line, indicating the reverse of the first region discussed.

For attributes which have no practical upper limit, such as time, cost, speed, etc., the difference required between two values to discriminate typically is not constant, but depends upon the level of the attribute. In general, as the level of the attribute increases, the amount of difference required to make a decision also increases. This may have the effect of stabilizing the ratio of the required difference to the level of consideration. In other words, although the absolute required difference varies, the required percentage difference remains relatively constant. This situation is termed a constant percentage difference criteria. Plotting this as before, the result would be a diverging set of straight lines, symmetric about the equality line, resulting in an expanding non-discriminatory region (see fig. 4). The interpretation of the three areas would be the same as in the constant difference case, again dependent upon the attribute in question.

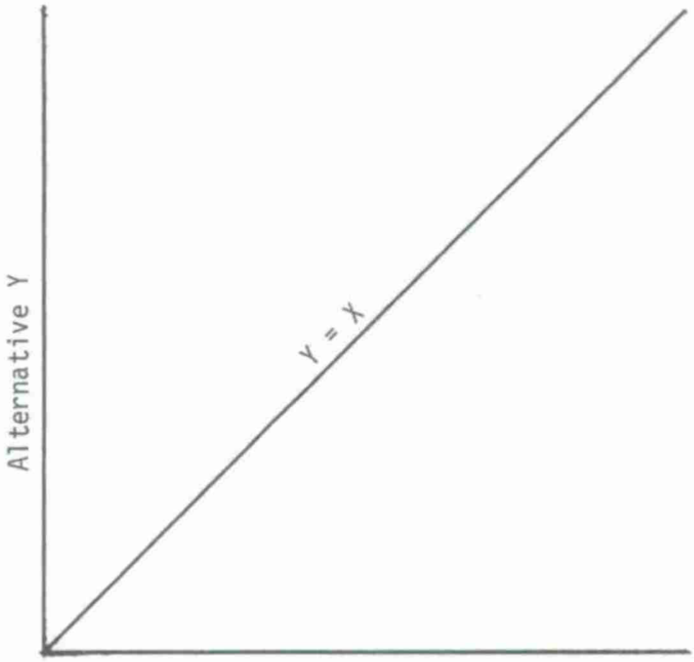

Figure 1

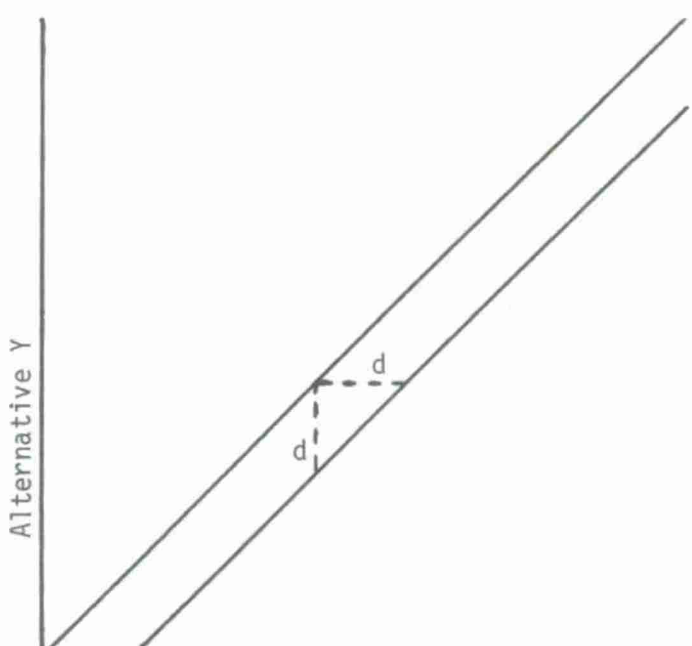

Figure 2

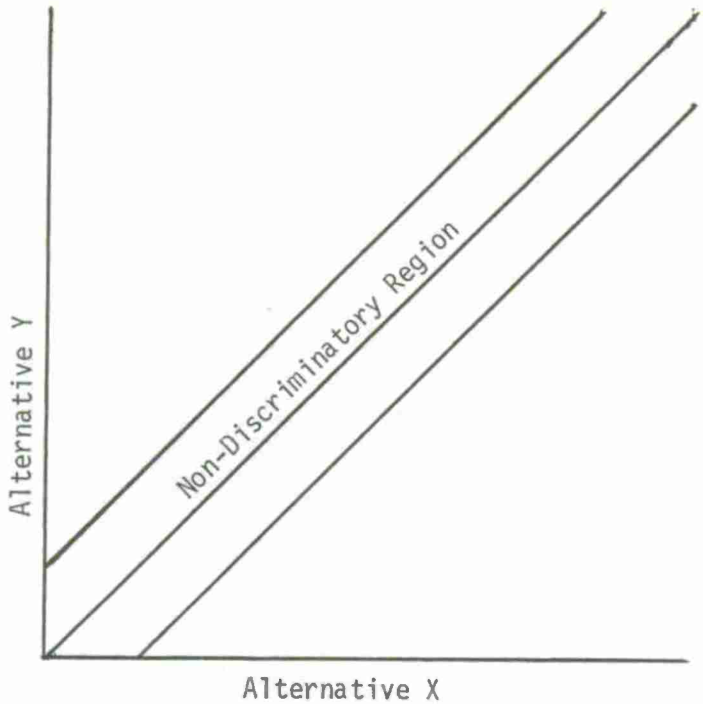

Figure 3

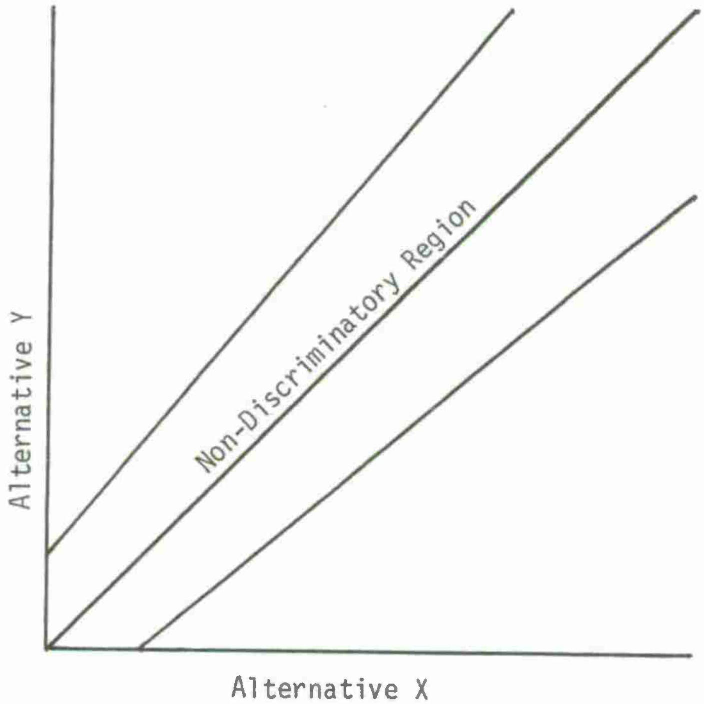

Figure 4

For attributes which are bounded, however, (reliability, avaiability, etc.), neither a constant nor a constant percentage difference may be appropriate. Especially in those cases in which the decision criteria is used to encode the decision maker's desires, the decision difference curves may be non-linear. The non-discriminatory region may change from large to small to large again over the range of values for an attribute such as reliability, with the narrowest width of the region lying in the neighborhood of some required value (see fig. 5). This type of curved decision difference criteria is indicative of a strong interest in the attribute for values close to the required value, and decreased interest in values substantially below or above the required value. This third type of decision difference curve can also apply to attributes which are unbounded, but for which a specific required value exists.

Once a decision difference criteria has been established for a particular attribute, all alternatives can be compared on a common basis for the purpose of discriminating between or among them. To compare two particular alternatives for this attribute, a point is located on the graph of the decision difference curve. Depending then on which region the point falls in, it will be said that either Alternative A is significantly better than Alternative B, B is better than A, or that no choice can be made (no significant difference exists for that specific system attribute). The next logical question that arises is: "If Alternative A is better than Alternative B, just how much better is it?" This is an important question because if this technique is to be used to rank more than two alternatives, it will be necessary to have a measure of the strength of the preference. This question was addressed somewhat intuitively earlier when it was pointed out that the further away from the non-discriminatory region a point lies, the stronger the preference that exists between the two values.

The original authors of this technique addressed this question by computing what they called "degrees of difference." The degrees of differences between two values is a measure of the strength of the preference between them. To compute this measure, the ratio of the actual difference existing between the values to the difference required to make a decision is taken. A ratio of one, then, indicates that the actual difference that exists between the two values is exactly equal to the required difference on which a choice can be made. A ratio of less than one would be obtained for a point at which a selection cannot be made, and a ratio of more than one indicates more than enough difference on which to base a decision. The greater this ratio, the stronger the preference between the two values in question. This ratio is called the degrees of difference. One important feature of the degrees of difference index is that since it is a ratio of two quantities which are measured in the same units, the ratio is a dimensionless number. Further, it was contended in the initial study employing this Significant Difference Technique, the degrees of difference index puts different attribute measures on a somewhat common scale. This seems intuitively appealing, but may not be capable of proof, and will be discussed later. At any rate, the concept of degrees of difference deserves consideration as a method of comparing multiple alternatives for at least a particular attribute. Several problems arise in computing degrees of difference and need to be resolved. One immediate problem that presents itself is: What is the difference required to make a decision, if the decision difference criteria is not a constant? That is, for a decision difference curve which is either a constant

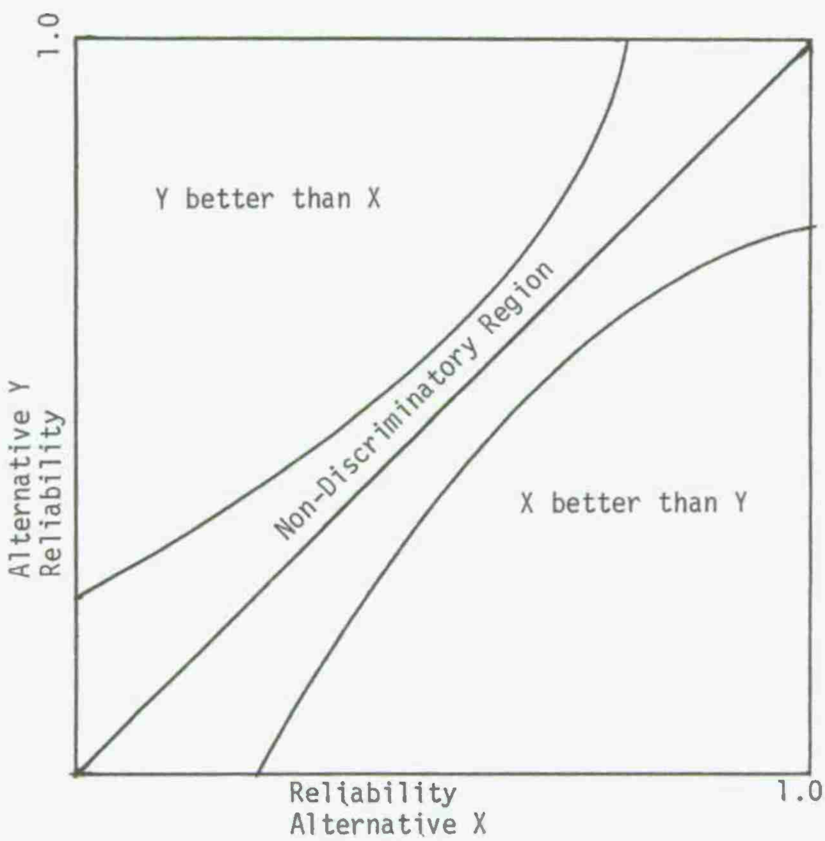
1.0
Alternative Y
Reliability
Y better than X
Non-Discriminatory Region
X better than Y
Reliability
Alternative X
1.0

Figure 5

percentage (linear, but expanding non-discriminatory region) or non-linear (curved non-discriminatory region) what should be used as the denominator in computing degrees of difference? Should the required difference be measured at the better value being considered, or the worse? The one which is used could obviously have a large effect on the resulting ratio, or degrees of difference. This problem was initially addressed by merely making a decision to always measure the required difference at the level of the better of the two values being considered and to be consistent in applying this rule. Research into this technique indicates that this may not be sufficient to resolve the problem, however. One approach that shows promise is, rather than using the required difference at just one level or the other, sweep the required difference across the entire range of values from the better to the worse. This gives rise to an integration of the reciprocal of the required difference function, with the limits of integration being the two attribute values for the alternatives being considered. This approach shows some promise and eliminates most of the problems encountered with the other method, namely non-additivity. Additional research is necessary, however, especially with non-linear decision difference curves.

The next question that arises is: Once the degrees of difference are computed for each attribute, how can these be combined to give an overall ranking of the alternatives? As stated earlier, the original contention was that the process of computing degrees of difference normalizes the attributes onto a common, dimensionless scale. Thus, the authors stated that degrees of difference can be simply added for all the attributes under consideration to achieve an overall index between any two alternatives. If this is done for all pairs of alternatives, an overall ranking for many attributes is attained. Whether or not this contention is true is yet to be completely proved. It is apparent that some weighting of attributes is inherent in the process of computing degrees of difference, since for less important attributes a larger relative difference is necessary for discrimination, and thus the ratio for the attributes is reduced. Whether or not this implicit weighting is correct or sufficient is an open question. Again, additional research is necessary before any firm statements can be made on either position.

In summary, then, the Significant Difference Technique is a new approach to a very difficult problem, that of measuring weapons effectiveness and comparing against cost and schedule factors for the purpose of selecting among competing systems or alternatives. It has the advantages of simplicity and directness, being easily related to by decision makers, and the disadvantages of incomplete development and proof. It is a promising technique, well deserving of serious inspection and further research by Operations Research Analysts, as it may prove to be of great value to the US Army.

A METHOD FOR DETERMINING THE SURVIVABILITY OF SURFACE-TO-AIR MISSILE (SAM) SYSTEMS DURING AN ATTACK BY AIRCRAFT CARRYING CONVENTIONAL ORDNANCE

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A. INTRODUCTION

The methodology presented here was generated to investigate the survivability of surface-to-air missile systems (SAM) when they are attacked by manned aircraft using conventional ordnance. This is a complex problem involving the consideration of the capabilities of the SAM system, the aircraft, the pilot, the ordnance, the weather and many other parameters. This methodology is an attempt to provide a means by which the sensitivity of SAM survivability to various parameters can be investigated and the survivability of different SAM systems can be compared. The approach taken is basically that of an expected value model utilizing the binomial probability distribution to represent expected probabilities of occurrence.

B. METHODOLOGY

B-1 BASIC MODEL

The survivability calculations for this paper are based on a determination of all the ways in which a SAM system can interact with attacking aircraft. Each possible interaction in the program generates an expected probability of survival for the SAM site. Thus, in general, the expected probability of site survival is as follows:

$$EP_S = \sum_{i=1}^{N_i} P_i P_s(i) \qquad \text{B-1}$$

where

EP_S = expected probability of site survival,

N_i = the number of ways the SAM site can interact with the attackers,

P_i = the probability of the i'th interaction occurring, and

$P_s(i)$ = the probability of site survival for the i'th interaction.

B-1.1 Underlying Assumptions.

The assumptions* listed below were made in this paper in order to simplify the mathematics while maintaining realism.

B-1.1a Site Assumptions:

1. There is only one unsupported site.

2. An interaction occurs if aircraft fly past the site, regardless of whether an engagement (aircraft by site or vice versa) occurs.

3. The site engages aircraft only in sequence, in the defended zone, i.e., closest one first, because the scenario makes these the highest threats.

4. The site fires only one missile per aircraft (due to the high missile cost and high probability of kill).

5. This model assumes that "h" groups of aircraft will be fully engaged; that they are followed by one partially engaged group; and that all following groups are unengaged.

B-1.1b Aircraft Attack Assumptions:

1. Any number of groups of aircraft can be employed, but they must all be the same size. The group size can vary from one attack to another.

2. Aircraft cannot attack the site unless they detect it visually and can successfully convert their flight path for accurate ordnance delivery. (Detection without successful conversion does not permit an attack.)

3. If one aircraft in a group successfully attacks the site, all other members of that group can do likewise. All succeeding groups are then credited with this capability because the site location is marked.

4. No groups preceding the first successful group can use this information to deliver a successful attack.

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*This methodology could be enlarged to lift some of the limitations these assumptions impose upon it. In this presentation, we are concerned only with the methodology as employed in this study.

B-1.2 Basic Characterization of Model Interaction.

In enumerating the various interactions which can occur between the SAM site and the attacking aircraft, there are two major categories of events that can occur: either the aircraft are able to attack the site or they are not able to attack the site.

For groups of aircraft that are able to attack the site, there are three distinct interactions that can occur between the site and the aircraft.

(1) all aircraft of an attacking group are engaged by the site;

(2) only some of the aircraft in a group are engaged by the site;

(3) none of the aircraft in the group are engaged by the site.

The probabilities of site survival for the above interactions depend upon where the aircraft first detect and convert within each situation. By convert it is meant to change the aircraft's flight path to accomplish an aimed bomb release.

A fourth type of interaction arises from the second category cited above. This interaction arises from the situation where a group of aircraft are unable to attack the site but the site is able and does engage the group of aircraft.

In the mathematical calculation four terms were developed to describe the four types of interactions between the aircraft and the site:

First Term: Represents the expected probability of survival of the site, given that first detection, conversion and attack occur by a group that is then fully engaged by the site.

Second Term: Represents the expected probability of survival of the site when only some of the aircraft in the first group to detect, convert, and attack are engaged by the site.

Third Term: Represents the expected probability of survival of the site when the first detection, conversion, and attack occur by a group which the site is unable to engage.

Fourth Term: Represents the probability of survival of the site in the situation where an interaction does not lead to an attack on the site.

Equation B-1 can now be expanded to include these four terms as follows:

$$EP_S = \sum_{i_1=0}^{N_1} P_{i_1} P_S(i_1) + \sum_{i_2=0}^{N_2} P_{i_2} P_S(i_2)$$

$$+ \sum_{i_3=0}^{N_3} P_{i_3} P_S(i_3) + \sum_{i_4=0}^{N_4} P_{i_4} P_S(i_4) \qquad \text{B-2}$$

where

$$N_i = \sum_{j=1}^{4} N_j$$

B-1.3 Formulation of P_i and $P_S(i)$ Terms.

The methodology will employ the use of the binomial distribution to describe both the probability that interactions occur (P_i) and the probability that the site survives a given interaction ($P_S(i)$).

B-1.3a Binomial Representation of the Probability of Occurrences of Interactions.

The binomial distribution for the probability of k aircraft surviving out of a group of m aircraft, when m missiles are fired at the group, is:

$$\binom{m}{k} P^{m-k} Q^{k} \qquad \text{B-3}$$

$$k = 0,1,2,\ldots m$$

where

P = Probability of the missile killing the aircraft, and

Q = Probability of the missile not killing the aircraft, $(Q = 1-P)$

and

$$\binom{m}{k} = \frac{m!}{(m-k)!k!} \qquad \text{B-4}$$

The probability that a group of k aircraft will survive, detect, and convert on the target is:

$$\binom{m}{k} P^{m-k}Q^{k} P_{CD}(k) \qquad \text{B-5}$$

$$k = 0,1,2,\ldots m$$

where

$P_{CD}(k)$ = Probability of detection and conversion by a group of aircraft.

The expected probability that at least one aircraft survives to detect, convert, and attack the site is represented by summing this expression (Equation B-5) over all possible numbers of survivors. Thus it can be seen that Equation B-5 represents the probability of occurrence (the P_i of Equation B-1) for the situation of k survivors, and it is this concept which will be used to describe the more complex situations which will be developed later.

B-1.3b Binomial Representation of the Probability of Survival.

If one further multiplies Equation B-5 by the probability of survival of the site, given k aircraft attack, then the summation over the number of aircraft represents the expected probability of survival of the site:

$$EP_S = \sum_{k=1}^{m} \binom{m}{k} P^{m-k}Q^{k} P_{CD}(k) (1-P_{SSK})^{k} \qquad \text{B-6}$$

where

P_{SSK} = Probability of kill for a single aircraft attacking the site.

It should be noted that Equation B-6 does not include the event in which no attack occurs. Attacks will not occur when all the aircraft are destroyed or when the surviving aircraft are unable to detect and convert. These interactions can be included in Equation B-6, as follows:

$$EP_S = P^m + \sum_{k=1}^{m} \binom{m}{k} P^{m-k} Q^k \left[P_{CD}(k) \;\; (1-P_{SSK})^k + (1-P_{CD}(k)) \right] \qquad \text{B-7}$$

Two interpretations can be made from this equation: (1) there are m+1 interactions, and the P^m term represents the interaction where all the aircraft are destroyed; and (2) the remaining m terms represent the interaction where some aircraft survive. The probability of survival in the first case is one; for the second case, it is the sum of the probability of survival given an attack occurs, plus the probability an attack will not occur.

B-2 COST OF SUPPRESSION INDEX

When more than one site was under attack by groups of aircraft, the methodology that was used to determine the results involved simply scaling up the results of one site being attacked. The probability of survival was used to determine the expected number of sites killed by the following equation:

$$N_K = N_T \, (1-EP_S) \qquad \text{B-8}$$

where

N_K = number of sites suppressed, and

N_T = number of sites attacked.

The number of aircraft killed per site was determined from the capabilities of each SAM system and the number of engagements which could be expected. Consideration was also given to the probability that a SAM site would survive the aircraft's attacks and engage the attackers as they depart. The expected number of aircraft killed in this case would be as follows:

$$NA_K = N_T \times EP_S \times NEG \times P'_{SSK} \qquad \text{B-9}$$

where

NA_K = number of aircraft killed,

NEG = number of rear engagements expected per site, and

P'_{SSK} = single shot probability of kill (missile against aircraft).

Adding the expected number of aircraft killed on the inbound attack and outbound flight determines the SAM capability at self-defense. Dividing this sum by N_K determines the cost of the SAM's extracted for each SAM suppressed.

If, in addition, the expected number of aircraft killed by the short range air defense system (SHORADS) is added to the aircraft killed by the SAM systems and this sum is then divided by N_K, the result is the cost to the attackers per SAM site suppressed. This result is defined as the suppression index.

If the sites being suppressed have a limited area of coverage, these calculations must be performed for each situation, whether the attack is in or out of the area of coverage. Then a suppression index is generated for each condition and the indices are averaged to arrive at the final suppression index.

C. EXAMPLE DATA

The following data are presented to illustrate the flexibility of this methodology.

Figure C-1 illustrates how sensitive survivability can be to visual conditions. The poor condition represents a site with a small visual signature in weather conditions of limited visual range. The good condition represents a site under conditions of a large visual signature and long visual detection ranges. The medium condition is a situation between these extremes.

The sensitivity of survivability to the probability an aircraft can suppress a site is represented in Figure C-2. It should be noted that this variable can be affected by defensive measures such as revetting and sandbagging critical elements of a site.

Figure C-3 illustrates the reverse case, where the site's ability to kill the aircraft varies. One example of why this parameter would vary is electronic countermeasures (ECM) employed by the aircraft to reduce the effectiveness of the site.

Figure C-4 illustrates the situation where the pilot is aided in his search for the site and can narrow his search area. The single glimpse probability of detection does not change, but there are more glimpses to accumulate.

The variation of suppression index is illustrated in Figure C-5 as a function of site hardness. Since this parameter is a measure of the number of aircraft required to suppress a site, it is evident that the large attack is better; although for high values of P_{SSK} the difference is small.

EFFECT OF VARYING VISUAL CONDITIONS

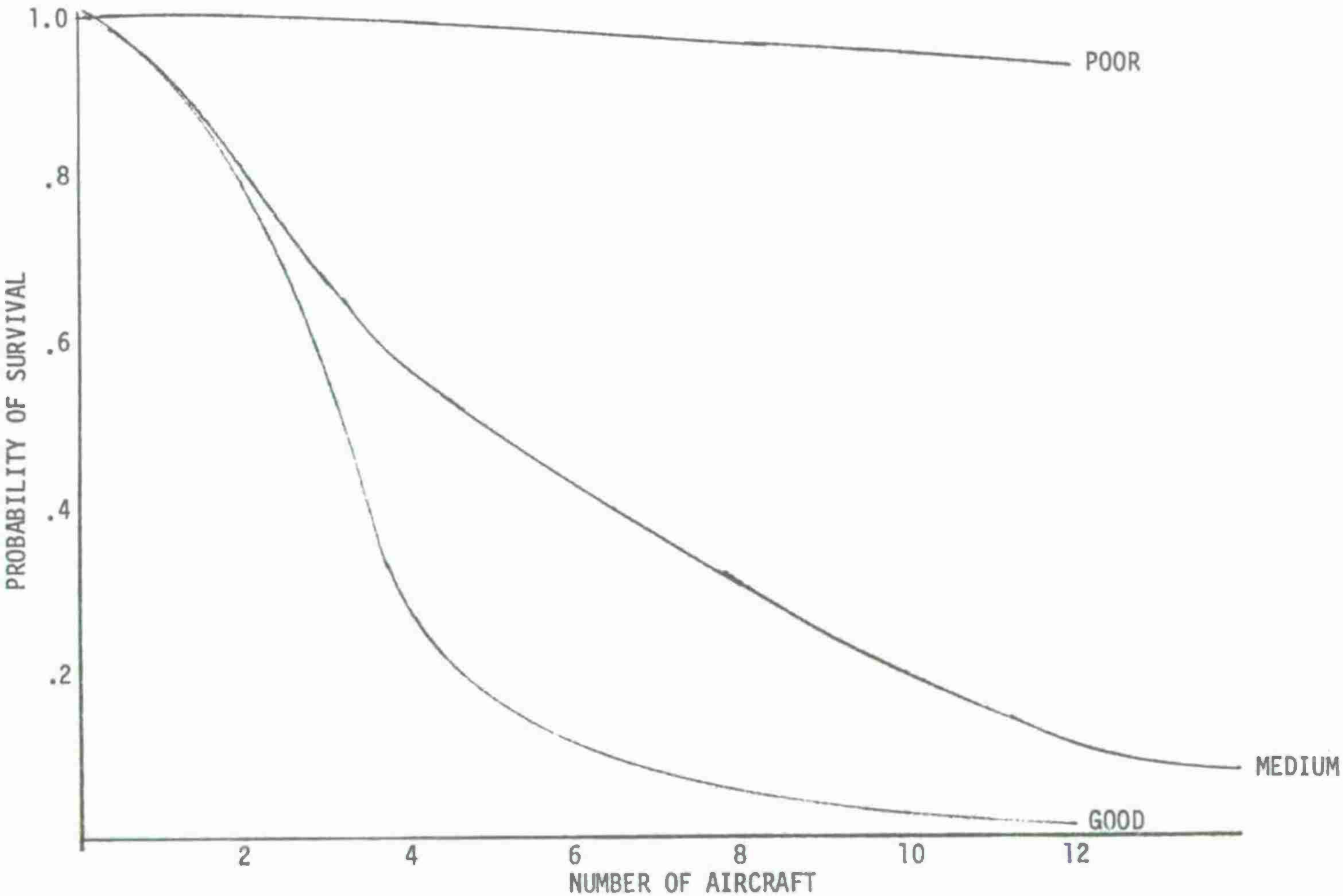

FIGURE C-1

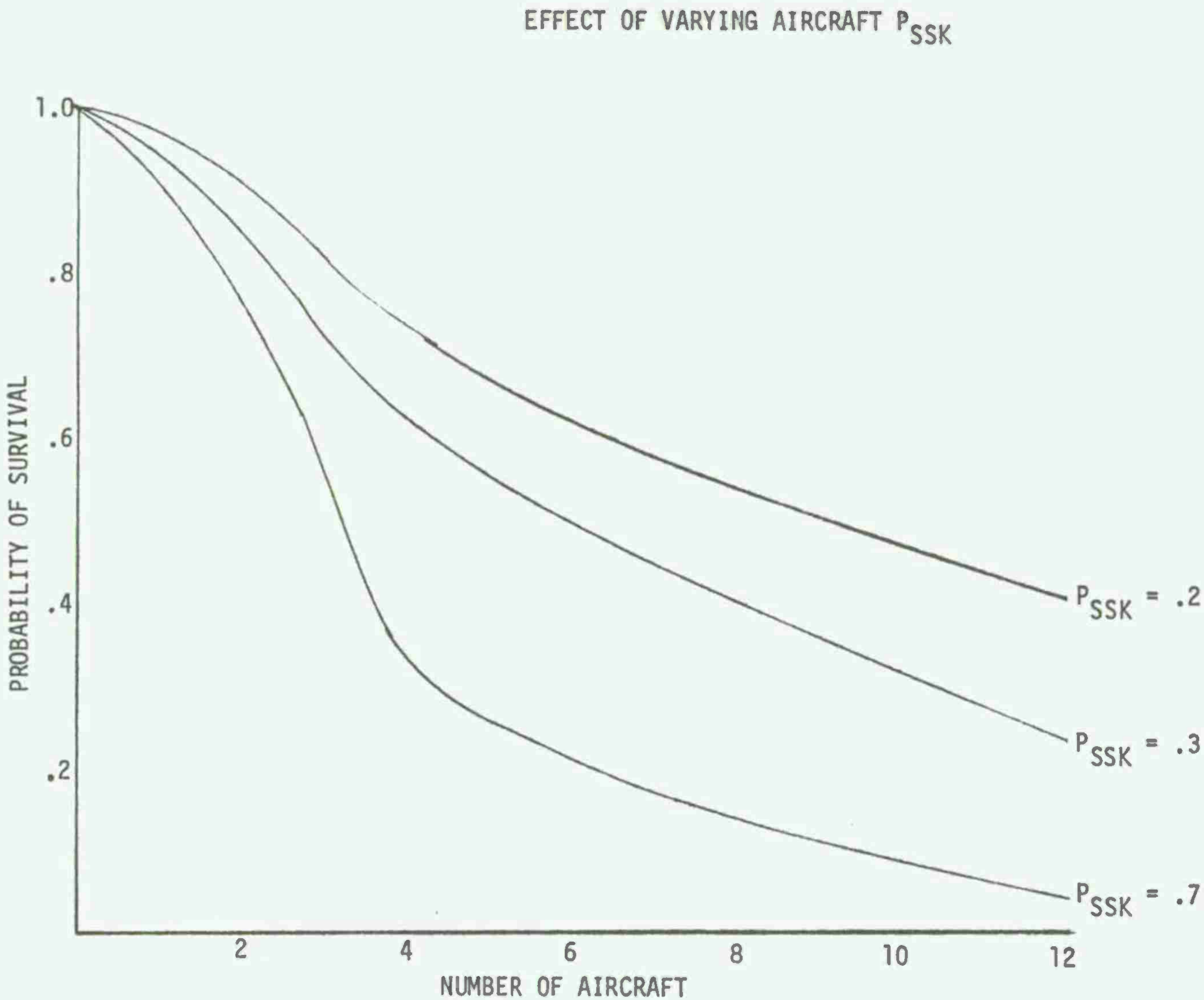
EFFECT OF VARYING AIRCRAFT P_{SSK}
1.0
.8
.6
.4
.2
PROBABILITY OF SURVIVAL
P_{SSK} = .2
P_{SSK} = .3
P_{SSK} = .7
2
4
6
8
10
12
NUMBER OF AIRCRAFT

FIGURE C-2

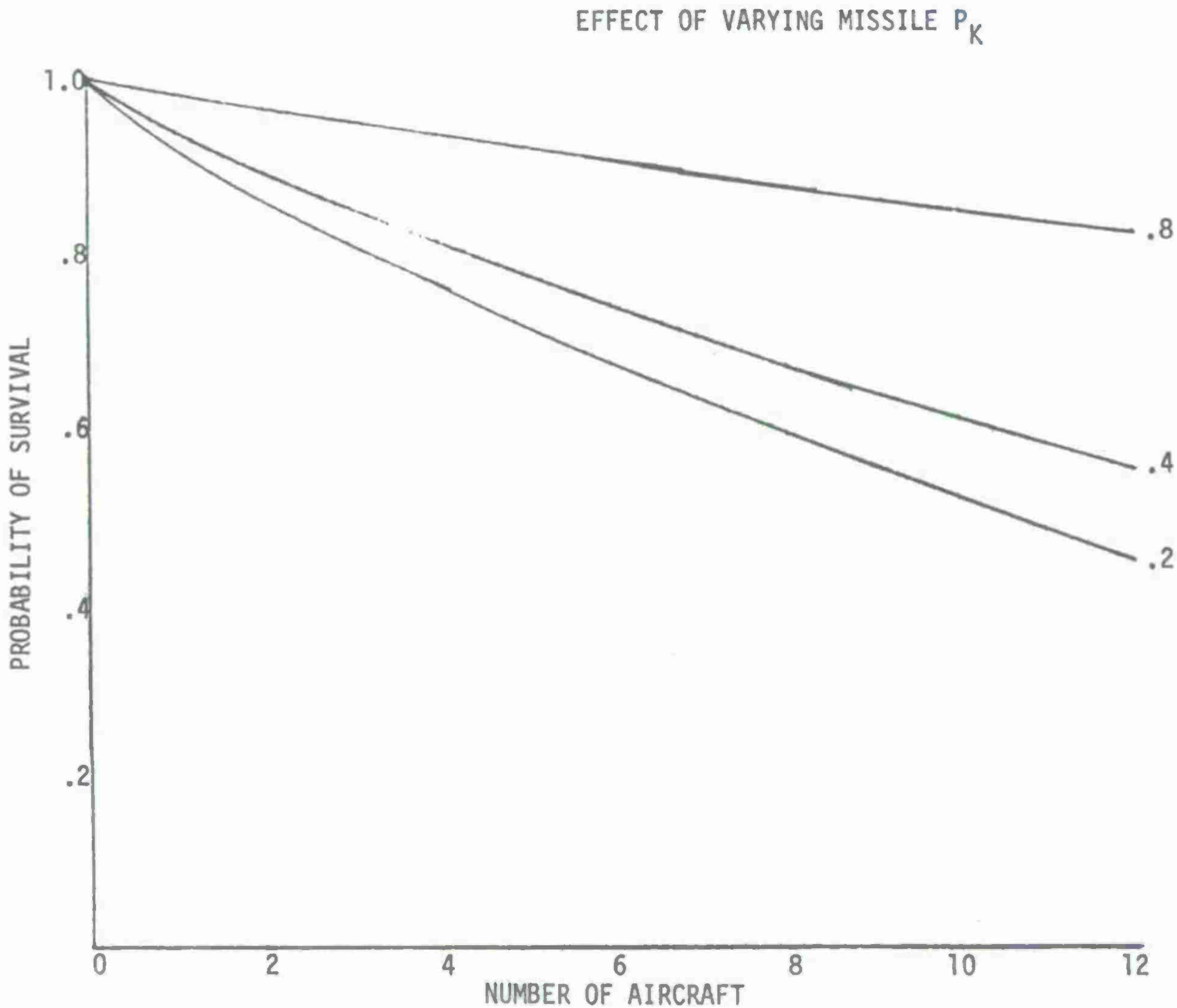
EFFECT OF VARYING MISSILE P_K
1.0
.8
.6
.4
.2
PROBABILITY OF SURVIVAL
0
2
4
6
8
10
12
NUMBER OF AIRCRAFT
.8
.4
.2

FIGURE C-3

EFFECT OF SEARCH SECTOR

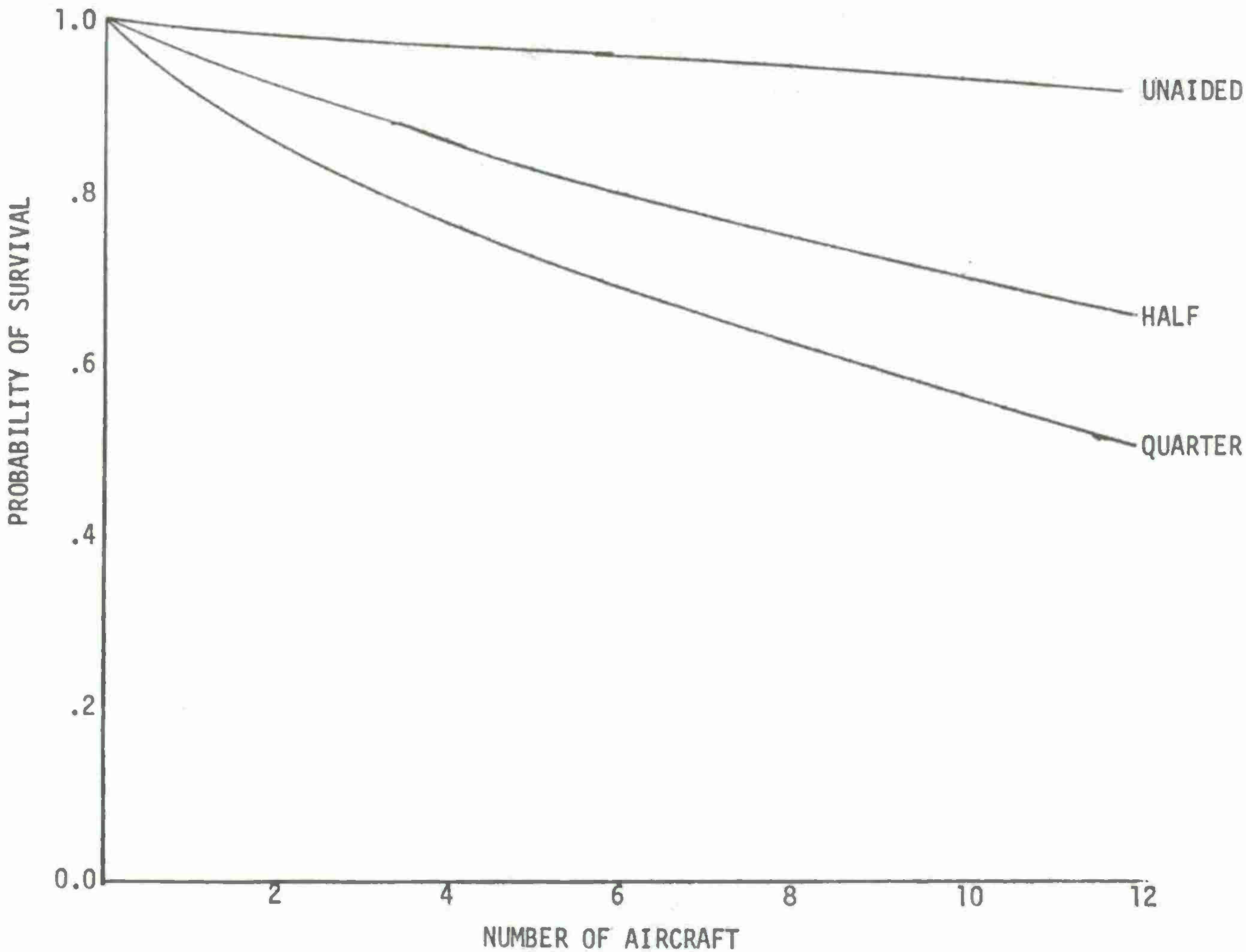

FIGURE C-4

EFFECT OF SITE HARDNESS ON
SUPPRESSION INDEX

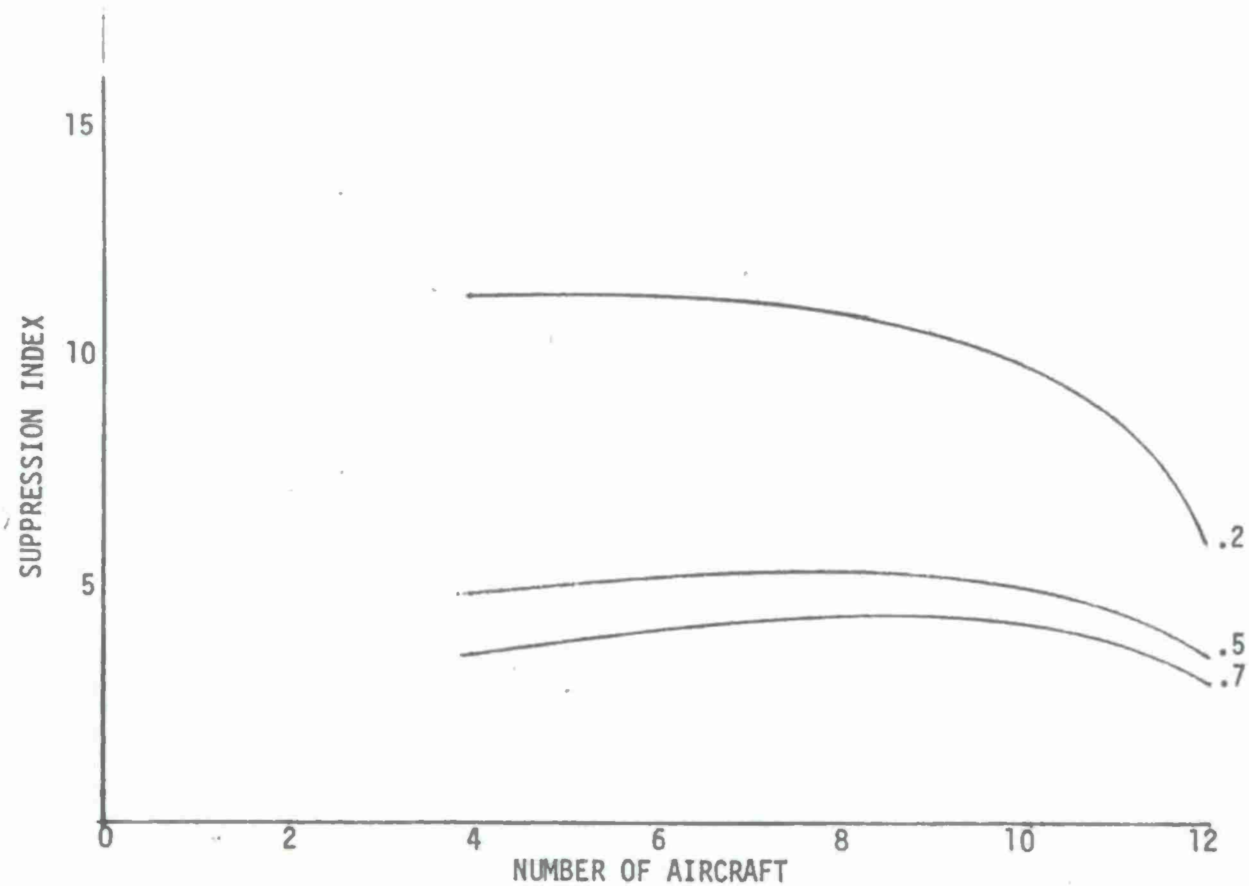

FIGURE C-5

Measures Of Effectiveness For Small Arms

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I. PURPOSE

This paper provides a framework for the evaluation of the effectiveness of small arms systems. Specifically, this is to be accomplished by first examining the historical development of measures of effectiveness (MOE) and then by determining appropriate measures to be utilized in field experiments.

II. HISTORICAL

Historically, one weapon system that has attracted a great deal of attention within the military and the public domain is the combat soldier's individual weapon. The importance of the proper selection of the most effective small arm is manifest. Procurement results in the expenditure of large sums of money (despite the low unit cost) and the combat effectiveness of the ground forces is directly related to the choice of weapon.

For many years, the primary measure of effectiveness used for small arms experiments and evaluations was accuracy. Accuracy was operationally defined as the number of rounds landing in a six inch diameter circle at 200 yards.

Subsequently, rate of fire was also used as an MOE. When considered with accuracy, this combination had an interpretation as the rate of destroying enemy targets. Consequently, the single shot cartridge replaced the muzzle loader, the bolt action replaced the single shot, the carbine (semi-automatic) replaced the bolt action and the automatic replaced the carbine. For approximately 100 years, accuracy and rate of fire were the sole determinants of which weapon was to be used.

Beginning in 1960, the number of MOE developed, defined, and used, expanded considerably. In fact, a recent literature search produced a list of 166 MOE [Ref. 5]. This proliferation was, in part, produced by the realization that, in an area such as the Republic of Viet Nam, the traditional MOE were not appropriate indicators of an effective weapon.

Recently, two major experiments/studies have made significant contributions to the determination of appropriate MOE for small arms systems. The first of these, the Small Arms Weapons Study (SAWS) is important in that the methodology for the determination of MOE was founded upon mission analysis. Consequently, this was the first experiment to utilize a MOE which is associated with the suppressive effects of a weapon.

The second, the Army Small Arms Requirements Study (ASARS) is unique in that the term measure of effectiveness is defined as an ideal and then all known candidate MOE are systematically evaluated in light of the qualities that a MOE should possess. Additionally, this study offers acknowledgement of the fact that the MOE selected determine the analytical and experimental models to be used, not vice versa.

The most current and best available source of information, USACDC Pamphlet 71-1, The Measurement of Effectiveness, provides a great deal of assistance in the selection and use of appropriate measures of effectiveness to evaluate land combat systems. Emphasis is placed on the methodology to develop measures of effectiveness and on the impact that MOE can have on modeling, military judgment and the conclusions of a study. The great value of this pamphlet is that it stresses the crucial role played by MOE in the decision-making process.

III. MOTIVATION

In a large amount of experimentation the reasons for the choice of the MOE are absent. Where justification is offered, frequently the rationale centers upon arguments that reflect a methodology of first enumerating possible MOE and then deciding if these MOE are related and if they are obtainable.

Rationally, the methodology for the determination of appropriate MOE must rest upon a thorough analysis of the mission. This analysis should provide conceptual effectiveness criteria which, in turn, can be transformed into specific operational definitions. Although some studies have applied this philosophy, they have neglected the determination of a complete list of effectiveness concepts and instead have concentrated upon the determination of the appropriate operational definitions for the few concepts selected. This lack of attention to the derivation of a complete list of effectiveness concepts is largely a result of an incomplete analysis of the mission of a small arms system.

The selection of inappropriate measures of effectiveness may lead to meaningless evaluations and to unsatisfactory decisions. Such a selection is tantamount to providing an answer to the wrong question. Thus, it is imperative that this portion of an analyst's evaluation be impeccable. Unfortunately, it is precisely this area which is the most elusive and disputed element of many otherwise well-founded studies, especially for land combat systems analyses.

IV. PROPOSED MOE'S

A. Approach

Analysis of the mission of a small arms system depends on the level at which we define the mission. When one considers the large variety of devastating weapons available to the commander of a battalion, company or platoon size unit, the effect of individual small arms at these levels may well be insignificant [Ref. 6]. Fire support such as artillery, armed helicopters and tactical air support is often under the direct control of the unit leader at these levels. On the other hand, below the platoon level, this type of firepower is seldom available for direct control. Thus, if one proceeds on a premise of choosing a level at which the system is of significance by itself, that level must be below the platoon.

It is at the squad and individual level that the small arms system will most often play a significant role. In the case of a rifle or pistol, the individual is the user/operator of the system and the psychological importance of the effectiveness of the weapon is overwhelming. Additionally, the squad is the smallest unit capable of fire and maneuver - the very essence of land combat. For these reasons, logic dictates that the mission of the small arms system should be determined at the squad and individual level.

At this level, the mission of the small arms system is to assist in the accomplishment of the ground force (small unit) mission. Effectiveness concepts can be developed by asking the question, "What do we desire the small arms system to provide in the form of outputs, considering the spectrum of attack, defense, and meeting engagements?" Note that this question eliminates the use of inputs, such as the rate of fire and the maximum range, as MOE. Instead, this approach allows weapons performance characteristics such as these to interact to produce outputs. Those outputs which assist in the accomplishment of the unit mission should be identifiable in terms of effectiveness concepts that may be further refined for use by developing suitable operational definitions.

B. Specific MOE

1. Availability

Within this framework, the sine qua non for small arms system is that it be available to assist in the accomplishment of the unit mission. Thus the first effectiveness concept is availability. Availability connotes not only that the weapon is physically present on the battlefield, but also whether the weapon is functionally capable of assisting in the accomplishment of the ground force mission. Consequently, availability can be conceptually separated into the terms of reliability and maintainability.

In some experiments, reliability is operationally defined as the number of times that a weapon would not fire. This definition does not provide a sufficient amount of information to be useful. Specifically, the information that a weapon failed to fire one time in one attempt is significantly different from the information that a weapon failed to fire one time in 100 attempts. Reliability should be operationally defined as the ratio of the number of failures to the number of attempted firings. Statistically, this ratio is an estimator for the parameter p of a probability distribution, where p represents the probability of a malfunction.

Knowing the reliability alone does not provide sufficient information concerning availability. For example, consider the case in which weapon A and weapon B had one failure in ten attempted firings, yet, in the case of weapon A, the soldier was able to repair the weapon in three seconds (immediate action drill), and, in the case of weapon B, the weapon was out of commission for ten minutes. In each case the operational definition for reliability provides equal values of 0.1 although it is apparent that, based upon this one experiment, the availability of weapon A is greater than that of weapon B.

A means to differentiate between the two weapons is provided by the concept of maintainability. Maintainability has been operationally defined in many different ways. However, a logically consistent definition is the mean time that a weapon is unable to operate during a malfunction. Mathematically, this should be estimated by the statistical average of all the inoperative times associated with the malfunctions of a weapon during an experiment.

The operational definitions of reliability and maintainability can be combined to form a single operational definition for availability. Assuming independence of the occurrence of a malfunction and the duration of the time of inoperative status due to a malfunction, the complete process can be described as a compound stochastic process. This process consists of a counting process for events and an independently distributed random variable to indicate the length of the event. Then,

$$A = \text{measure for availability} \sum_{i=1}^{F} D_i$$

where

F = the number of failures/malfunctions

D_i = the duration of the i^{th} failure

$F \sim$ general (n,p) where n = total attempted firings

$D \sim$ unspecified distribution that indicates the duration of a failure

One may operationally define availability as the expected value of A. Therefore, $E(A) = E(F) \cdot E(D)$ is the mean time that a weapon is not available during an experiment. In some cases, it may be possible to assess the distribution of D. In many cases, the use of generating functions and Laplace transformations will provide a great deal of information concerning the distribution of A and thus the statistical properties of the statistic used as an estimate for E(A).

2. Capability

The next desideratam is that the weapon be not only available but also be capable of assisting in the unit mission. The resultant effectiveness concept of capability is nothing more than the ability to influence the combat action in a manner which is favorable to the friendly ground forces. Under the assumption that the mission of a friendly unit will conflict with the mission of an enemy unit, a favorable environment for a friendly force is necessarily an unfavorable environment for the enemy. Thus, what is it that we want a small arms system to do to the enemy that will assist us in our mission? The only thing that the squad can do with the small arm is shoot at the enemy. The question then becomes, "What does the squad or individual hope to accomplish by shooting at the enemy that will assist him in his mission?" The answer to that question is that he wishes to either produce enemy casualties by hits or, if the projectile misses, to suppress the hostile force. In either case, the desired effect is to reduce the enemy's capability to perform his mission or to interfere in the accomplishment of the squad's mission.

It is desirable that the concept of capability be able to distinguish between wounding and killing of the enemy. For, if two weapons produced 100 casualties each, but in one case all of the casualties were fatalities and in the other case there were no fatalities, one might argue that the enemy's capability was reduced much more in the first case than in the second. Thus, the effectiveness concept of capability will be further described in terms of lethality (that part associated with fatalities), casualty production (that part associated with wounding enemy soldiers) and suppression (that part associated with missing the enemy soldier but still adversely affecting his ability to perform his mission).

Capability MOE should express both casualties and suppression in the form of a percentage of a force as a function of time. In the case of casualties, the frame of reference should be the percentage of the original enemy force and, in the case of suppression, the reference should be the percentage of the remaining force (non-fatalities) that is suppressed. The respective frames of reference of the original and the remaining force are ones that give an indication of the enemy's remaining capability. The necessity of knowing the respective percentages as a function of time is a result of the need to distinguish between a case of 50% casualties which occurred in the first ten minutes of a 60-minute scenario or experiment and a case of 50% casualties at the conclusion of the same 60-minute experiment. Obviously, the sooner you can destroy a certain amount of the enemy's capability, the better.

Similarly, the percentage of the remaining force that is suppressed as a function of time provides information that a measure such as reduction in cumulative exposure time cannot [Ref. 4]. In particular, ten minutes of cumulative reduced expocure time may be one enemy soldier suppressed for ten minutes or ten enemy soldiers suppressed for one minute. Furthermore, all ten minutes may have occurred initially or may have accumulated gradually throughout a 60-minute scenario.

The SAWS defines precisely an occurrence of suppression of a target. The MOE utilized for the concept of suppression in this study is the percentage of the remaining (non-fatalities) targets that are suppressed as a function of time where a suppressed target is one such that two rounds pass within two meters of the target during a three second interval. Similarly, the MOE utilized for the concept of casualty production should be the percentage of the original number of targets that have been hit one or more times as a function of time. This definition encompasses the concept of lethality because a target that is hit one or more times may be a fatality. The exactness of this MOE depends directly upon a suitable operational definition for lethality.

Developing an acceptable operational definition of lethality has been a subject of controversy during the past several years. One suggestion is that a group of medical experts could determine the probability of a soldier dying within 30 seconds given that he is hit by a projectile of a specific weapon. This determination could be accomplished by use of the Delphi technique when examining the effects of random hits upon human forms.

Armed with such a definition, it would be possible, on a properly instrumented range, to determine the number of casualties at any particular time and then multiply by the appropriate fraction to determine the number of fatalities. This information would form the basis for providing the values of the MOE selected for casualty production.

3. Sustainability

Given the availability and capability of a small arms system the next concern becomes that of sustainability. The effectiveness concept of sustainability is merely a reflection of the desire to continue the capabilities of the small arms system over time. This desire translates into consideration of supply shortages of ammunition. The natural question (something which unit leaders are taught to check after every combat action) is "how much ammunition is remaining?" But comparative results have no meaning unless the amount of ammunition that the soldier had at the beginning (the basic load) is known. Thus the operational definition for sustainability is the percentage of the basic load remaining at the conclusion of the experiment. This measure can only be interpreted when the system weight (weapon + ammo) is held at a constant level for all candidate weapons. Under such conditions, this measure of effectiveness provides a clear indication of the ability of the weapon to continue to provide assistance in the accomplishment of a subsequent mission.

The MOE associated with sustainability and the MOE that are used to describe the concepts of availability and capability possibly interact. An advantage or favorable outcome with respect to availability and capability may have a high correlation with a less favorable outcome in the area of sustainability. An extreme, hypothetical example, is the weapon that always fires and is capable of destroying an entire enemy battalion, but because of its weight the soldier can carry only one round. In more realistic cases, our technological intuition indicates that a weapon that is extremely lethal most likely has a heavier cartridge either due to a larger projectile or a greater velocity which requires more propellant. Similarly, a weapon that produces more casualties and suppression through an extremely high rate of fire necessarily uses more of the original basic load. In all of these cases, the indication is of a possible low output value of the MOE specified for sustainability. Generally, it seems that this is the area of trade-offs where systems "pay" for advantages enjoyed in other areas.

4. Compatibility

The implicit requirement exists that a small arms system not only assist in the accomplishment of the mission, but also, that it not detract or hinder the accomplishment in some other manner. This effectiveness concept is compatibility and it is reflected to a large degree in terms of human factors consideration.

Of primary importance within the area of compatibility is the concept of safety. If a weapon is unsafe, then it could hinder the accomplishment of the mission by injuring the friendly soldier. An unsafe weapon is one that does not meet the engineering safety specifications in the appropriate military publication or that produces problems during testing that could cause injury.

Also included within the classification of compatibility are those factors which could adversely influence the combat functions of a soldier. As an example, a flash suppressor that gets caught in the vines and weeds is a definite restriction upon the mobility and maneuverability of a soldier. Similarly, a weapon that reflects a great deal of sunlight or does not have an effective flash suppressor may hinder a soldier's attempt to conceal himself from the enemy.

Overall, it appears that the two areas of compatibility are safety and other mission considerations. For each of these MOE one could choose a yes-no classification or measure. Thus the MOE becomes operationally defined as answering the question of whether the weapon is safe according to published standards as well as testing results and whether the weapon could possibly interfere with any combat function of a soldier. In either case, carefully planned experimentation will be an essential element in the process of answering each question.

V. SUMMARY

In summary, sequential analysis of a broad mission statement for a small arms system produces the effectiveness concepts of availability, capability, sustainability and compatibility. For each of these concepts an operational definition and rationalization exist. These definitions provide a means and a logical framework for measuring the outputs of an experiment that are of interest in procurement decisions.

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The Gun Air Defense Effectiveness Study

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The Gun Air Defense Effectiveness Study (GADES) was conducted by the GEN Thomas J. Rodman Laboratory, Rock Island Arsenal, from December 1970 to April 1974. The United States Armament Command, formerly the United States Army Weapons Command, was responsible for the overall management of the GADES program. A GADES Review Board of representatives from major Army Agencies was established to monitor the progress of the GADES Program, and to advise and offer appropriate guidance.

Prior to GADES, consistant, validated methodologies for evaluation of gun air defense systems were not available and lack of a detailed understanding of the effectiveness of these gun systems was a continuing problem. The 20mm VULCAN Gun System effectiveness had notbeen determined with confidence even though the system had been tested extensively. Areas for product improvements and their contributions to increased system effectiveness could not be determined with high confidence. The need for a validated methodology for evaluating gun systems plus the need for factual information on the VULCAN Air Defense System led to an evaluation of this system in GADES.

Four major objectives were established for GADES:

1. <u>Develop improved means for gun air defense testing.</u>

Development of sophisticated, long-range air defense gun systems with high rates of fire and more accurate weapon pointing had emphasized the need for more accurate and expeditious means of testing. The GADES program was designed to develop new test procedures and techniques, more efficient and accurate test instrumentation, and improved data formats and recording methods.

2. <u>Provide validated methodology for evaluation of present and future gun air defense sytems.</u>

Sound, consistent methodologies for gun air defense system evaluations have notbeen available. Prior evaluations were made on the basis of system tests in the field or on unsubstantiated computer simulation results. Analysis and evaluation of these sources of data have often resulted in confusing and conflicting results. Concern over a lack of a reliable analysis methodology has led to the formulation of this GADES objective.

3. <u>Determine VULCAN effectiveness.</u>

VULCAN Air Defense System (VADS) effectiveness had not been previously determined with confidence (even though the system had been extensively used). Accurate evaluation of VADS effectiveness was needed to determine the value of VADS in the field, to evaluate proposed product improvements, and to allow comparison with other gun air defense systems.

4. <u>Identify VULCAN improvement areas and analyze product improvements.</u>

Many of the deficiencies of VADS have been recognized and system improvements have been proposed. These product improvement proposals were submitted to an objective evaluation in order to select the most cost effective and beneficial improvements.

The accomplishment of the GADES objectives demonstrates the value of Operations Research to the U.S. Army. First, the effectiveness of VADS was assessed as well as the resultant improvement in effectiveness under the assumption of product improvements. These data have been placed on a sound basis and have been obtained from a well-planned and well-executed Operations Research Study. "Hard numbers" of this type are invaluable to the decision maker.

Secondly, GADES methodology, techniques, and methods are available for application to future gun air defense programs. GADES personnel continue to work in air defense gun program at Rodman Laboratory. This expertise is invaluable in future study and analysis, and in selection of the Low Altitude Foreward Area Air Defense System (LOFAADS) systems.

A more complete discussion of the accomplishment of the GADES objectives follows:

<u>Objective 1</u> - Test Instrumentation and Methodology

Planning and conducting of the GADES Tests resulted in the development or purchase of instrumentation to enhance and expedite the tests. A list of the major test equipment used in the GADES test is shown below.

MISS DISTANCE INDICATING RADAR (MIDI)
DATA ACQUISITION SYSTEM (DAS)
HULCHER 70mm GUN CAMERA
N9 16mm THRU SIGHT CAMERA
MUZZLE VELOCITY RADAR (MVR)
FIBERGLASS AERIAL TARGET (FIGAT)
DYNAMIC FIELD EVALUATOR (DFE)

-- MIDI RADAR --

The MIDI Radar was developed to meet GADES test requirements and to support future gun and missile systems testing. The MIDI replaces the photographic method of measuring miss distance. It can score a variety of surface-to-air weapons. Projectiles as small as 0.50 caliber and as large as modern air defense missiles have been scored. Firing rates of up to 3,600 rounds per minute can be accommodated. Vector miss-distance measurement (both distance and direction to the point of closest approach) is computed on each individual round scored.

Two radar antenna modes are provided: one for short range, wide field of view and one for long range, narrow field of view operations. A television camera, mounted on the antenna, provides the operators with a visual display of the target during tracking and aids target acquisition. During tracking, the MIDI records target position on magnetic tape and transmits this information in near real-time to a line printer. The position of each round detected is computed for calculation of the vector miss-distance and printed on the line printer. The actual dispersion for each burst is optically displayed on a CRT for a coarse scoring evaluation. Miss distance information, which can be available within two hours by additional processing, includes miss-distance data by burst, scoring summary by burst, miss-distance summary by burst (centroid and standard deviation), direction cosines, miss distance per round, and a general burst summary.

The major advantages of the MIDI radar are: (1) the accurate and precise tracking and scoring of small radar targets, (2) the capacity to score closely spaced (high rate of fire) projectiles, (3) the capacity to "read" vector miss-distance (projectile to target), (4) the wide spatial coverage about the target, (5) the capacity to score projectiles when target drones are used (wide variation in radar cross section), (6) rapid and accurate automatic calibration, (7) immediate printout of scoring data, and (8) low cost over previously used photographic techniques.

-- Data Acquisition System (DAS) --

The purpose of the DAS was to record the VULCAN Air Defense System performance data during testing. The DAS records up to 27 channels of analog data and up to 32 channels of discrete event data every one-hundredth of a second on a magnetic tape. Range time is also recorded. The analog data are recorded as voltages, transmitted to the DAS instrumentation van, and stored on magnetic tape

Major advantages of the DAS are those of immediate, "quick look" analysis of raw data allowing "timely" acceptance or rejection of target pass data plus "next day" printout of format data for complete analysis. This availability of large quantities of data in near real-time reduces the time and cost of data reduction and analysis when compared with standard photographic data reduction methods.

-- CAMERAS --

The Hulcher 70mm camera was used to measure gun lead angles. The 16mm THRU SIGHT camera was used to record the tracking performance history of the gunner. The camera data were reduced, recorded on magnetic tape, and compared with DAS data as a check on the validity of the two sets of instrumentation.

-- MUZZLE VELOCITY RADAR --

The muzzle velocity radar "computes" the muzzle velocity of each round for use in ballistic computation. The system has been tested with projectiles ranging in size from 5.56mm to 175mm and velocities from 260 to 1,000 meters per second. Muzzle velocity is computed to an accuracy of ±.25% for projectiles 20mm and larger in diameter.

-- FIBERGLASS AERIAL TARGET --

The FIGAT has been extensively used in air-to-air gunnery practice by both the Air Force and the Navy. It was first used in ground-to-air gunnery tests by the Army during the GADES project. The FIGAT is dart-shaped, 30 feet in length, weighs 500 pounds, and has a nominal broadside area of 105 square feet. The FIGAT has demonstrated tow speeds to Mach 0.9 (approximately 600 knots) and maneuvers to 4.5g's. An F4 Phantom jet aircraft was the tow craft during the GADES test.

-- DYNAMIC FIELD EVALUATOR --

The Dynamic Field Evaluator (DFE) was developed under contract from engineering concepts for a VULCAN dynamic tester formulated at Frankford Arsenal. A variety of simulated aerial threats are presented by the DFE to the VADS and its operator. The various system parameters can be readily and accurately measured and recorded for analysis. The DFE will generate data for the target paths, and measure and record up to 48 parameters on magnetic tape for further analysis.

Either the self-propelled or the towed version of the VADS can be used in conjunction with the DFE. Each system requires the mounting of a sight attachment for display of the synthetic target image, a digital processor and calligraphic symbol generator, and a radar target simulator. The DFE Control console comprises a teletype machine, a Nova 1200 mini-computer, a high-speed paper tape reader and punch, a cathode ray tube, and a magnetic tape unit.

The three major advantages of this equipment are:

- Synthetic target presentation saves cost of flying real targets on a test range.

- Accurate digital and analog recordings of all important signals are possible.

- Any target path may be simulated (no range limitations).

A notable advance has been made in Air Defense Gun Testing. The MIDI Radar has provided the capability to plot the projectile miss distance with respect to the target. New weapon system instrumentation has improved accuracy and increased frequency of response. New camera techniques, coupled with larger targets, have extended the range of accurate tracking error measurements. Quick-look capabilities have been improved to provide better management of testing because of the ability to determine the quality of data acquired. Atmospheric data acquisition, especially measurements of winds aloft, has been improved. All these improvements make possible the use of new design of experiment techniques to improve data evaluation and reduce test cost.

<u>Objective 2</u> - GADES Tests

The GADES Aerial Firing tests were conducted on the Dona Ana 45 Range at Ft. Bliss, Texas, from April to September 1973. The tests were conducted with four M163 Self-propelled VADS. Each M163 system comprises an open-turret mounted M168 20mm Gatling-type cannon on an M741 (modified M114) tracked vehicle. The 20mm cannon fires at a high rate of 3,000 shots per minute. The gun and turret are electrically powered from 28 volt NI-CAD batteries charged by the vehicle alternator or an auxiliary power unit. Ammunition is supplied to the gun through a linkless feed system from a 1,000 round capacity drum. The fire control consists basically of the M61 lead computing sight, the AN/VPS-2 Range Only Radar, an analog computer (Sight Current Generator), control panel, and positioning servos for the gun.

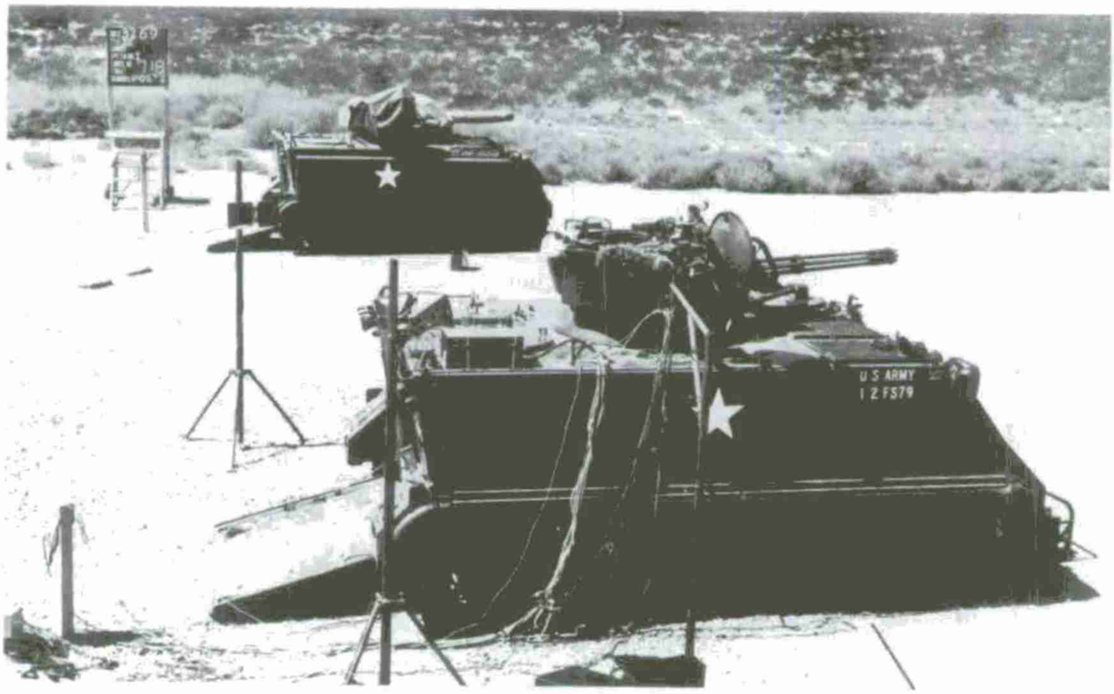

Figure 1 Instrumented M163 VULCAN Air Defense System

Three distinct tests were conducted. These tests were as follows:

Test I - A nonfiring test to determine the system tracking performance.

Test II - A firing test to evaluate system sensitivity to engagement parameters.

Test III- A firing test to establish the effect of dynamic firing upon tracking performance and to determine system accuracy.

The test design was structured to test the extreme limit of system performance. Twenty-nine basic flight paths were chosen. Five repetitions of each basic flight path were flown in Tests I and III. Each repetition is distinguished by the range of the burst. One burst is fired at long and short range, two bursts are fired at medium range, and one burst is fired at will. The variation in range of burst causes changes in rates necessary to describe the extremes of the system.

Test II was designed to test for parameters such as, difference among gunners, the effect of burst length and the effect of pass direction.

The number of completed test passes for the VADS test is shown in the table below. A pass was considered completed only if the data satisfied the standards of quality desired. Consequently, one completed pass may have required multiple target passes.

			RUNS PLANNED	RUNS COMPLETED (%)
Test I	-	Tracking	145	99
Test II	-	Gun Parameters	80	87
Test III	-	Firing	145	93

Seven hundred and fifteen target passes were flown. The data sets not completed were the result of test site safety restrictions or hardware limitations. In addition, a test of the prototype Automatic Track VULCAN System (AVADS), a VADS product improvement, was also completed.

Objective 3 - Models and Validation

Three levels of computer simulation models were developed or acquired during the GADES project to assess the effectiveness of VADS. These models are as follows:

NAME	DESCRIPTION
ISO-PK	1-1, Deterministic, Error Budget Model
FUE	1-1, Stochastic, Engineering Model
TAGWAR	M-N, Deterministic, Combat Effectiveness Model

-- ISO-PK --

The ISO-PK model incorporates a deterministic burst kill algorithm and a simple contour plot to present isometric burst kill probability contours at selected altitudes. The burst kill algorithm is a function of rounds in the burst, vulnerable area of the target, mean and standard deviation of burst dispersion, and mean and standard deviation of gun pointing position. The means and standard deviations are computed from static gun and sensor errors which are input to the model. Model engagement parameters are used in the computation of these algorithm inputs in order to assess the effect of rate of change of the parameters on the burst.

The model can be used for extensive parametric sensitivity testing of system performance under variation of gun and sensor error sources. This type of analysis is useful in the deletion of obviously deficient system comcepts from consideration before they are submitted for more extensive and expensive analysis.

-- FUE --

The Fire Unit Effectiveness Model (FUE) is a Monte Carlo simulacion of an engagement between a VADS and a passive, high performance aircraft. The FUE has two purposes: First, it is the primary analytical tool used to evaluate VADS effectiveness. Secondly, it is used to explore the effect of design changes in the VULCAN acquistion and tracking system, fire control system, and ammunition.

FUE is an engineering orientated model designed specifically for VADS. Major submodels are (1) Target, (2) Acquisition, (3) Fire Control, (4) Human Gunner, and (5) Exterior Ballistics. A brief description of these submodels follows:

(1) Target - The target aircraft is represented as a point in space flying along a predetermined flight path. Target position and velocity are inputted from field test data for validation purposes. Target vulnerability is modeled by use of the standard parallelopiped or "shoebox". On the basis of target orientation, the same vulnerable area is computed and a corresponding radius of a circle with the same vulnerable area is determined. A round is said to have "killed" the target if it passes within a distance less than or equal to the computed lethal radius.

(2) Acquisition - This submodel comprises a sequence of random and constant time delays to account for various acquisiton events. Events considered include a random time delay for visual detection, a random reaction time to slew the weapon, a random time for radar detection, and a constant delay time to smooth track.

(3) Fire Control - The VULCAN fire control system is modeled by a state-space representation of the traverse and the elevation control axes. A schematic diagram of the traverse axis is shown in Figure 2. The elevation axis is similar. The traverse and the elevation axes function with the human operator (gunner) closing the control loop formed by the system hardware.

The visual display consists of functions which define the tracking error as observed by the gunner. Inputs to these functions are the gun angles, lead angles, and target position. The gunner then displaces the handlebars an appropriate amount on the basis of the observable tracking position from the reticle. The lead angle computation is determined by the output of the sight current generator, which is a function of the present range of the target, the range rate, and the total lead angle.

(4) Human-Gunner - This submodel is one in which modern control and estimation theory are combined with human response theory to obtain a predictive model of the input-output tracking response of the gunner. Target states, tracking error, and their rates are presented to the gunner, and handlebar displacement in traverse and in elevation is returned.

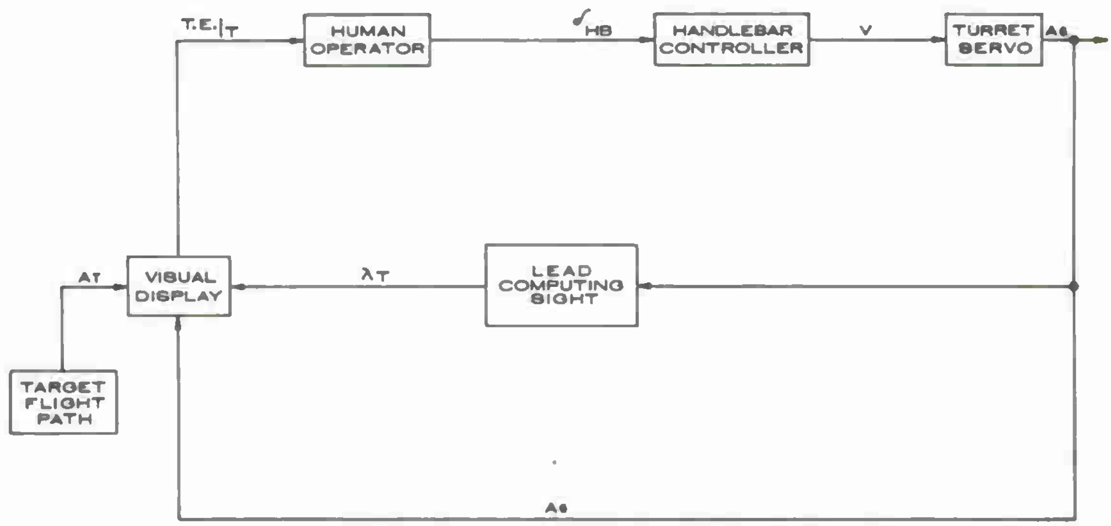

Figure 2 Traverse Axis - VULCAN Fire Control System

(5) Exterior Ballistics - This submodel is a three degree of freedom model in which the trajectory of the projectile is described on the basis of initial conditions at the time of fire. With this routine, field data from the target passes are inputs, and include such items as wind data, average projectile muzzle velocities, and their standard deviations.

The FUE was validated by "tuning" the model with field data selected at random from 60% of the target passes from each of Test I and Test III. This procedure assures a sound basis for comparing test and model results. After tuning, the FUE was replicated to compare model results with the remaining 40% of the test passes. Performance criteria include gun positions, lead angles, tracking errors, handlebar positions, the sight sensitivity factor Tn, and miss distance computations.

A typical result for gun position statistic is given in the following figures. The solid black line depicts the field data while the dashed line depicts the mean of fifteen replications of the model. The black dots represent the replication means plus or minus two time the sample standard deviation. The model results were considered in agreement with the test results if the test results lay within the envelope formed by the dots for most of the pass.

A total of eighty-three individual passes were simulated during the tracking phase of model validation. Approximately 75% of these passes showed good agreement between model and test. The poor agreement in the remaining passes can be attributed to observable phenomenon such as poor tracker performance or erratic target performance. In general, model agreement with test results could not be categorized by type of pass.

Validation of miss distance was accomplished with the Test III, Firing

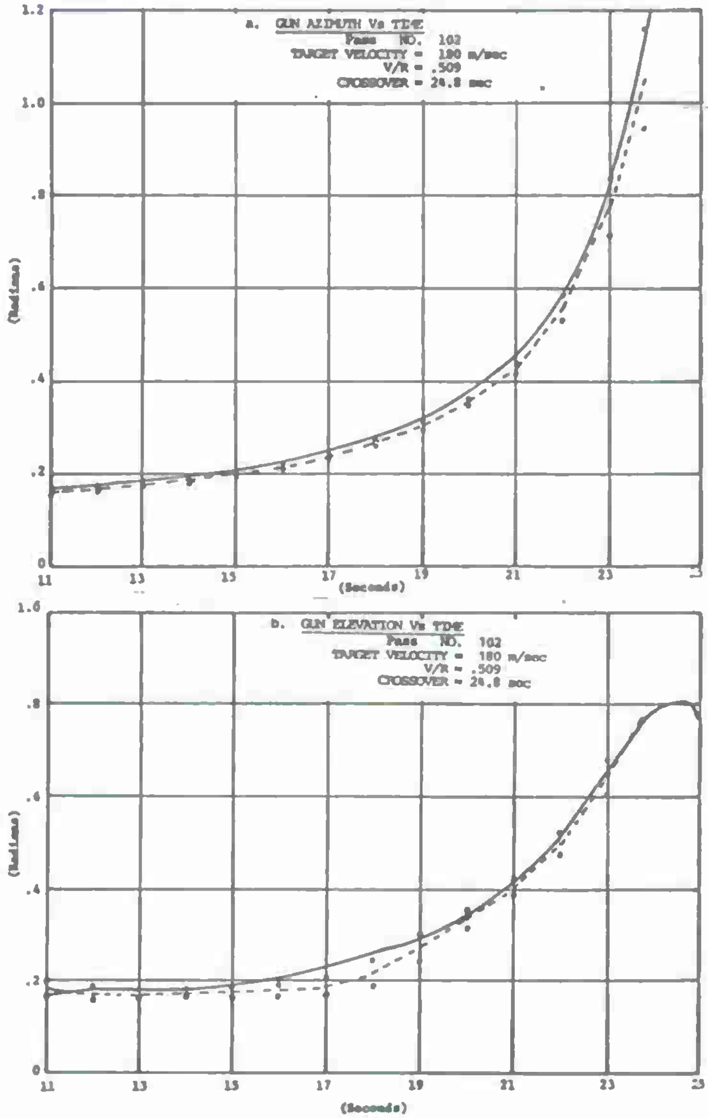

Figure 3 Comparison of Gun Positions for Field Tests Versus Model

Test data. The gun parameters established during the tracking validation were retained and only parameters in the external ballistics model were "tuned".

A total of twenty seven individual flight paths were selected from twenty of the twenty nine basic flight paths. Simultaneous confidence intervals for the X-Y-Z coordinates of each burst miss distances were computed. The model and test results were considered in agreement if the average X-Y-Z components of test miss distance fell within the cube formed by the simultaneous confidence limits formed from the replicated model results.

Good agreement between model and test results was obtained on 75% of the passes. As before in the Tracking validation, agreement between the two data sources could not be categorized by type of course.

The FUE model was compared with the ISO-PK model to ensure that the two models were compatible. Three 450 knot and three 250 knot GADES flight paths were used. Two bursts were fired at different engagement ranges on each pass. Each burst was replicated twenty-five times to determine the burst probability of kill.

A comparison of the two models was performed with Bayesian techniques. The results indicate agreement for all except four burst. Two of these bursts are at the high altitude where the FUE effectiveness is higher than ISO-PK. The other two bursts are on the slow courses where the FUE model has a greater effectiveness than does ISO-PK.

-- TAGWAR --

The Tactical Air-Ground Warfare (TAGWAR) model is a sophisticated, state-of-the-art computer model by which the air-to-ground battle, the ground-to-air battle, or a combination of the two for a complete engagement analysis, are simulated. The engagements are conducted in a multiple threat and attack environment.

Detailed mathematical models are included for the aircraft, avionics systems, air defense guns, and surface-to-air missiles, aircraft penetration tactics, weapon delivery maneuvers, and terrain masking on the overall effectiveness evaluation of any system or design change in the system.

Because of the late acquisition of this model, TAGWAR was not used in the evaluation of VADS effectiveness. However, TAGWAR can now be used in the evaluation of future systems. The ISO-PK kill algorithm has been incorporated into TAGWAR to make the two models more compatible.

Objective 4 - PIP Evaluation

VADS product improvements were evaluated and their relative merits were assessed. A parametric sensitivity analysis was conducted on the FUE model to relate the sensitivity of miss distance and hit probability to different levels of the independent variables of target position and gun system errors. The series of experiments were structured into three groups: Group A - long range or first burst conditions, Group B - short range or second burst conditions, and Group C - long range with winds and improved ammunition. Each of the individual experiments is based on a rotatable composite design in which eleven independent variables can be examined simultaneously.

Some of the significant conclusions of this analysis follow:

- The results of all experiments were dominated by the independent variables of range, elevation, and angular rates. These results suggest a general incapability of the VADS fire control to accurately solve the fire control problem against straight, level, constant speed targets.
- No optimum fire point was revealed by this analysis. This part arises from the design of the fire control system to be precise at one target point and speed.
- Hits and kills appear to be more sensitive to sensor errors at long range and to gun and fire control errors at short ranges and high angular

rates.

- Hits and kills seem more sensitive to vertical miss distance than to horizontal miss distance.
- A ranging error of less than 10 meters produces negligible degradation in hits and kills. However, a ranging error in excess of 20 meters produces a drastic reduction in the number of hits and kills.
- Hits and kills are relatively insensitive to burst size and gun dispersion. This result may be the results of large magnitudes of miss distance.

In addition to the sensitivity analysis, specific product improvement proposals were evaluated. The ISO-PK model was used in this analysis to ensure a level of comparability between VADS and AVADS evaluation. Product improvements recommended for implementaion were:

1. The XM10 VULCAN Gunner Tracking Evaluator (VTGE) - Increases gunner tracking capability through improved gunner evaluation and training.

2. The Sight Current Generator (SCG) Improvement - Provides more accurate ballistic computations.

3. The Range Only Radar (ROR) Test Set - Provides improved diagnostic and radar calibration, resulting in more accurate target range inputs for fire control computations.

Other product improvements evaluated, but not recommended for immediate implementation were:

1. Optimum Muzzle Clamp - No significant advantage

2. Optimum Firing Light Circuit - Analysis against expected number of hits and kill probability of each burst indicates an inconsistent relationship with the measurable engagement parameters of range and angular rates.

3. Redesigned Full Bore Ammunition - Cost versus effectiveness ratio, too high.

4. Subcaliber Penetrator Ammunition - Cost versus effectiveness ratio, too high.

5. AVADS - Continue to improve the system, include the system in LOFAADS selection.

SUMMARY AND CONCLUSIONS

The value of Operations Research to the Army is in the production of viable, quantitative data and alternatives to the executive decision maker. The value of any particular operations research study is enhanced when the study produces a definitive methodology or body of techniques that can be applied to similar problems. With the development of such methodology, consistent information can be provided to the executive.

The GADES study has provided definitive data and methodology in the study of gun air defense. The quantitative results and recommendations of the GADES study have been reviewed in this paper. A review of the activities of GADES personnel shows the additional benefit of the GADES project to current Army programs. This expertise was not available to the Army before the initiation of GADES.

GADES personnel have been actively involved in various air defense study efforts during and after the GADES study effort. These studies include the following:

- Divisional Air Defense Study (DIVADS)
- Evaluation of Foreign Guns (EFG)
- Exploitation of Foreign Guns
- Hit Evaluation Program (HITVAL)
- Gun Low Altitude Air Defense System (GLAADS)

A more complete discussion of the GLAADS project will show the benefit of GADES expertise. The GLAADS experimental prototype program is the test-bed evaluation of the latest technology for gun air defense. It is to be accomplished by the design, fabrication, and testing of an experimental prototype system mounted on a MICV-65 carrier vehicle. System performance evaluation will include nonfiring tracking tests against high performance aircraft and firing tests against air defense targets.

GADES personnel are responsible for the GLAADS test design. They are also modeling the system using GADES validated methodology. The GADES expertise will provide the Army with experienced, objective means of evaluating this test bed system.

USING TERRAIN DATA TO ESTIMATE ABORT RATES FOR WIREGUIDED MISSILES

1. Introduction. Intervisibility between antitank weapon and target has long been recognized as a key factor in determining the attrition rates of attackers and defenders. For the wire-guided missile there is another aspect in addition to the primary one of having to see the target in order to fire. This other aspect concerns the missile abort which occurs when the target goes out of view during the flight time of the missile. Available data, although meager thus far, permit some farily clean estimates of abort rates to be made.

2. Discussion

a. The TETAM Study (done by the Combat Developments Command, Reference 1) gives cumulative probability distributions of intervisibility path lengths for test areas on the North German Plain and in the Fulda Gap vicinity of Germany. (Some limited data from terrain at Fort Lewis, Washington, and Hunter-Liggett Military Reservation are also given.) This cumulative distribution is defined to be the probability that an approaching tank will be continuously visible to a ground-situated fixed defender weapon while it traverses a path of length ℓ or greater, given that it is at least momentarily visible. Notice that this definition says nothing about the probability of intervisibility itself (although the TETAM Study addresses this question, too) but merely arranges the observed intervisibility lengths into a distribution — e.g., 100 percent of the time the path was greater than zero, 90 percent of the time the path was greater than 200 meters, etc. The distributions, plotted as functions of intervisibility segment length, begin at 1.0 for the shortest lengths and decrease monotonically as the length segments get longer.

b. The plots of intervisibility segment length distribution in the TETAM report were replotted on semilog paper to bring out their exponential character. An example is shown on Figure 1. From the plots, a constant $\underline{a}$ was determined for each area (Fulda, N. German Plain, etc.) and range to the attacker. This constant produces a fit of the data to a function of the form

$$P = A \exp(-\ell/a)$$

where $\underline{P}$ is the probability that the path segment length exceeds ℓ and $\underline{A}$ is a constant whose value depends upon the lower cutoff value of ℓ (i.e., the shortest length that is included in the distribution). The value of $\underline{a}$ is the segment length which will be exceeded only 1/e of the time (about 1/3 of the time) when the distribution is truly exponential in form. (This $\underline{a}$ value also turns out to be the average segment length.)

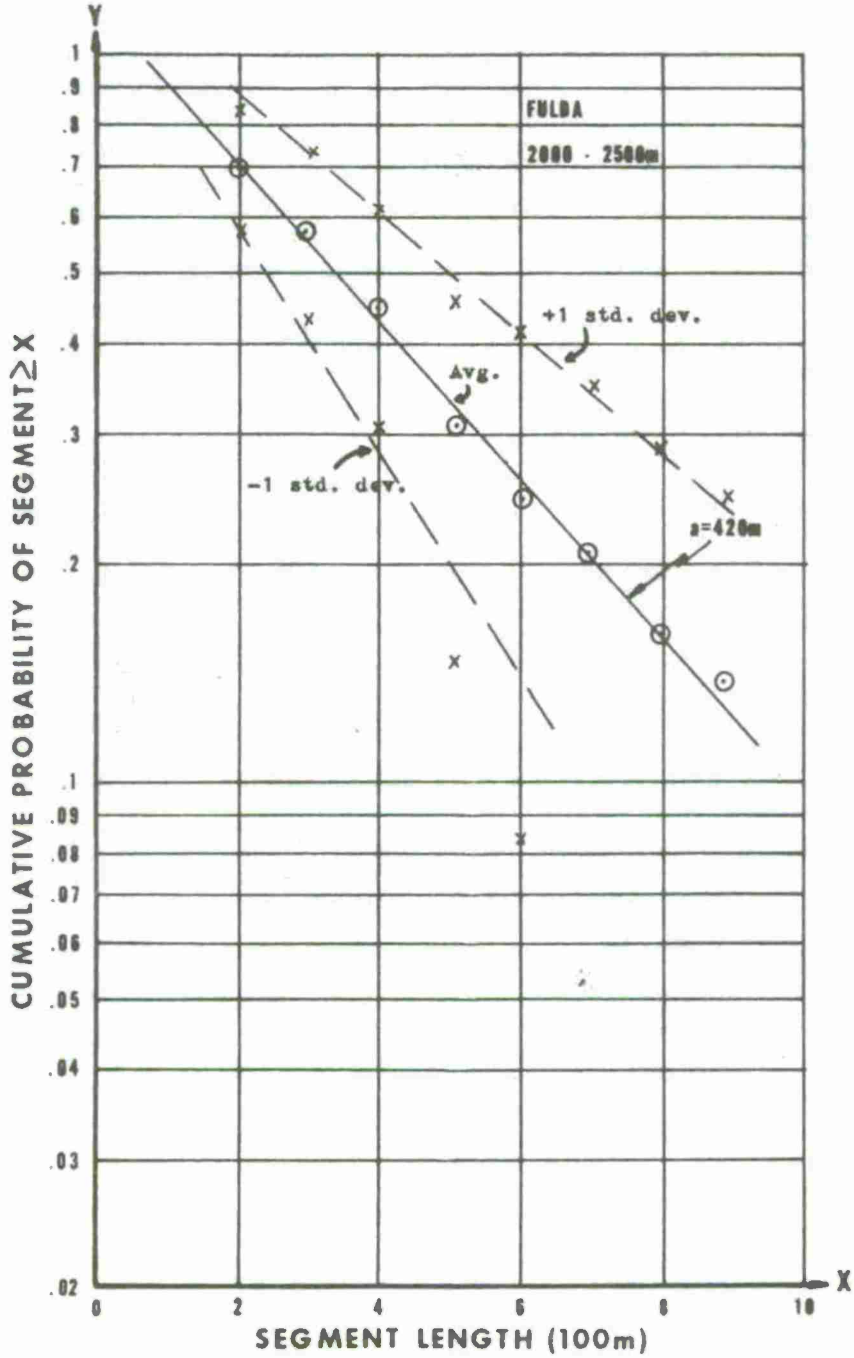

FIGURE 1 Intervisibility Segment Length Distribution

c. To calculate the terrain-induced abort rate, one assumes that a path length increment $\Delta \ell$ is traversed by the attacker during the time-of-flight of the missile (Figure 2). The abort rate due to intervisibility considerations alone is then given by:

$$\text{Abort rate} = 1 - \frac{\text{probability of having a path long enough for impact}}{\text{probability of having a path long enough for firing}}$$

$$= 1 - \frac{\text{probability of segment length} > (\ell + \Delta \ell)}{\text{probability of segment length} > (\ell)}$$

$$= 1 - \frac{A \exp(-(\ell + \Delta \ell)/a)}{A \exp(-\ell/a)}$$

$$= 1 - \exp(-\Delta \ell / a)$$

$$= (\Delta \ell / a) - 1/2(\Delta \ell / a)^2 + \text{higher order terms}$$

The terms beyond the first can be ignored for values of $(\Delta \ell / a)$ less than 1/4. The quantity $\Delta \ell$ is calculated from the missile velocity (v_m), the range to the target (R), and the attacker velocity (v_t) as follows:

$$\Delta \ell = v_t (R/v_m)$$

Thus the terrain-induced abort rate becomes, to first order,

$$\text{Abort rate} = (v_t/v_m)\ (R/a)$$

d. The abort rate as calculated here does not depend upon the path length necessary for acquiring the target and firing the missile. This is strictly true only if the distribution of intervisibility segment lengths has the pure exponential form given. When the distribution departs from the pure exponential, as it often does, one can still consider the distribution to be a pure exponential near the segment length necessary for firing and use the corresponding value of a to figure the abort rate. This means taking the slope of a line on the semilog plot which is tangent to the curve at the appropriate segment length. The complication here is in determining this appropriate length, since it brings in numerous factors like training, speed of the target, intensity of combat, and target visual contrast. It is probably not worthwhile to carry the analysis that far when starting with data as variable as one has for terrain. Thus the analysis here simply treats all of the intervisibility segment distributions as if they were pure exponential in form.

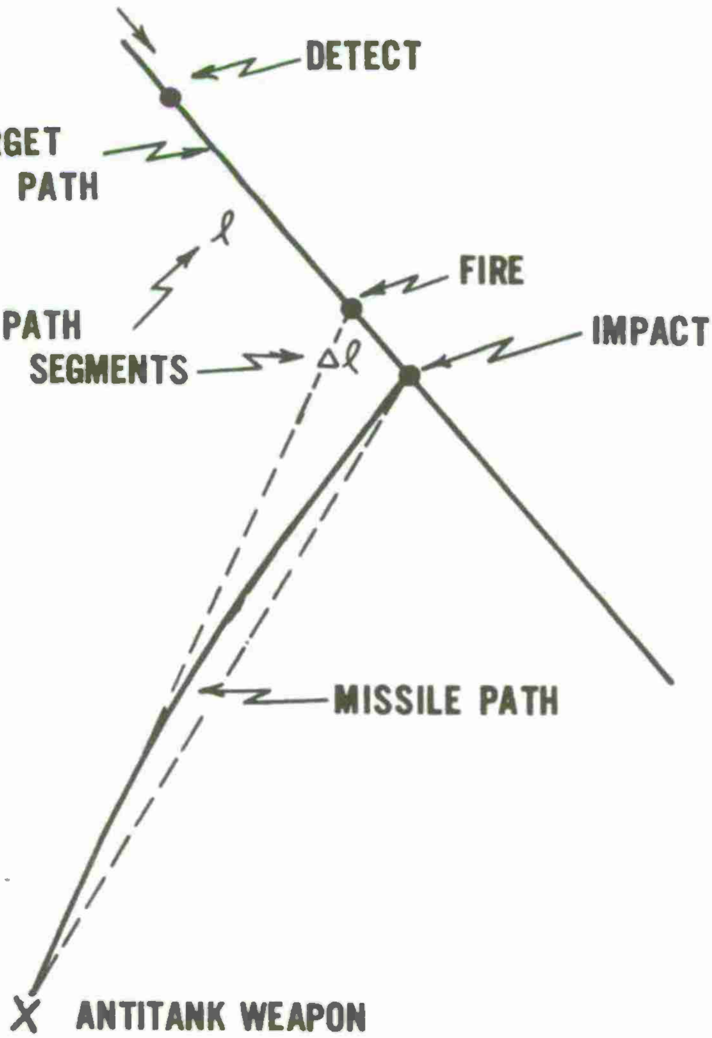

FIGURE 2 Geometry of Target and Missile Paths

e. The quantity a is easily read off the straight line plots by measuring down a distance corresponding to a factor (1/e) and then scaling off along the abscissa the length interval that will give a reduction of that amount. (It is repeated here that a is the average segment length for a pure exponential distribution.) All of the data do not make equally good straight line plots on the semilog plots--nor would this be expected from terrain data. Some fits are surprisingly good, however, and in some cases a double exponential phenomenon seems to be present. By that, it is meant that one end of the distribution fits a different straight line than the other. The 2000 to 2500 meter range band data from the North German Plain (Figure 3) show this effect to an extreme degree. Notice the steeply sloping line out to a segment length of about 300 meters and the much more gradual slope beyond. The steeply sloping portion accounts for 90 percent of the available segments so its value of a (95 meters) is used to calculate the abort rate. The tail of the distribution has a much longer a value (780 meters). The Plain is characterized by level terrain with much vegetation. It is interesting to speculate that the long a value might correspond to the land relief itself while the short value of a might be determined by what is on the land (vegetation and structures).

f. The TETAM report clearly states the opinion of the experimenters that the wide variability of the intervisibility data prevents classification of areas according to their intervisibility characteristics. The data are said to be extremely "site dependent," which means that one cannot predict what will happen at a particular site. The present work tends to support the view that some classification is possible, particularly if it can be demonstrated that vegetation or cultural features can be separated from the land relief. One could postulate a three-number classification -- an a value for the land, and a value for the covering over the land, and a percentage to show the relative contribution of the two.

g. The results of applying a values from the TETAM study to the calculation of abort rates for the TOW and DRAGON missiles are given in a CAA report on the subject (Reference 2) which is classified CONFIDENTIAL.

h. Some analysts are concerned with the problem of seeing several tanks from one weapon location or of seeing several weapon locations from one approaching tank. This introduces the concept of correlation length; tanks or weapons clustered within a dimension smaller than the correlation length have a high probability for all members of the cluster being simultaneously visible or masked. Members spaced out at distances large compared to the correlation length will be independent, with the probability of two simultaneously in sight being the product of the two individual probabilities. One would expect the correlation length to be roughly comparable to the quantity a discussed throughout this paper. The TETAM data tend to support this, although they did not attempt to measure correlation lengths.

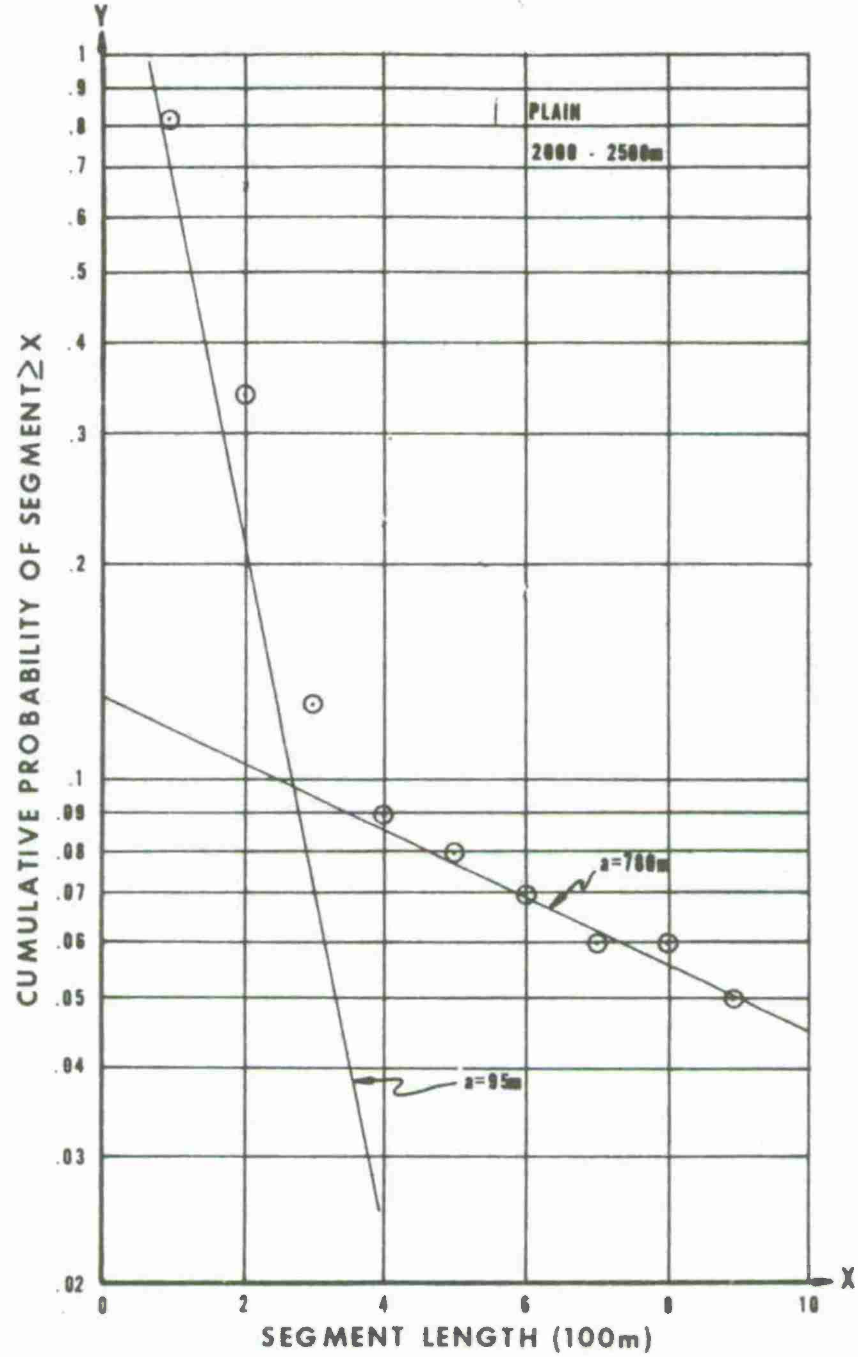

FIGURE 3 Intervisibility Segment Length Distribution

i. Present training apparently emphasizes concentration on a single target and ignoring the rest of what is in the optical field of view--especially the missile itself. However, the field of view for the TOW (for example) will cover a 200 meter width at 2000 meters range. This is enough to provide a good probability that there will be several targets in view during a strong attack. A gunner will know of other targets in view before he fires, because he will be spending a few seconds each time selecting the best one. The natural inclination of a good gunner to do what he can to keep from wasting his round will motivate him to swing the missile to a new target when the object of his concentration disappears. Some training in target switching would surely help him.

j. Another partial remedy for a high abort rate might be to wait for the original target to possibly come into view again. The following discussion will investigate the reduction in the abort rate which could be expected when the gunner keeps the missile guided toward the approximate location of the target while waiting for it to reappear. Another type of data is needed for this discussion. This is the mean distance between initiations of intervisibility segments. This quantity is found in field measurements by counting up the number of times a target comes into view, as it traverses a given path, and then dividing the total path by the number of separate appearances of the target. The TETAM reports contain such information. The symbol used for this mean distance will be $\underline{b}$. (The value of $\underline{b}$ must be greater than $\underline{a}$.)

(1) The probability of an impact in the second segment (P_2 as distinguished from P_1 for the first segment) is the integrated product of several probabilities: (1) the probability that there was no impact in the first segment, (2) the probability that a second segment begins, and (3) the probability that the second segment is long enough to achieve impact at the target. These latter two probabilities depend upon the time along the flight path of the missile at which the first segment ended. If too little time is left before the missile reaches the range of the target, the chance of beginning a new intervisibility segment will be small. If too much time is left, the chance of running out of visibility on the second segment will be large. The probability of impact at the target in the second segment can be calculated by integrating over time, as will be shown.

(2) The probability that intervisibility will be lost in the first segment in a time increment dt_1 at time t_1 is found by differentiating the abort rate. It becomes

$$P_a = (v_t/a)\exp(-(v_t/a)t_1)\ dt_1$$

(3) The probability that a second intervisibility segment will begin at some time t_2 later than t_1 can be calculated by using the quantity b, the average spacing between segment beginnings. The probability for a second segment to begin in a short time increment dt_2 at time t_2 is

$$P_b = \left[v_t/(b - a)\right] \exp((-v_t/(b - a))(t_2 - t_1))\, dt_2$$

(4) Finally what is needed is the probability that a second segment which begins at time t_2 will be maintained until impact at time R/v_m. This is simply

$$P_c = \exp((-v_t/a)((R/v_m) - t_2))$$

which is identical to the probability of a successful impact in the first segment, except for a shift to a new starting time, t_2.

(5) The product of the three probabilities P_a, P_b, and P_c is the probability that a target will be lost in time increment dt_1 at time t_1, that it will be regained in time increment dt_2 at time t_2, and that it will remain on the second segment long enough for impact to occur. A double integral over t_1 and t_2 will yield P_2, the probability of achieving impact on a second intervisibility segment. After some rearrangement of the factors

$$P_2 = \left[v_t^2/a(b - a)\right] \exp(-v_t R/av_m) \cdot \int_{t_1 = 0}^{R/v_m} \exp(-v_t(b - 2a)t_1/a(b - a)) \cdot \int_{t_2 = t_1}^{R/v_m} \exp(v_t(b - 2a)t_2/a(b - a))\, dt_2\, dt_1$$

Integrating this out leads to

$$P_2 = (a(b - a)/(b - 2a)^2) \exp(-v_t R/av_m) \cdot \left[\exp(v_t R(b - 2a)/av_m(b - a)) - 1\right] - (v_t R/(b - 2a)v_m) \exp(-v_t R/av_m)$$

This function is well behaved when b = 2a in spite of the factors (b - 2a) in the denominators. The limit of P_2 as b approaches 2a is

$$(1/2)(v_t R/av_m)^2 \exp(-v_t R/av_m)$$

For the condition of b = 2a, it will usually be preferable to use this limit; otherwise one could choose b slightly off from the 2a value and compute with the general expression for P_2.

(6) It is of interest to observe what happens to P_2 at the two extreme limits of b to verify that ordinary logic is not violated. As b approaches infinity, P_2 goes to zero. This is what one would expect, since the intervisibility segments are becoming rare. As b approaches its lower limit, a , the value of P_2 goes to

$$(v_t R/av_m) \exp(-v_t R/av_m) \text{ or } (v_t R/av_m) P_1$$

where P_1 is the probability for successful impact in the first segment. This expression would hold for the situation in which the breaks in visibility are short, as when produced by tree trunks. Here P_2 may actually exceed P_1 when the bracketed quantity is large enough. This is what one would expect if the target has a good chance of passing a small obstacle before the missile has gone very far. Then some intervisibility segments after the first would give higher probabilities than the first.

(7) Sample calculations of P_1, P_2, and their sum are presented on the table below in order to gain an appreciation of how much reduction in the abort rate might be expected from including intervisibility segments beyond the first. The average spacing between segment beginnings and the range to the target were varied, while everything else was held fixed. The values assigned to the fixed quantities were the following:

v_t = 10 meters/sec (target speed)

v_m = 200 meters/sec (missile speed)

a = 300 meters (average segment length)

PROBABILITIES OF ACHIEVING IMPACT AT THE TARGET

b - meters	R - meters	P_1	P_2	$P_1 + P_2$
450	1000	0.846	0.021	0.867
	2000	0.717	0.072	0.789
	3000	0.607	0.130	0.737
600	1000	0.846	0.012	0.858
	2000	0.717	0.040	0.757
	3000	0.607	0.075	0.682
750	1000	0.846	0.008	0.854
	2000	0.717	0.028	0.745
	3000	0.607	0.054	0.661

(8) Neglected in this discussion has been one obvious consideration. When the obstruction in the line-of-sight comes behind the missile (after the missile has already passed the range of the obstruction) the missile will be lost by the tracker unless the obstruction is of short time duration. The gunner is able to control this type of missile abort to some extent by raising the flight path of the missile and then lowering it again when the target reappears. If it is desired to calculate P_2 assuming all tracking losses to result in missile aborts, an additional factor can be included in the integral. This factor is $(1 - (v_m t_1/R))$, the probability that an obstruction, which is equally likely anywhere along the flight path, has appeared at range greater than $v_m t_1$ and hence has not affected the line-of-sight to the missile. The integration with this factor included is straightforward, but it leads to a complicated expression for P_2 which will not be given here. The expression given takes in only factors which are beyond the control of the gunner, namely the terrain and the speed and range of the target.

3. Conclusions

a. From a comparison of the probability of achieving impact in a second intervisibility segment with the probability for achieving impact in the first segment, it is seen that only a slight improvement can normally be expected by having the gunner wait for reappearance of the target. When there are multiple targets, switching to a new target would be preferable if it can be done.

b. For the special condition in which breaks in line-of-slight are short, it becomes advantageous to wait for reappearance of the target. The formulas given in this paper enable one to calculate the reduction in the abort rate which follows from using the second intervisibility segment.

c. The method presented can be extended to any number of intervisibility segments, but diminishing returns are reached so rapidly that it does not seem worthwhile to go beyond the second.

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VISUAL AND OPTICALLY AIDED VISUAL TERRAIN SEARCH RATES AS DERIVED FROM LAND MINE DETECTION AND TANK VS AT WEAPONS TESTS

by

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ABSTRACT

The predictability of probability of detection within time t, Pd(t), for visual and optically aided visual detection presented in AORS XII by the hypothesis:

$$Pd(t) = 1\text{-}\exp[-N(r_x/A_x)A_t(t)/a_u] \qquad (1)$$

where N = number of observers

r_x = rate of search for a target of presented area, A_x

r_x/A_x = constant = 430 sec^{-1} for resolvable targets in daylight in open terrain

A_t = area of target presented to observer

a_u = area of uncertainty being searched

is shown to be good for several scatterable mine tests and the USACDEC TETAM tests. The weak dependence of r_x/A_x on target clutter, background shape, color, activity, camouflage and use of magnifying optics suggests that it is a constant associated with the human's rate of information processing rather than variations in visibility under a wide range of daylight conditions. This work is an extension of that presented in AORS XII which showed that the results of helicopter pop-up detection experiments could be predicted by a similar expression. Implications of those findings on the design of surveillance and target acquisition systems are described.

INTRODUCTION

The author presented a paper[1] at the XII AORS that showed that the measured detection time of a tank size target by helicopter crewmen of the USACDEC 43.6 Phase IV Experiments[2] could be predicted by the expression

$$Pd(t) = 1\text{-}\exp[-N(r_x/A_x)A_t\ t/a_u]$$

where $N(r_x/A_x)A_t$ was found to be 17,500 m^2/sec for two crewmen searching for a 20.4 m^2 target (tank presented area) in uncluttered terrain during daylight. a_u was determined from the CEP of the crew's knowledge of the target's location with respect to its own location.

In a cluttered background the term $N(r_x/A_x)A_t$ was found to be 13,700 m^2/sec. The prediction was independent of range from 2000 to 5000 meters. The results were independent of whether magnifying optics were used or not. The scaling rule for target size was demonstrated for low-light level conditions from the data of the Warren Grove SEANITEOPS[3] tests for the unaided eye and binoculars. This paper reports on the applications of this hypothesis to other unclassified data concerned with the detection of advancing tanks and APCs by the ground defense from the USACDEC TETAM[4] Experiment and other tests of the detection of surface land mines by personnel advancing into a simulated scatterable minefield.[5,6,7] Not reported herein are other tests of the hypothesis applied to air-to-ground detection from fixed-wing aircraft[8] and helicopters using FLIR[9] because the data are classified. Emphasis is placed on the analysis TETAM experiment in this paper because this work has not been published, as yet, elsewhere. The information on mines is in an unclassified appendix to a SECRET document.[10]

TEST OF HYPOTHESIS AGAINST TETAM EXPERIMENT, Phases IA and IB1

TETAM Phase IA measured intervisibility between 36 defensive positions and 10 tank trails simulating a rapid advance toward the area occupied by the defensive positions for two partially overlapping sites (Site A and Site B) at Hunter Liggett Military reservation. The sites differed in that the average height of the defensive positions above the tank trials was 18 meters for Site A and 9 meters for Site B and the maximum separation of the ten tank trials on Site B (approximately 1000 m) was less than on Site A (approximately 1500 m). Line of sight was measured at 25 meter intervals along each of the tank trails for various heights of the defensive positions and target vehicle heights above the terrain. Three statistics were derived: P_{LOS}, the probability of line of sight averaged for the 36 positions to the 10 tank trails over range brackets 0-1000, 1000-1500, 1500-2000, 2000-2500, 2500-3000 and >3000 meters; $\overline{N}$ the number of initiations of line of sight similarly averaged; and $P(L' \leq L)$ the conditional probability, given line of sight, that the trail stayed in view L meters or more, also similarly averaged. Note that $P(25 \leq L) = 1$. With only one exception, ($\overline{N}$, 0-1000 m) each of these statistics was systematically greater over all brackets for Site A than Site B. P_{LOS} and $\overline{N}$ generally decreased as range increased and $P(L' \leq L)$ stayed approximately constant.

TETAM Phase IB1 measured the time from initiation of line of sight until a detection occurred for 36 single observers in the same defensive positions on Sites A and B in four successive trials in which a varying selection of 6 of the 10 tank trails were used by armored vehicles advancing toward the defensive positions at a median speed of approximately 8 miles per hour. The number of opportunities to detect were derived from the LOS measurements, and the detection time was determined from direct measurement of the armored vehicle location at the time of detection. The resulting data were provided in the form of the conditional probability of detection within time t or less, given a detection occurred, $Pd(t' \leq t|d)$. Table 1 shows that the detection probability as a function of range bracket was approximately constant, and that both the number of detections and the detection probability was substantially higher on Site B than on Site A.

Table 1

COMPARISON OF SITE A AND SITE B DETECTION PROBABILITY*

Range bracket 1000 m	$\overline{N}$		No. of opp. n_o**		No. of det. n_d		Det. prob. $Pd(\Delta R)$	
	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B
0-1.0	1.3833	4.6389	1195	4008	178	814	.149	.203
1.0-1.5	1.0566	1.0361	912	895	130	273	.143	.305
1.5-2.0	1.5167	.3667	1310	317	170	96	.130	.303
2.0-2.5	1.1111	.4222	960	365	147	72	.153	.197
2.5-3.0	1.0556	.1361	912	118	130	11	.143	.093
>3.0	2.0861	.0111	1802	10	160	3	.089	.300
Overall	8.2083	6.6111	7091	5713	915	1269	.129	.222

*For defensive position height of 7'8" and target height of 7' ("High-Blue").

**$n_o = \overline{N} \times 36$ defensive positions × 6 trails × 4 trials = $864\overline{N}$

The expected number of detections for each observer was 915/864 = 1.06 for Site A and 1269/864 = 1.45 for Site B. Table 2 shows the area of uncertainty estimated for the two sites based on the idea that only the open areas were searched and that the observers searched a width 150 meters to either side of the extreme tank trails, where $a_u = \sum_b [(\overline{W}_b + 300) P_{LOS,b} R_b]$.

Table 2

ESTIMATION OF a_u FOR SITES A AND B FROM TEST AREA PARAMETERS

Range bracket 1000 m	$P_{LOS,b}$		R_b 1000 m	Trail span + 300 m		a_u - 1000 m^2	
	Site A	Site B		Site A	Site B	Site A	Site B
0-1.0	.5089	.3935	1.0	1900	1500	967	590
1.0-1.5	.4602	.0952	.5	1800	1300	414	62
1.5-2.0	.4111	.0525	.5	1800	1300	370	34
2.0-2.5	.4076	.0530	.5	1400	1200	285	32
2.5-3.0	.3306	.0162	.5	1200	1000	198	8
>3.0	.1006	.0016	1.0	900	1100	45	2
Total						2,279	728

If it is assumed that the searchers randomly searched the entire area of uncertainty then the probability of detection given an exposure time t is, from expression (1),

$$Pd(t) = 1-\exp(430 \times 20.4\ t/a_u) \text{ for both sites}$$

Pd(t) could also be derived directly from the published data package.

$$Pd\left(\frac{\Delta L}{V}\right) = n_d(\Delta L)/n_o(\Delta L) = 1-\exp(-r\overline{\Delta L}/a_u V)$$

where $n_d(\Delta L)$ = the number of detections occurring when the exposure distance fell between L_n and L_{n+1}

$n_o(\Delta L)$ = the number of detection opportunities on the interval ΔL

$\overline{\Delta L}$ = the average exposure distance on the interval L_n and L_{n+1}

V = median velocity of the target

Figure 1 compares the two exponents calculated in the two different ways. For Site B there is good agreement. For Site A there is a poorer fit. It is strongly suspected that on both sites the searchers used a strategy of searching a band of about 350 meters in front of where the open areas began. This would explain the constant value of $Pd\left(\frac{\overline{\Delta L}}{V}\right)$ over the times from 100 to 250 seconds for Site A. It would have very little effect on Site B since there was only a small number of occasions when the exposure time exceeded 100 seconds. This strategy of search resulted in $Pd(t' \leq t|d)$ for Site A being greater for short exposure times than would be predicted by the hypothesis of a random search of the area of uncertainty but did not improve the overall detection probability. This is illustrated in Figure 2 where the calculated values of $Pd(t' \leq t|d)$ were derived from

$$Pd(t' \leq t|d) = \sum_{L'} \frac{P(L' \leq L) \quad d[1-\exp(-rL'/a_u V)]/dL'}{\sum_{L'} \{P(L' \leq L) \quad d[1-\exp(-rL'/a_u V)]/dL'\}} \qquad (2)$$

where $r = 8750\ m^2/sec$

$a_u = 2{,}279{,}000\ m^2$ Site A
$\quad\;\; 728{,}000\ m^2$ Site B

$V = 3.576\ m/sec$ (8 mph)

The denominator of this expression is just Pd(R) the overall detection probability and the numerator is the probability of a detection on the exposure length L times the probability that the length L or greater occurs. Since $P(L' \leq L)$ was readily available only out to 3000 meters, the observed and calculated values are shown out to 3000 meters. The agreement between the calculated and observed values of $Pd(t' \leq t|d)$ for Site B is very close, as would be suspected. Great care was taken in these calculations to account for the fact that all data were taken on 25 meter intervals. Thus $P(25 \leq L)$ is an average of exposure distances for $0 \leq L'$ <50 meters, and detection times recorded as negative were on the interval $0 \leq L' < 25$ meters.

This result allows the prediction of the detection probability wherever P_{LOS} and $P(L' \leq L)$ data are estimated for a defensive position and a search strategy is defined. Lasken[9] has already used it to show that the correlation of tank engagement ranges of WWII with the distance between obscurring objects first shown by Peterson[11] was the result of a strategy of minimizing the time to detect by primarily searching the first interruption of the line of sight.

In Phase IIA of TETAM, measurements were made of the ability of stationary aggressor tanks to detect defender vehicles placed on the HLMR defensive positions, where line of sight existed between 90% of the

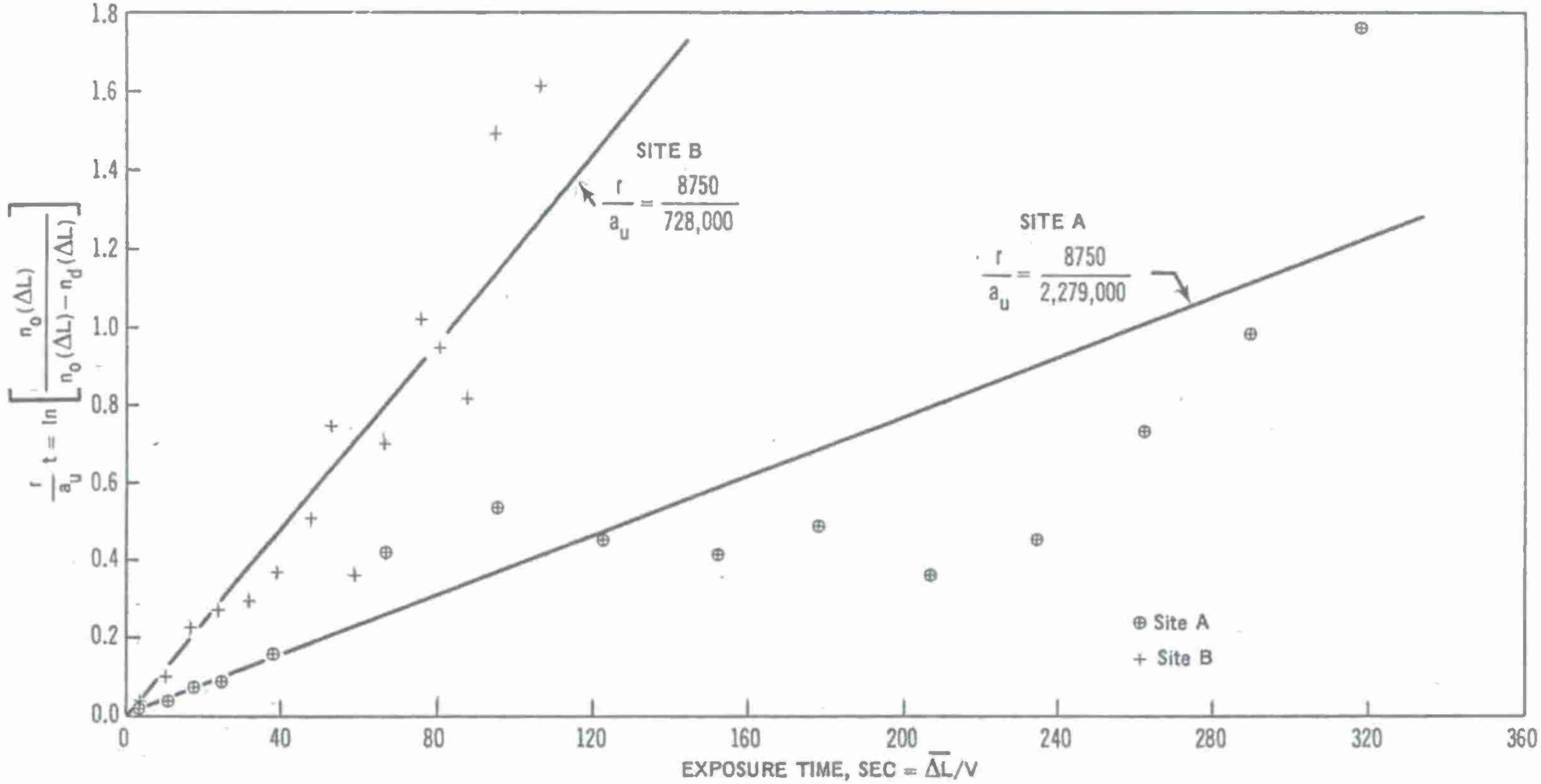

Fig. 1—Comparison of Observed Detections per Opportunity with That Predicted from Test Site Parameters and Search Rate Constant—Target Speed 8 mph—TETAM Test Sites A and B HLMR

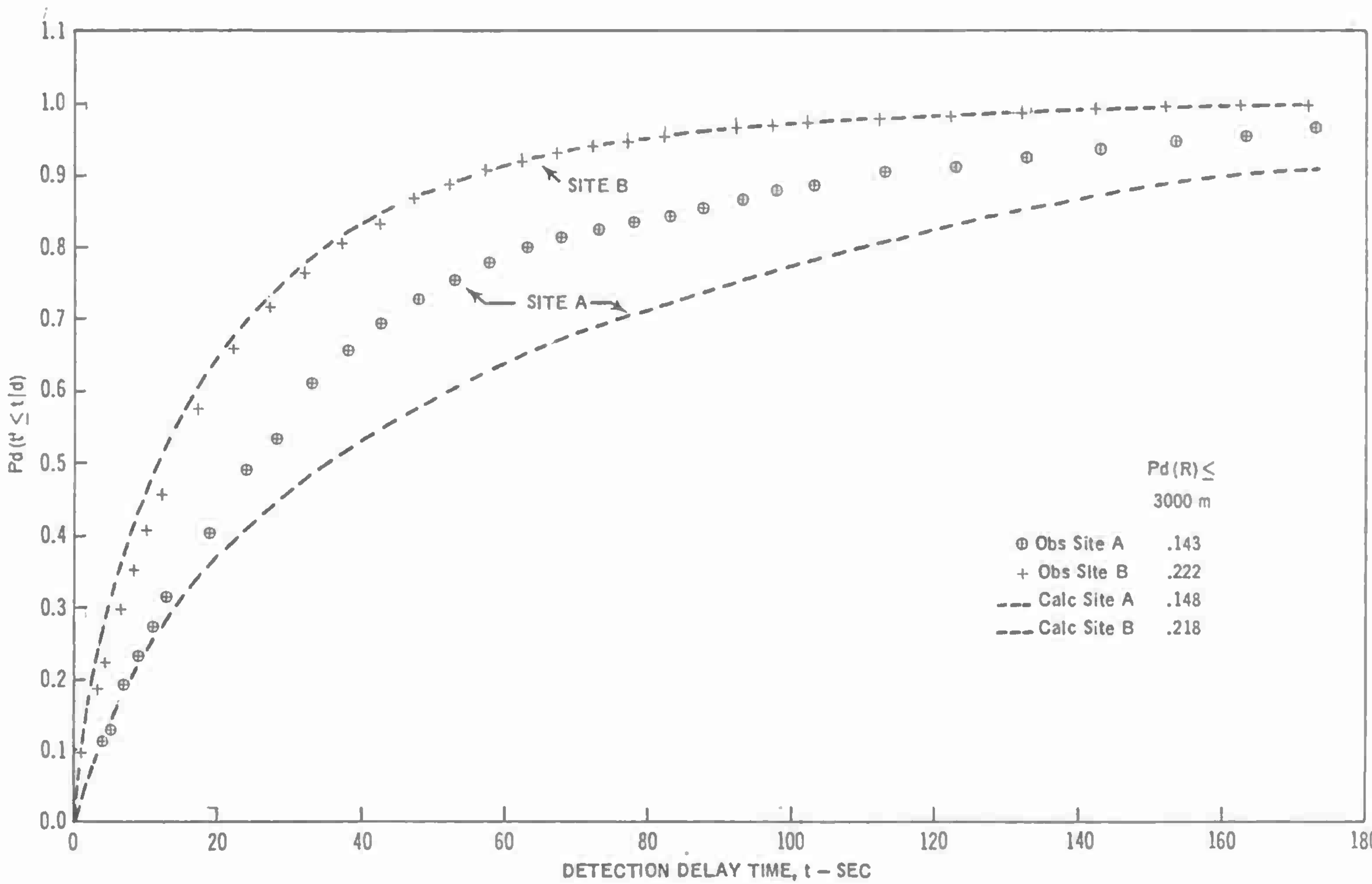

Fig. 2—Comparison of Observed Pd (t' ≤ t|d) with Calculated Values Assuming Constant Rate of Search of Visible Areas of the Visible Portions of Two HLMR Test Sites

defender vehicle-target tank pairs. The results of the experiment are predictable by the hypothesis of assuming random search over the area of uncertainty (the area containing the defender positions). If it is assumed that the median duration of flash, smoke, and dust (not measured) was 9 seconds, then the proportion of detections of firing defender vehicles due to noise, flash and smoke (40%) vis a vis random sighting (60%) is also predictable on the hypothesis that the searcher's eye fell on the vehicle while the firing effects endured.

TEST OF HYPOTHESIS AGAINST DETECTION OF SURFACE SCATTERED MINES

All the tests of surface scattered mines consisted of measuring the detection probability over an effective path width, W_e, by one or more searchers, N, moving at varying speeds, V, into a field of scattered objects of differing areas, A_t, colors and shapes lying on the terrain. This expression (1) can be written

$$Pd(t) = r_d/n_o = 1-\exp(N430A_t t/a_u) = 1-\exp(N430A_t/W_eV) \qquad (3)$$

where $a_u = W_eL$

t = time spent in minefield = L/V

L = length of path through the minefield

$Pd(t) = Pd(L/V)$ = fraction of mines detected

In the Camp Drum Tests,[5] detection probability of 5-inch diameter by 2-inch disks was measured. Twenty-one tank crews were instructed to traverse three 20 meter wide by 265 meter long lanes having regions of 20, 15, and 10 mines successively in strips of 50, 75, and 100 meters respectively and attempt to determine when they had entered and departed the region of mines along these lanes. Three crew members actively searched from each unbuttoned tank. The average speed in traversing the lanes (although not necessarily the mined regions) was 1.406 m/sec. Solution of equation (3) for N=3, W_e=20, A_t = .0127 m^2 is Pd(t) = .441. This compares to the ratio of detections to opportunities to detect, n_d/n_o = $405/21 \times 45$ = .428.

In the AMSAA tests[6] detection probability of replicas of the XM-34 AT mine with a presented area of 9.75×7.62 inches = .057 m^2 was indirectly measured. In these tests, the objective of the crew was to avoid passing over the surface scattered mines laid with a density of one mine per 45 square meters in lanes 18 by 90 meters. The number of mines encountered (passed over an 8-inch mine with a 143-inch wide tank = 3.83 m) was measured. The test was conducted with two crew members in each tank with hatches open in two trial sets and hatches closed in one trial set. An objective was to determine if the number of encounters was affected by the color of the mines consisting of olive drab, sand and a blue and red mix. No significant effect of color was found. However, equation (3) can be applied to the test assuming that mine size was the only effect. The data are summaried in Table 3. Since the crews were only attempting to avoid the mines, the test of predictability is in the constancy of the value of W_e, the effective width of search by the tank crews. The result is both highly systematic and plausible for a tank negotiating an 18 meter wide lane.

Table 3

SUMMARY OF AMSAA TESTS

	Open hatch		Closed hatch
	Phase I	Phase II	Phase II
Number of trials	30	20	20
Traverse time - sec	79.9	76.8	63.2
Eff. no. of searchers - N	2	2	1
Det. opp. - n_o*	230.4	153.6	153.6
Encounters	7	5	41
Detections - n_d	223.4	148.6	112.6
n_o/n_d	.970	.967	.733
$\overline{V}$ - m/sec	1.126	1.172	1.424
A_t - m^2	.057	.057	.057
W_e - m	12.4	12.3	13.0

*n_o = (Trials)(Tk+mine width)(Lane length)(Mines/m^2)= (Trials)(7.68).

In Reference 7 no differences in the visual detectability of small geometrical objects scattered on the ground was found between the plain metal object and the same object coated with adhesive and rolled in the indigenous ground litter. No shape effects were observed. However a size effect was observed, with the detectability being roughly proportional to the size of the object. These test results, while not readily transformable to the form of a search equation, tend to confirm its underlying hypotheses.

MILITARY APPLICATION

Application to military problems of this search rate hypothesis has been made already in addressing the question of engagement ranges in ground warfare, the accuracy requirements for helicopter navigation in the target handoff process from an aerial or ground scout, and range of air-to-ground missile lock-on. In addition, it has been applied to the evaluation of scatterable mines and the determination of the best place for emplacing them relative to a defensive position. Its potential applications are even wider, in that the effect of ground mobility in the engagement can now be estimated. It will be noted that the results of the TETAM test of detection time are critically dependent upon the target time in view (hence speed of movement) the assigned search sector and search strategy in addition to the number of observers, the P_{LOS} and the distribution of segment lengths. The findings of this analysis also are important in defining what detection of a target, provided it can be resolved sufficiently for recognition by the unaided human eye, is only weakly dependent on.

These are magnification, clutter, camouflage, range to target and target motion, per se. This is not to suggest that targets are not more often detected while moving, since targets in the open, when they can be detected, are usually moving toward concealment. It usually takes longer to detect targets at longer ranges because the area of uncertainty is larger, but both USACDEC 43.6 and 11.8 show that this is not true when the area of uncertainty remains the same.

THEORETICAL IMPLICATIONS

The idea that a search rate can be defined by a rate term of 430 target areas per second suggests that the detection problem is one of establishing the existence or non-existence of a target in the area being searched at the rate of 430 times per second. Since it appears weakly dependent upon those factors known to influence visual performance such as contrast ratio, angular resolution, etc., the possibility exists that this is a rate of mental processing of visual information. Since the process of search is essentially a binary process, it is suspected that the bit rate of the observers information processing system is 430 times the number of bits required for shape discrimination.* This opens a new area to seek correlative information that the author has not yet explored.

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*The problem of detection as measured in experiments where there is search of an area of uncertainty within the resolution limits of the eye is essentially the same, for the USACDEC experiments at least, as the problem of shape recognition. This is attested to by the fact that detection to recognition times were too short to be measured.

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TITLE: Combined Arms Tactical Training Simulator

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Commanders and staff officers on future battlefields will have a greater variety of complex tools to manage, and less time in which to manage them, than any commander since the beginning of warfare. During the past several decades, technology has placed a large arsenal of sophisticated weaponry at the disposal of the combat leader---at every echelon of command. Commander mobility has been significantly improved by new generations of ground combat vehicles and aircraft; his ability to communicate, gain information and give orders, far exceeds that of his predecessors. Logically, arsenals will become even more complex; transportation will become more rapid; and communications will be more efficient in the future. Consequently, the knowledge and skill required to manage these new systems will increase.

In March of 1969, a brigade commander in Vietnam wrote to the Infantry School suggesting the idea of a command and control simulator. Extracts from his letter follow:

> "Last night... I... once again had the experience of monitoring and managing a new battalion commander in one of his first exposures to commanding from the air. He is a good man but like all new battalion commanders he was going through a totally new experience and he did a bad job of it. It was clear that he was simply unprepared to command in an airmobile environment...."

> "We need a simulator for training our battalion commanders. The Air Force has simulators...in which student pilots can fly entire missions from takeoff through cross country to landing. Everything, including time, is real enough to be meaningful. This is not exactly what we need, but it is along the right line."

> "We should put a student battalion commander in...a simulator for the Huey Command and Control Ship. The student should plan an insertion and extraction. He should go 'airborne' and coordinate the air and artillery preparations, the gunship preparation, the insertion and the extraction. He should have a hot LZ at some point (these are a real shock, as you know, and require lots of cool to handle properly). He should maneuver troops in contact from the air, work light fire teams and hunter killer teams, control orbit positions for aircraft, run artillery blocking fires, run dustoffs, run resupply, contend with a brigade and division commander, decide when to put himself onto the ground to command..."

"...Quick-minded men with good background exposure to tactical matters learn the airmobile trade fast, but such men are fewer than one might think. We need to bridge the gap between theoretical and actual application of airmobility and reduce the price of learning the hard way. I believe that the Infantry School should lead the way."

This letter identified a critical training need which extended both in time and importance beyond the immediate circumstances in which it gained formal recognition. Recognizing the importance of this training need, the Infantry School developed, through a progressive iterative process, training vehicles which depicted airmobile operations and utilized a model board approach to four terrain areas: desert, gently rolling, mountainous, and jungle. These training vehicles are manually operated by instructor personnel, and while they effectively illustrated the value of environmental stress factors, they lack the capacity to provide realistic real time information sufficient to conduct a full scale simulated tactical combat operation. Consequently, the Infantry School prepared a draft proposed training device requirement for a simulator which embodied the demonstrated stress factors and also included the capacity of providing sufficient information in real time to conduct realistic combat operations.

The Combined Arms Tactical Training Simulator (CATTS) is being developed to provide a variety of simulated combat situations for the training of future commanders and staff officers. The CATTS, through simulation, will impose typical stress conditions and problems that will allow decision making experience which can now be obtained only by actual participation in combat operations. Primarily, the simulator will realistically approximate the placement of a commander and his staff in either of two simulated combat options; a ground command post environment for conduct of tactical ground operations, or a command and control helicopter environment for conduct of airmobile tactical operations. The CATTS will be capable of conducting simulated combat operations in any one of five typical terrain areas: desert, gently rolling, mountainous, jungle or Arctic. To assure that feasibility and training effectiveness are economically demonstrated, the program has been divided into two phases. During Phase I, the ground command post will be simulated utilizing two of the five terrain areas with leased computer hardware.

The US Army Training Device Agency has been assigned development responsibility for CATTS. Utilizing the facilities of the Naval Training Equipment Center, a contract for the Phase I system was awarded to TRW, Systems Group, Redondo Beach, California on 1 June 1973. An overview of the system developed by this contract as it will be installed at Fort Benning, Georgia, is shown in figure 1.

The players area consists of three simulated M577 vehicles in the standard mechanized Infantry "T" configuration and the commander's simulated M113 vehicles. The players are the battalion commander and

SYSTEM OVERVIEW

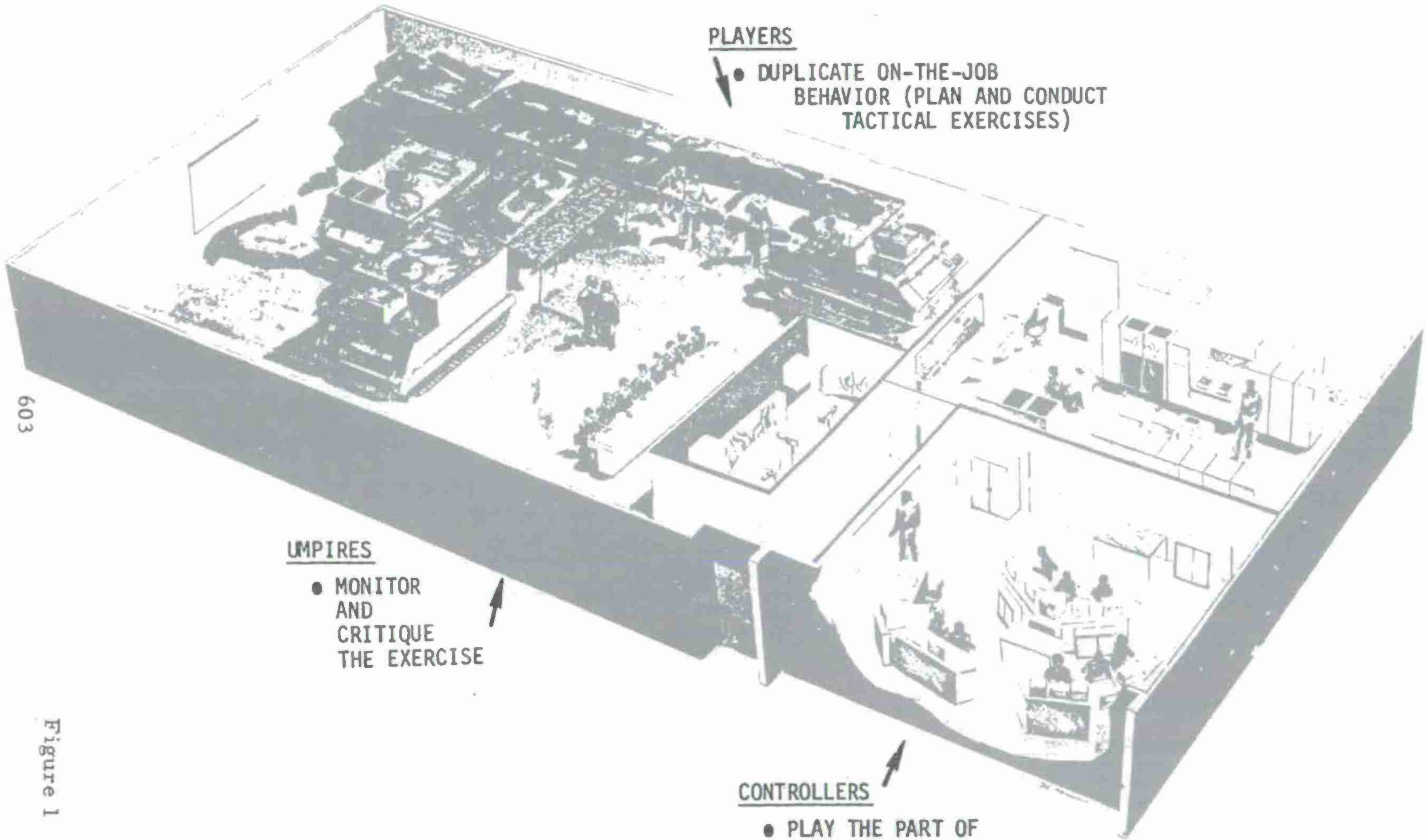

Figure 1

his staff - fire support coordinator, operations officer, intelligence officer and any other personnel indigenous to the training exercise being conducted. The players will have available to them the tools normally found in a Tactical Operation Center (TOC), i.e., standard map products, simulated radio and telephone communication systems. The players area will also include sound effects such as incoming and outgoing artillery, battle sounds and motor generator noise. During the conduct of an exercise the players utilize their simulated communication equipment to obtain information or give orders to: subordinate, adjacent, or higher unit commanders.

The controllers area has been designed to accommodate three controllers, one of which will be designated the principal controller, and six aides. The controllers and aides play the roles of subordinate, adjacent and higher unit commanders by communicating with the players and translating their requests for information or orders to the computer. The computer maintains the status of all units and equipment, both friendly (blue) and enemy (red) from an initial starting point and configuration. The controllers direct the play of game in response to the battalion commander's orders and receive information at significant points to relay to the battalion commander either as new status or in response to requests. The red forces are also directed by a controller and can be controlled in a manner which will shape the training exercise.

The umpire's area has been designed to allow two groups of four people to monitor the exercise. All eight people can monitor all simulated communications and each group of four can monitor any one of the controller's graphic displays.

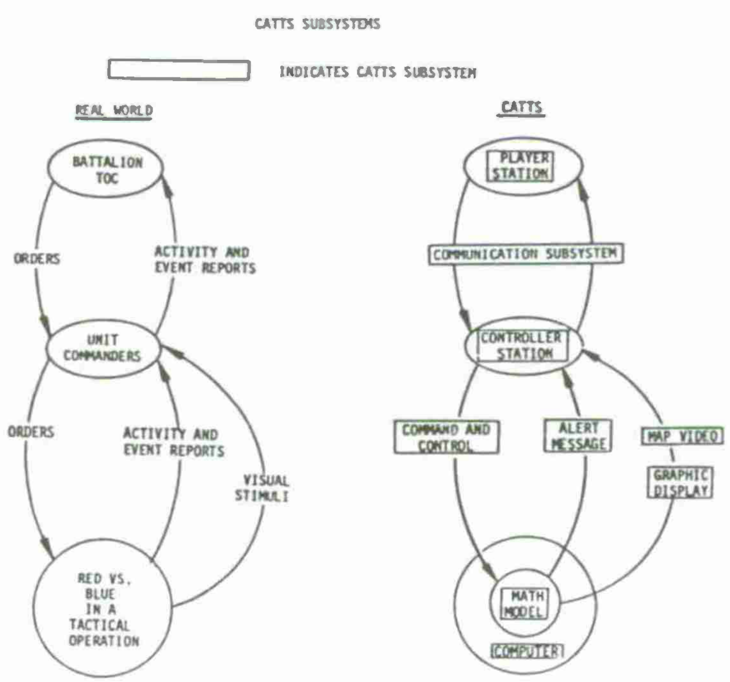

Figure 2

A simplified comparison of the real world versus CATTS simulation is presented in figure 2. It should be noted that a one to one correspondence exists. The Battalion TOC and the players station are very similar and their respective communication systems have the same apparent capability. The controllers in the CATTS controller station play the part of unit commanders. Through the use of command and control the controllers can direct the computer and its resident math model which simulates the Red versus Blue tactical situation. The alert message, map video and graphic display subsystems provide information about the tactical situation which can in turn be relayed back to the players station.

The Communications Subsystem is the basic link between the players and the controllers. Realism is achieved in the player's area by modifying surveyed GFE radios and using operational telephones. The radios are configured to permit eight nets, each with a primary and secondary frequency, or sixteen selectable frequencies. Each frequency has a clear or secure mode of operation. The communications systems at the controller's stations and aid's stations have been developed considering ease of operation and versatility. Each controller and aid can monitor any number of radio frequencies but can transmit over only one frequency in either clear or secure. The principal controller's station has the capability of injecting variable amplitude static and/or jamming on any of the frequencies. The telephones in the TOC are connected to an aid position which will act as a switchboard and route the call to the appropriate controller or aid. Additionally, any controller or aid can answer an incoming call and, in a somewhat limited manner, transfer the call. An intercom system has been provided to assure efficient coordination between controllers and aids.

The Map Video Subsystem provides the three controllers with a working view of the area of operations. In the desert scenario, this area is approximately 30 x 100 kilometers and is displayed on a 1:50,000 scale map which has been specially prepared for clarity in a closed circuit television application. Three color TV cameras, each connected to a controller console, view three of the special maps mounted on cylindrical mapboards. Each controller can select the area of operation that he is interested in by panning, tilting, or zooming his TV camera. The gimbal mounted cameras are servo driven by the computer under the direction of the controllers. Positive positional feedback to the computer is assured by 13-bit digital shaft encoders on each axis of movement. At minimum zoom, the controller's monitor will display an area 40 x 50 kilometers; at maximum zoom, the area is reduced to 4 x 5 kilometers.

The Graphics Display Subsystem superimposes the tactical situation over the area of operation. The controllers can independently select, for blue or red forces, any combination of the following displays: unit location and area occupied, direction of movement, location of and area covered by obstacles and minefields, sensor activations--location and area covered, control measures, front-line traces, weapon fire direction, impacting fires, and preplanned targets. The displays are presented in three colors--blue, red, and white. When the camera is panned, tilted, or zoomed, the display is updated to correspond to the new location at the completion of the movement or is automatically updated every minute. The display symbols are in standard Army format with alphanumeric legends where appropriate.

One of the major challenges presented by CATTS was the requirement to allow personnel not specifically oriented to ADP to be able to interface or input data into the computer conveniently, rapidly, and accurately with a minimum of training. The Command and Control Subsystem is the result of this requirement. The simulated battle is started by specifying an initial set of conditions which define in detail the location, area covered, organization including men and equipment, and the initial direction and rate of movement of every unit defined for the problem. As the game progresses, the controllers may change at their option or at the direction of the battalion commanders, any of the following: task organization, unit location, control lines and points, rate and type of fire, air missions and air defense, route of march, and weather. The selection of any of these options will result in a menu appearing on the bottom one-third of the graphic display monitor. The menus are consistent in makeup; on the extreme left will appear a time at which the change should occur, either the present or a day-hour-minute time group which relates to the game clock. Selection is accomplished by the use of an acoustic analog tablet which controls a cursor displayed on the monitor. Placing the cursor over the desired option and pressing completes the selection. Next will come the unit affected, then the manner in which the unit is affected. Finally, a choice appears; i.e., REPEAT-IGNORE-DONE. If more than one unit is to be changed, REPEAT will be selected. If an error has been made, IGNORE is selected. If the change is complete, selection of DONE will implement it. Since the selection of the appropriate command and control function is straightforward, and since the menus are displayed in a recognizably accepted language, data input to the computer can be accomplished with minimum training.

The computer simulates the tactical situation. The machine selected is a Xerox Sigma 9 Model 3 with two 45 megabyte disk packs, dual tape drives, line printer, card reader and keyboard. As illustrated in figure three, the software is divided into two major categories, foreground and background both under the control of the Xerox RBM operating system. The foreground software is basically concerned with providing the where-with-all to input data to and output data from the math model. The command and control section allows selection, generation and interpretation of the command and control menus which the controllers use to direct changes in the tactical situation. The graphic section is an output which results in a display of the tactical situation. The video section assures registration of the map used by the controllers over the terrain data base within the math model. The alert section provides an output which will be discussed later.

The math model functions around the terrain data base which is a precise representation of the map viewed by the controller and contains

CATTS SOFTWARE STRUCTURE

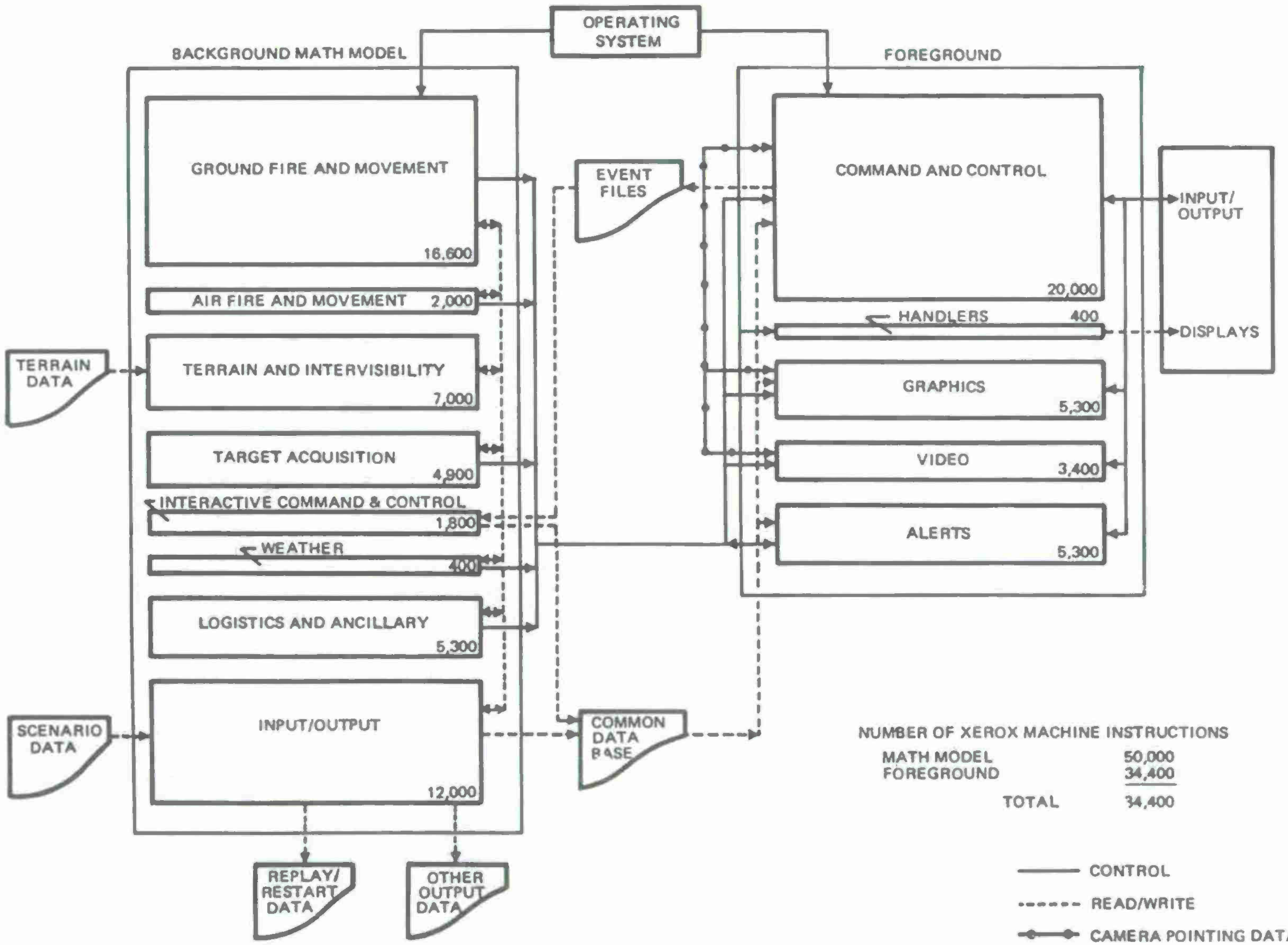

Figure 3

elevation relief at 25.4 meter intervals, 16 classes of vegetation, 8 classes of soil and cultural features. The data base is necessary for line of sight calculations which in turn are necessary for target acquisition by any of several means: visual (including aided and unaided), aural and various detectors. The data base also affects ground movement rates of personnel and vehicles (tracked and wheeled) from the aspects of slope, vegetation, and soil type. Weather interacts with terrain, ground movement and detection modules. The math model also assesses casualties (personnel and equipment), resulting from a variety of direct and indirect fire weapons. Fire rate and casualty calculations take into consideration factors such as deployment, terrain, and supression. Provisions have been made for aircraft in both reconnaisance and ordnance delivery roles, and air defense weapons such as REDEYE, VULCAN and CHAPARRAL are also included. The model maintains a record of fuel and ammunition used and remaining.

As a result of the initial conditions or subsequent command and control actions, the status of the personnel and equipment assigned to units changes. Since there can be 99 units and 80 equipment types in the war game, it is necessary to apprise the controller of any change in their status. Consequently, an alert will be displayed in alphanumeric form on a CRT monitor when a significant change occurs in movement rate or readiness condition. Alerts are also generated when: an engagement or detection takes place, fuel or ammunition is depleted below a specified level, a control measure is crossed, a unit is taking fire or casualties are incurred. The controllers will evaluate these alerts and determine which situations require battalion level attention.

The subsystem description presented above with the schematic representation, as illustrated in figure four, provides a brief overview of the CATTS system. However, the purpose of this paper is not to extoll the virtues of the CATTS system for two reasons. First, this configuration of CATTS is a concept feasibility model and as such is far from the ultimate system; its utility, cost and training effectiveness are yet to be determined during user testing. Secondly, the intent of this paper is to identify the areas where operations research (OR) techniques were effectively used in the development of CATTS.

It is apparent that OR was used extensively in the development of the software, particularly in the math model. Identification of all of the parameters, especially where there are complex interactions, requires the discipline of OR techniques. The successful use of OR in the development of software has been demonstrated many times and as such is a well accepted approach. It is of interest, however, to consider extending OR techniques into other development areas.

If OR techniques are applied to the definition of requirements, the initial objective function for CATTS would be the training of a battalion commander and his staff. The variables contributing to this function are information and environment. Each of these parameters is then examined through an iterative process at succeeding smaller increments

CATTS HARDWARE STRUCTURE

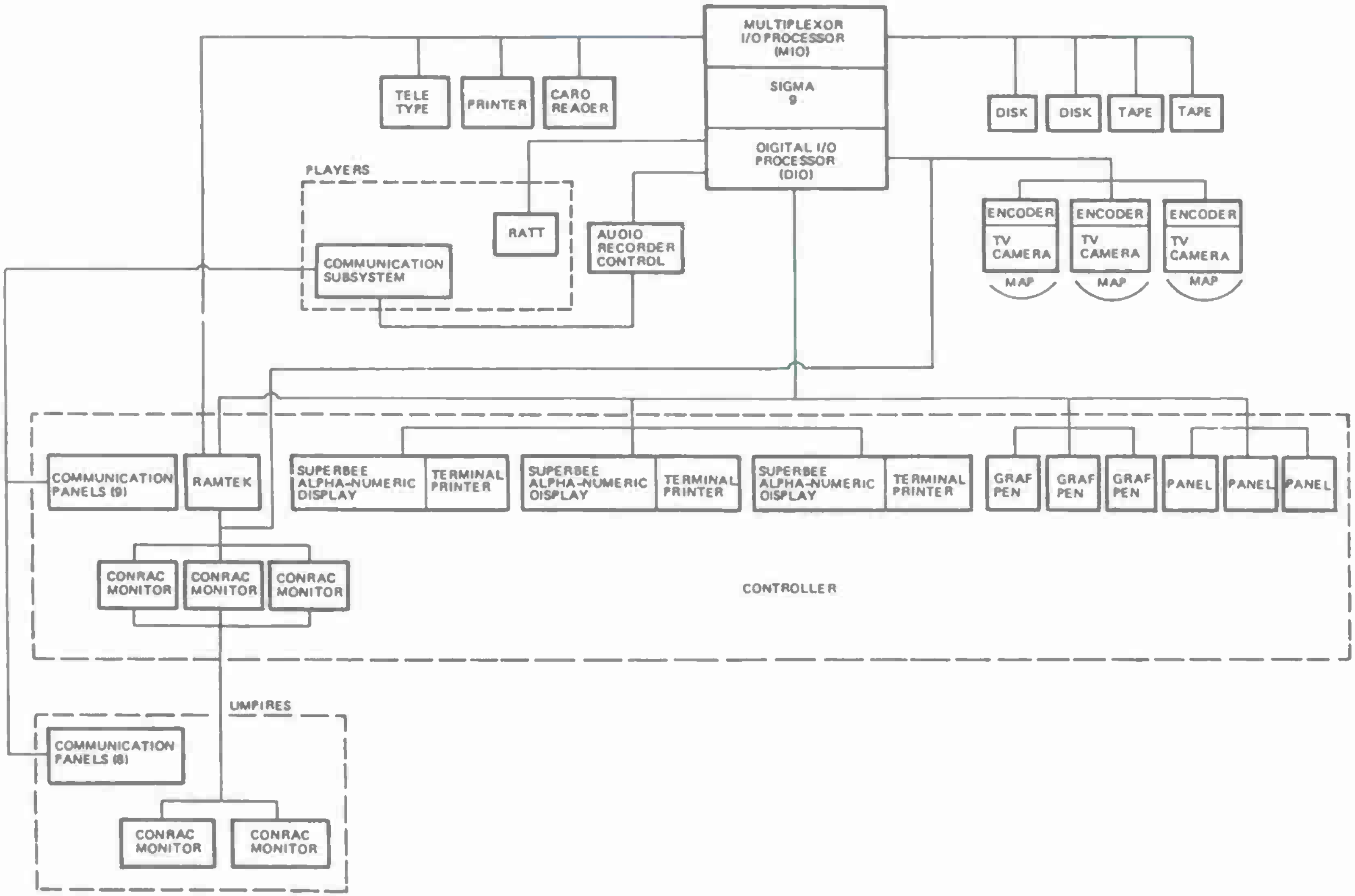

Figure 4

to determine the controllable and uncontrollable inputs. With this approach in mind it is not difficult to envision how the present CATTS system evolved.

Continuing into the development of hardware, the map video system presented a unique challenge. The controllers must view the same type of material that the player is using to allow effective communication. This is a standard 1:50,000 map. This requirement defines the initial objective function. The parameters which influence this function are: accuracy, ease of use, and cost. Several possible means of providing the desired presentation were examined, i.e., hollograms, slides, and closed circuit TV. The system selected provided the best tradeoffs in cost, accuracy and ease of use. An iterative process was followed for each level within the map video system. The same techniques were used in the selection of: the TV camera, the monitor, the maps and map boards.

It may be of interest to point out an area where cost savings may have resulted if the same techniques had been applied more rigorously. A low speed line printer was selected on the basis of cost only since it appeared to fulfill the basic requirement. However, as computer use increased it now appears that the difference in cost would have been realized in wait time alone. In other words, a harder look at all of the parameters which influence the objective functions must be accomplished.

In closing, OR, like CATTS, is not a panacea. CATTS will not solve all training problems and OR will not solve all development problems. But, both properly used in appropriate applications have value to the Army.

OPTIMIZATION OF RESERVE COMPONENT MOBILIZATION STATIONING

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Headquarters, United States Army Forces Command

INTRODUCTION

The Army and the Defense establishment have, for some time, espoused the principle of "One Army" and the "Total Force." With the conclusion of American involvement in Vietnam, the subsequent draw down of the Active Army, and in light of our world-wide military commitments and the need to maintain a responsive military force capable of reacting to a wide range of contingency plans, these terms have assumed greater importance. Accordingly, there has been an increased emphasis and reliance on the Reserve Components of the Army.

This increased reliance on the Reserve Components has been manifested in an extensive testing program to discover ways to upgrade Reserve Component training readiness and in several small studies aimed at reducing Reserve Component deployment time. It is the latter area to which this paper is addressed -- specifically, to the reduction of time by optimizing the Reserve Component mobilization stationing plans.

BACKGROUND

In September 1973, the Chief of Staff of the Army directed FORSCOM to undertake a review of the existing planning times for deployment of the Reserve Components and to recommend changes to effect reductions. As a part of this review, a critical look was taken at the Reserve Component mobilization stationing plan, the method by which it was developed, and the need for periodic revisions. Concurrent with this study effort, the Affiliation Program was being developed. This program resulted in numerous requirements for changes to the stationing plan. In addition, a desire to adjust the DA Master Priority List (DAMPL) and the Postmobilization Deployment List (PMDL) to reflect changes in the readiness status of Reserve Component units promised to further complicate preparation of stationing plans.

In view of these requirements and possible changes, it was felt that some means of optimizing stationing to minimize deployment time was required. It was understood that the method developed for this purpose had to be responsive to frequent and sometimes radical changes, and that the response time to these changes had to be brief.

SCOPE

This is a practical, real-world problem which needs to be solved and which lends itself to solution by a systems analysis approach using operations research techniques. This paper describes the conduct of an initial systems analysis. It addresses the basic form of the problem, the complicating factors involved, possible approaches to the solution of the problem, the general form of these approaches, and some simplifying assumptions that can be made to aid in the solution of the problem. Because it is an on-going action, the definition and formulation of the problem are stressed.

DISCUSSION

The basic problem is that there exist several thousand Reserve Component units which, upon mobilization and before movement to a port, must be moved to a mobilization station to complete their training and preparation for movement to a theater of combat. Each of these units has a priority for deployment established by the DAMPL or PMDL.

The initial reaction was to formulate the problem as a simple assignment or transportation problem. These are both special cases of the general linear programming (LP) problem and have relatively simple and efficient solution techniques associated with them. The transportation problem may be stated as follows:

Find x_{ij} $(i = 1,2,\ldots,m;\ j = 1,2,\ldots,n)$ to minimize

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij}$$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i, \quad \text{for } i = 1,2,\ldots,m$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \quad \text{for } j = 1,2,\ldots,n$$

$$x_{ij} \geq 0 \quad \text{for all } i \text{ and } j$$

where

m = the sources
n = the destinations
a_i = the units available from source i
b_j = capacity of destination j
c_{ij} = cost (time) to move a unit from source i to destination j.

The assignment problem is a special case of the transportation problem where $m = n$, $a_i = 1$ for all i, and $b_j = 1$ for all j.

Further examination of the transportation problem, however, showed that the model has feasible solutions only if

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j,$$

and the stationing problem is such that this requirement is not satisfied; i.e., the supply of units exceeds the station capacity. The constraints, therefore would have to be formulated as inequalities.

$$\sum_{j=1}^{n} x_{ij} \leq a_i, \quad \text{for } i = 1,2,\ldots,m$$

$$\sum_{i=1}^{m} x_{ij} \leq b_j, \quad \text{for } j = 1,2,\ldots,n,$$

and the stationing problem must be formulated as a general linear programming problem.

System Analysis

Although the basic problem could be formulated as a general LP problem, it was not surprising to discover that the detailed problem had parameters that could not be ignored and which frequently did not conform to assumptions of linearity. Some of these are listed below.

- Incompatibility of some units and stations.
- Time-phased availability of installations.
- Limited outloading facilities and transportation.
- Required delivery date overseas.
- Varying station capacities.
- Constraints imposed by computer capacities.
- Fragmented units with numerous home stations.
- Multiple mobilization stations required for some units.

Some of these could be handled routinely with standard techniques of LP. For example, the incompatibility of units and stations can be addressed by the assignment of an extremely high cost (time) for movement from the unit location to the particular station(s) with which it is incompatible. Varying station capacities merely require that the capacity for each station for possible mixes of units and equipment be identified in advance and defined as the right hand side of the constraint equations.

Other problems may be eliminated by making simplifying assumptions. Since the basic problem only assumes importance in the event of full mobilization (and, one supposes, extreme national emergency) it can be assumed that most available transportation assets would be used for the movement of military units and equipment. The number of units requiring multiple mobilization stations because of specialized equipment and training requirementsis small and the probable effect on the solution appears to be minimal, so it may be assumed that units require only a single mobilization station.

The majority of the parameters listed, however, affect the choice of a solution procedure and could require redefinition and/or reformulation of some elements of the problem. These merit some additional explanation.

The complete set of mobilization stations includes many inactive and semi-active installations. These installations require establishment or expansion of the garrison force necessary to accept mobilized units and administer a post. The time required to gather this garrison together, refurbish facilities, and prepare the installation for occupation by a mobilized unit introduces time phasing, a dynamic aspect, into the problem.

Not all units possess the same degree of importance to the accomplishment of a combat mission. Accordingly, priorities for introduction of units into the theater of operations have been developed. In effect, these priorities impart a weighted value to each of the units. This could require that the problem be reformulated in terms of a measure of criticality to the success of combat operations. The problem then would be to maximize the index of success. This greatly expands the scope of the original problem and includes a great many unknown and undefined factors.

Many of the units in the Reserve Components are fragmented into numerous detachments and sub-units which are located at widely separated locations. Complete identification of movement times from each of these locations could make the problem so large that it could not be solved on most computers. Thus some method of grouping units by location is required. Related to this problem is the variety of equipment assigned to units. These different types of equipment and units require different movement techniques and thus have different movement times associated with them Again, the possible combinations involved could render solution of the problem impossible, so another grouping or categorization may be needed for unit/equipment types. The extent and nature of the groupings may be dictated by the capabilities of the computer to be used, so the analysis must include a study of the computer facilities.

Problem Solving Techniques

Having thus analyzed the system, some additional consideration must be given to the techniques for solving the problem. These additional techniques should be examined with regard to the system parameters just discussed and the effect these parameters have on the basic problem of optimizing the mobilization stationing of Resrve Component units to minimize deployment time.

One very appealing approach is to consider only a sub-set of the units and to develop an optimal stationing plan for this sub-set using LP. Because of the emphasis on the Affiliation Program, directed mutual support programs, and other "high priority" packages of units, a key sub-set of units could be easily identified. This would significantly reduce the size of the problem, stationing could be limited to active installations, and some of the relatively more important units would receive priority.

Another possible approach is the use of LP to optimize the stationing of a sub-set of units sufficiently large to use the assets of the immediately available (i.e., active) stations. Additional LP problems could be solved by adding installations as the inactive and semi-active installations became ready to receive units. This approach would require the solution of a LP problem each time an additional station became available for use and each time a unit completed training and cleared a mobilization station. This is obviously a suboptimal approach to the problem. It could result in an unacceptable delay in moving some larger units to a mobilization station by filling vacancies with smaller units or, conversely, could extend times by maintaining vacancies at a station until enough space became available to move the larger units.

Techniques other than LP may also be considered. The most likely candidates are simulation and dynamic programming. Simulation, using standard techniques such as GPSS, GASP, and SIMSCRIPT depending on the available computer programs, seems particularly well suited to the problem. -- While it would not guarantee an optimal solution, it could provide a near optimal one. Simulation is particularly well suited to handle the dynamics associated with completion of training and addition of stations, and the problem could readily be expanded to include the movement of units from the mobilization station to a port.

Dynamic programming has many of the same advantages as simulation; it allows the introduction of the dynamics and the solution of the two-stage problem (i.e., the movement of units to the mobilization station and thence to a port). Further, it could provide an optimal solution.

If the stationing list is to be formulated in advance of mobilization and used as a planning document, both the simulation and dynamic programming approaches would require estimates of the amount of time required at the mobilization station by each unit. Estimates of this time which are currently available are subject to frequent change and are not considered to be highly accurate.

It is also feasible to use combinations of these problem solving techniques. For example, an optimal stationing plan for a critical sub-set of units could be developed using a LP approach, and the remainder of the stationing plan could be developed using simulation or dynamic programming. Or, LP may be used to optimize the stationing for a sub-set of units and all active installations; simulation or dynamic programming would then be employed to develop the rest of the plan.

Of those techniques considered, it is the last one discussed (the combination of an optimal solution for the largest possible sub-set of units and stations and the use of simulation or dynamic programming) which seems to offer the greatest promise.

The Chosen Approach

Let us then look again at the problem and address its solution in terms of the selected problem solving technique.

The original problem was to develop an optimal mobilization stationingplan such that it minimized the deployment time of units. The methodology for developing this stationing plan was to be responsive to frequent and sometimes drastic revisions and the time required to effect the revisions was to be as short as possible.

To reduce the problem to manageable proportions, several simplifying assumptions were made:

- Transportation and outloading facilities would be available for immediate movement of units to mobilization stations.

- Units require only one mobilization station.

Also, some grouping or categorization of the problem elements is required to preclude exceeding the computer capacities.

Groupings of units would be made based on two characteristics — size and classes of equipment requiring different movement techniques. Sizes would be grouped according to the number of personnel (e.g., brigade, battalion, section), and equipment could be described as "light, air-transportable equipment," "light equipment requiring special handling techniques," " heavy equipment not transportable by air," etc. Each mobilization entity (subentity in some cases) would then be described by two coded identifiers specifying size and type of equipment.

To further reduce the size of the problem, key transshipment centers must be identified and associated with a specific geographic area. Then the movement times for different size and class units from a given transshipment area to a given mobilization station can be developed.

The elements are now at hand to allow the formulation of a meaningful LP problem for stationing, at active installations, of a sufficiently large sub-set of the deployment entities to fully utilize these installations. These elements are defined below.

x_{ij}, y_{ij}, z_{ij} = the decision variables; the number of units of type x, y, or z to be moved from transshipment center i (= 1,2,...,m) to station j (= 1,2,...,n). (A separate decision variable is required for each pairing of identifiers for size and class of equipment).

$t_{ij}^{x(y,z)}$ = the time to move a type x (y,z) unit from transshipment center i to station j.

a_i = the number of type x units within center i.

b_i = the number of type y units within center i.

c_i = the number of type z units within center i.

d_j = the capacity of station j.

The problem is to find x_{ij}, y_{ij}, and z_{ij} so as to

$$\text{Minimize} \sum_{i=1}^{m} \sum_{j=1}^{n} (t_{ij}^{x}\, x_{ij} + t_{ij}^{y}\, y_{ij} + t_{ij}^{z}\, z_{ij}) = T$$

$$\text{subject to} \sum_{j=1}^{n} x_{ij} \leq a_i \qquad \text{for all } i$$

$$\sum_{j=1}^{n} y_{ij} \leq b_i \qquad \text{for all } i$$

$$\sum_{j=1}^{n} z_{ij} \leq c_i \qquad \text{for all } i$$

$$\sum_{i=1}^{m} (x_{ij} + y_{ij} + z_{ij}) \leq d_j \qquad \text{for all } j$$

$$x_{ij},\ y_{ij},\ z_{ij} \geq 0 \quad \text{for all } i \text{ and } j.$$

Solution of this problem would yield the number of type units in a transshipment center i to be moved to station j. These units would then be selected from the available sub-set of mobilization entities in accordance with previously established priorities (DAMPL, PMDL, etc.). Thus, the initial utilization of available mobilization stations is defined.

Having specified the initial stationing, estimates of time required at the mobilization station by each unit and estimates of the dates the semi-active and inactive installations will be able to accept units can be used to design a computer simulation program for developing the stationing plan for remaining units.

At this point the scope of the problem could be easily expanded to include the movement of units from the mobilization station to a port by expanding the simulation program.

SUMMARY

The intent of this paper has been to describe how a systems analysis approach has been used to examine a real world problem of concern to the Army and to show how operations research techniques can be used in its solution. As the problem is further developed, it may be concluded that it is not worth pursuing to its end. Even if this is the case, the diligent application of ORSA techniques has benefitted the Army by the increased understanding of the system and its parameters.

AN ANALYSIS OF SIMULATED DEPLOYMENT OF THE US ARMY AIRMOBILE DIVISION

by

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1. Introduction. This is a summary of a study,* requested by the United States Readiness Command (USREDCOM), which is a conceptual analysis of ways and means to improve the strategic deployment capability of the US Army airmobile division to support a contingency operation with the airlift and sealift assets presently available. The objectives are to reduce the time required to become operationally ready (OPRDY) overseas and to determine the optimum transportability mode. Initially, the study analyzed deployment of helicopters and equipment to Europe using only modern ocean shipping, i.e., fast containerships, barge-ships, and roll-on/roll-off (RORO) ships. The goal was to have the helicopters in as close to flyaway configuration as possible upon arrival at the oversea port of debarkation (POD). A follow-on analysis was requested by USREDCOM to include requirements for deploying to developing countries where containership facilities are nonexistent and comparing the sealift options with an all-air movement and an airlift/sealift combination.

2. Assumptions. The following assumptions were generated within MTMC to give this simulated deployment a realistic base for a parametric analysis:

a. Movement requirements. The movement requirements were the DA approved Table of Organization and Equipment (TOE 67-000-H1)(modified) of an airmobile division with 15 days of accompanying supplies. Ammunition was assumed to be made available from theater assets.

b. Outloading. The division was outloaded from Fort Campbell, Kentucky. The outloading capability was considered adequate. There were no serious constraints at the selected airports and seaports of embarkation (APOE/SPOE).

c. Deployment. The deployment scenario included a 10-day warning time. D-day, for the purposes of this analysis, was 5 January 1974. This served as a base point from whence the availability of ships could be determined. Deployment was over an unrestricted distance of 6,000 nautical miles to avoid any classification or political scenario writing. A total air deployment, a total surface deployment of equipment with troops moving by air, and an air/sea combination deployment were analyzed.

*MTMC Report 74-19, same subject, May 1974, Military Traffic Management Command, ATTN: MTMC-PL, Washington, D.C. 20315.

d. Airlift assets. The Military Airlift Command (MAC) assets used for this simulation are contained in Annex J of the Joint Strategic Capabilities Plan Fiscal Year 1974 (JSCP FY 74). Although no mobilization was assumed, wartime surge flying-hour rates for the C-5A and C-141A aircraft were used. Neither the Civil Reserve Air Fleet (CRAF) nor the C-130 aircraft were used. Overflight and refueling privileges were assumed to be granted. The refueling stop was at the half-way point (3,000 nautical miles), which obviated any critical leg problems.

e. Sealift assets. Sealift assets considered are those US Flag ships contained in the current Military Sealift Command (MSC) Merchant Ship Register. Availability of selected types of ships on or just prior to D-day was confirmed by MSC.

3. Deployment Requirements. The total movement requirements of the airmobile division consisted of 17,162 troops and TOE equipment and accompanying supplies amounting to 87,451 measurement tons (MTON) or 14,681 short tons (STON). Major items of equipment include 422 helicopters and 3,261 vehicles. A breakout of the authorized helicopters in the airmobile division are contained in Table 1. The 48 CH-47 Chinooks pose the greatest transportability problem because of their size, 302 MTON each.

TABLE 1
AIRMOBILE DIVISION HELICOPTERS, BY TYPE

Helicopter	No.
UH-1H Huey	193
OH-58A Kiowa	88
AH-1G Cobra	87
CH-47C Chinook	48
UH-1M (STANO)*	6
Total	422

*Surveillance, Target Acquisition, and Night Observation.

4. Airlift Deployment.

a. In conjunction with the US Army Aviation Systems Command (AVSCOM), MTMC developed helicopter disassembly and reassembly time factors. These factors were approved for use in the study by the Director of Army

Aviation, Office of the Assistant Chief of Staff for Force Development, Department of the Army, on 10 December 1973. All helicopters were transported in the C-5A to minimize disassembly requirements. The four smaller size helicopters require very little preparation for C-5A transport, primarily removal of the rotor blades and some preservation, which averages only 5 man-hours each. However, the CH-47 Chinook requires 222 man-hours (6 men working 37 hours) to prepare for C-5A movement.

b. The greater preponderance of time in disassembling the CH-47 is that required to remove the aft pylon, rotor head, and ancillary power train. The aft pylon is prepared for movement aboard an AVSCOM-provided transportability skid. The forward transmission assembly and rotor head is mounted on a similar skid. During transport, the smaller element is secured inside the CH-47; the larger assembly is stowed in the C-5A adjacent to the CH-47. C-5A loadings of minimally disassembled helicopters are contained in Figure 1. Reassembly time of the CH-47 presents an even more dramatic picture. Because of the tolerances that must be regained and the requirement for maintenance operational checks and functional test flights, it takes 456 man-hours (6 men working 76 hours) to make the CH-47 operational after C-5A transport. Only an average of 9½ man-hours is required for the smaller helicopters.

c. Considering that the Chinook is in fact the most difficult piece of equipment in the entire division to transport, the total time required to deploy the CH-47 assault support helicopter battalion of the airmobile division is most critical (Figure 2). In this analysis consideration was given to preparation by only the organic division maintenance personnel, plus the potential for augmentation. The 72 man maintenance capability internal to each of the aviation companies was aggregated to assist in preparing the initial company for deployment. By deploying the initial company with all troops, its organic maintenance segment would require 8½ days, at the rate of 76 hours per aircraft, to prepare the company for operations in the overseas area. The second company required a slightly longer time for home station preparation and the third company considerably longer. Reassembly times remain the same because each company used only their organic maintenance element. With organic disassembly and reassembly only, this battalion can be deployed and OPRDY by D+18. If a similar 72 man maintenance element from an existing general support company at Fort Campbell augments the three companies as they prepare for movement, outloading time can be reduced and operational readiness attained in the theater three days earlier, by D+15. With sufficient MAC assets made available, the remainder of the division can be outloaded and deployed within the same time frame.

5. Sealift Deployment.

a. Modern ocean ships are designed to transport a specific class or classes of cargo; containerships carry containers; RORO ships transport vehicles; and the barge-carrying ships, Sea Barge (SEABEE) and Lighter Aboard Ship (LASH), handle bulk cargo and/or vehicles and containers. Ship utilization is maximized when two approaches to cargo loading are followed:

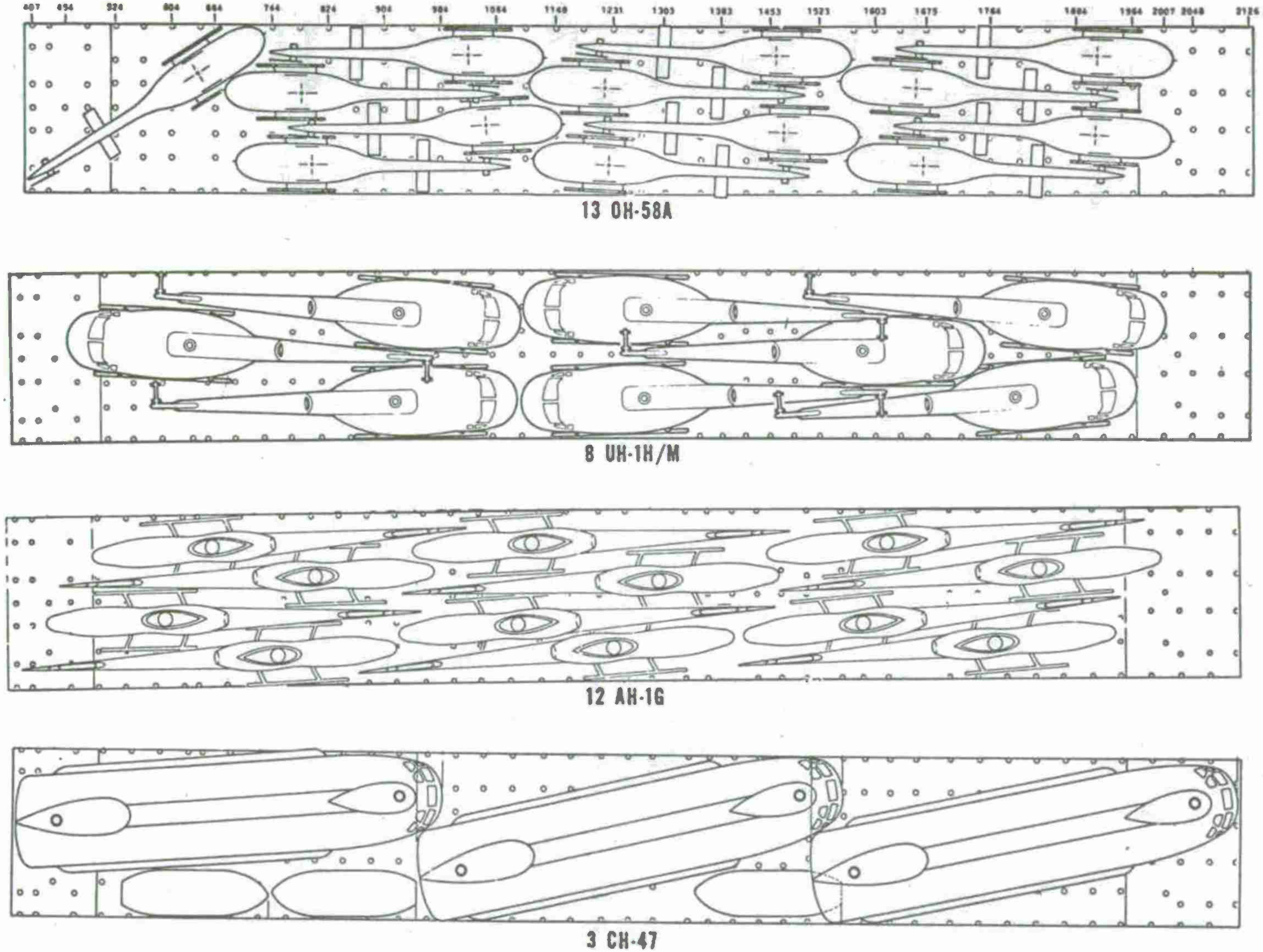

Figure 1.. Helicopter Loadings by Type in C-5A Aircraft.

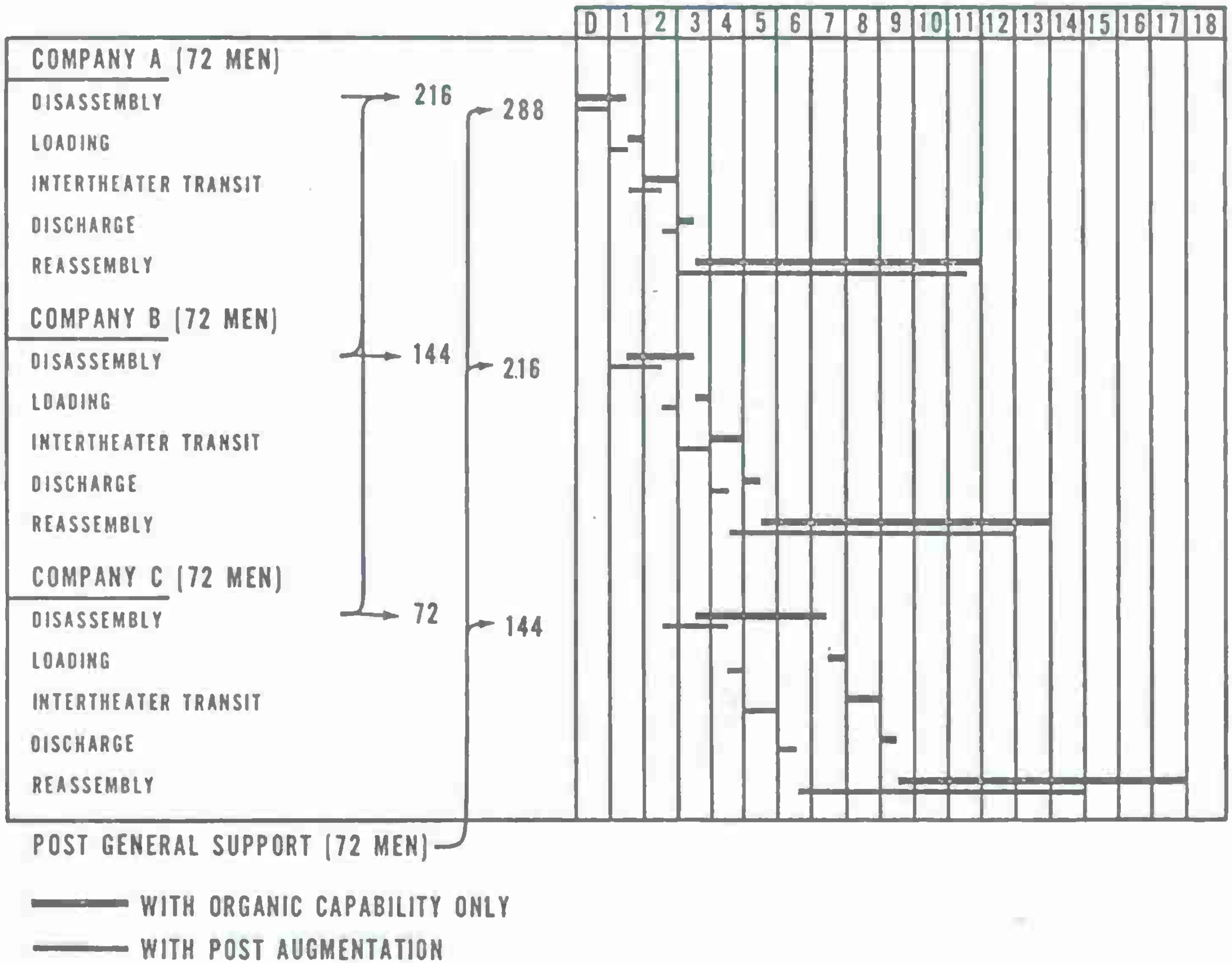

Figure 2. Time Phasing for CH-47 Aviation Battalion Airlift Deployment.

(1) Load each class of cargo on the type of ship designed to transport that cargo class.

(2) Use the largest, fastest vessels to maximize each lift and reduce turnaround time.

Based on the above approaches and considering that approximately 40 percent of the airmobile division's equipment is containerizable, it would dictate that the more numerous containerships should be considered first, then the RORO for the noncontainerizable wheeled and tracked vehicles, and other noncontainerizable cargo on LASH and SEABEE vessels in that priority. However, the order of priority had to be exactly reversed to comply with the USREDCOM guidance of minimum disassembly and preservation of the division's 422 helicopters to keep them in close to flyaway configuration. The SEABEE ship, because of its design and adaptability, was the first choice for optimally transporting the helicopters. The LASH also could carry helicopters and, once committed, it had to be fully loaded out, particularly with noncontainerizable equipment. The RORO was still primary for the outsized vehicles and fully loaded out with smaller vehicles. Then, the remaining containerizable cargo was sent to a containership.

b. Another consideration is the type of country to which the division is being deployed. If it is to Europe or other developed areas where shoreside cranes with a rapid rate of discharge are available, the use of nonself-sustaining containerships is desirable. However, when going to a developing area, such as the Persian Gulf or some ports of Asia where container facilities are inadequate or nonexistent, it becomes necessary to substitute break-bulk (freighter) or barge-carrying ships for the containership. Also, the 160 40-foot containers on the SEABEE and the 72 20-foot equivalent (TEU) containers on the LASH ships cannot be used, further increasing the break-bulk requirements. This analysis considered deployments to both developed and developing countries.

c. Many vessel combinations were considered before selecting two as optimum; Sealift A deploying to a developing country and Sealift B to a developed country such as Europe. Both used a 21.7 knot SEABEE, a large 22.5 knot C9 LASH, and a large 25 knot RORO ship. In addition, two fast (20 knots or better) C4 break-bulk ships were selected for Sealift A. Their self-sustaining capability would be a real advantage in ports where cranes were in short supply and outweighs the disadvantage of their slightly slower speed. A containership, with the minimum size of the C6 class, was required for Sealift B. Jacksonville, Florida, was selected as the primary POE with New Orleans, Louisiana, as an alternate. To test actual vessel availability, MTMC requested the type ships for the day required in relation to D-day, 5 January 1974. The MSC ship nominations are contained in Table 2.

TABLE 2
SHIP SCHEDULE[a/]

Type of Ship Rqr	Day Rqr	Port: Jacksonville	Port: New Orleans	MSC Ship Nomination
SEABEE	D-Day	D-Day	D-2	Doctor Lykes
C9 LASH	D-Day	D-Day	D-Day	Delta Norte (Altn - C8 LASH Espania)
RORO	D+1	D-2	D-Day	Ponce De Leon
2 Fast C4 Break-Bulk[b/]	D+1	D-Day	D-Day	2 Unnamed
C6 Container-ship[c/]	D+3	D+2	D+3	SL-7 Sealand McLean

[a/] MSC only confirmed that these ships could physically be present at the selected ports on the date required. They stated that some of these ships, if not all, were not yet part of the Sealift Readiness Program, a voluntary program to permit early acquisition of a number of US ships for defense contingencies. Therefore, if these ships could not be obtained under normal charter procedures it could require high-level decisions to requisition the required ships.

[b/] Sealift A.

[c/] Sealift B.

d. Stowage of the CH-47 Chinook helicopter in the SEABEE ship is accomplished by placing them in 4 columns abreast, 2 columns per side of the ship's centerline support structures. By overlapping 12 Chinooks nose-to-tail per column, it would be possible to stow all 48 of the division's CH-47 helicopters in the protected lower deck (Figure 3). CH-47 disassembly for stowage aboard the SEABEE merely requires removing the rotor blades and minimum preservation. This can be accomplished in 18 man-hours (3 hours elapsed time) as compared with 222 man-hours (37 hours elapsed time) for C-5A transport. A comparison of reassembly times between SEABEE and C-5A transport of the Chinook is even more dramatic; only 26 man-hours (5 hours elapsed time) are required to prepare for flight as compared to 456 man-hours (76 hours elapsed time) for reassembly and testing after airlift.

e. With careful loading techniques it is estimated that 19 UH-1H and 3 AH-1G helicopters could be stowed with no disassembly or preservation in the 2 lanes between the CH-47 helicopters (Figure 4). The remaining 174 Hueys and 84 Cobras would be loaded in 26 barges located

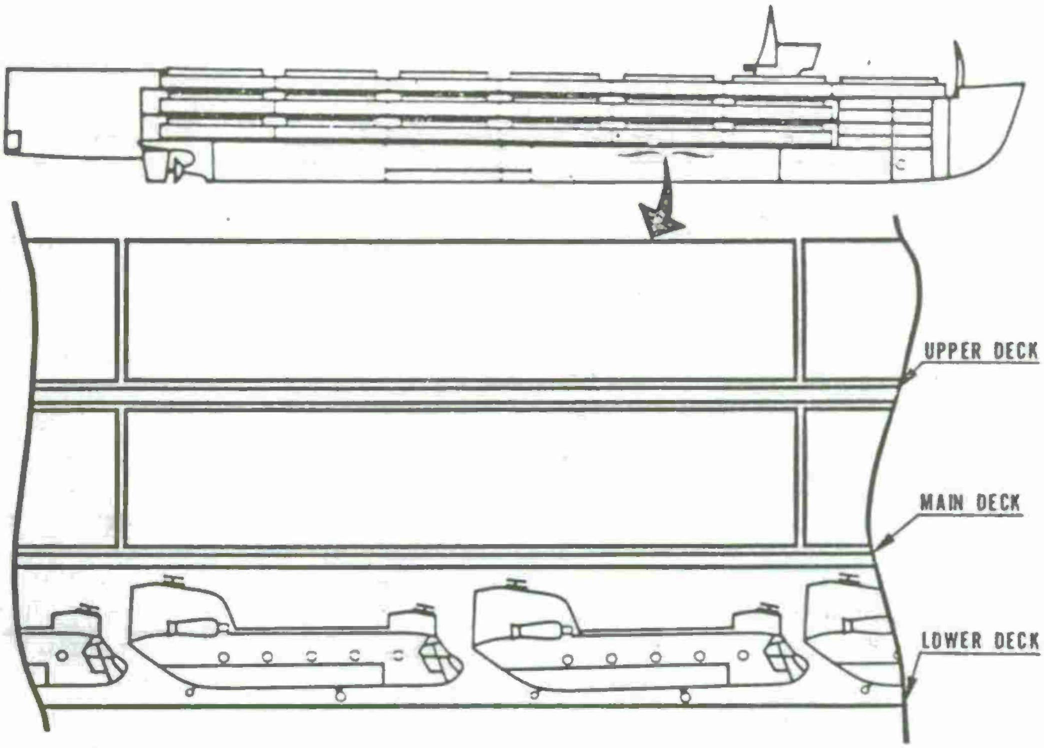

Figure 3. Proposed Method of Stowing CH-47 Helicopters in SEABEE Ships.

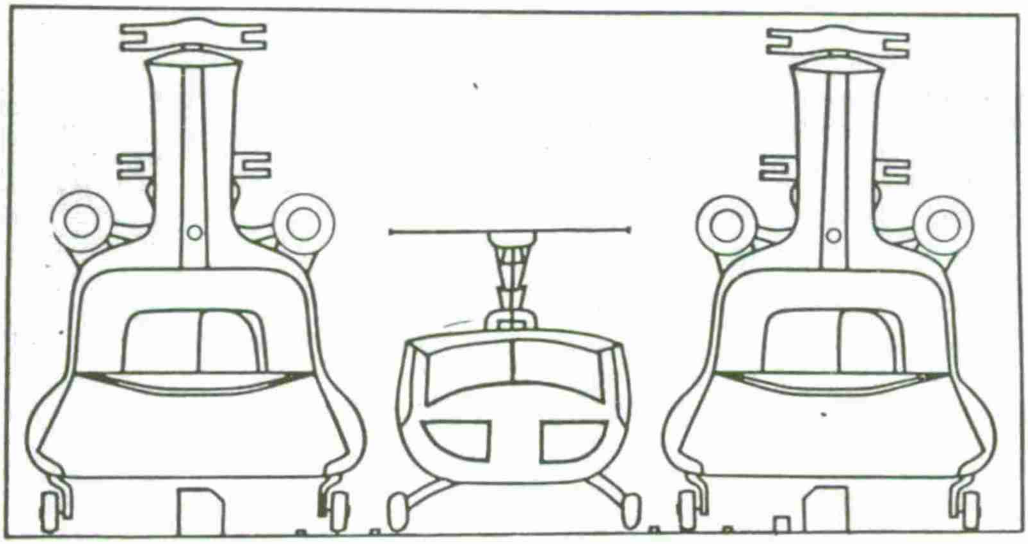

Figure 4. Conceptual Helicopter Loading (Aft View) in Lower Deck of SEABEE Ship.

on the main and upper decks. The height of the SEABEE barge (Figure 5) will permit covered stowage of these helicopters without removal of the rotor head or mast.

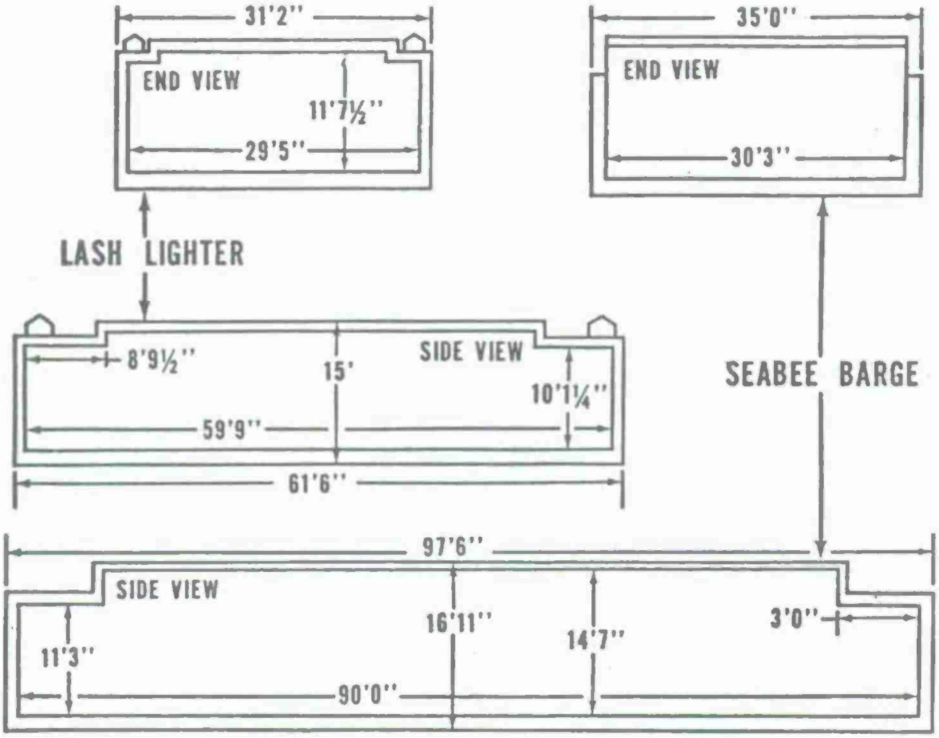

Figure 5. Size Comparison of LASH Lighter to SEABEE Barge.

Six Cobras can be stowed when only the rotor blades are removed in 4 man-hours (Figure 6). However, by also removing the stub wings and

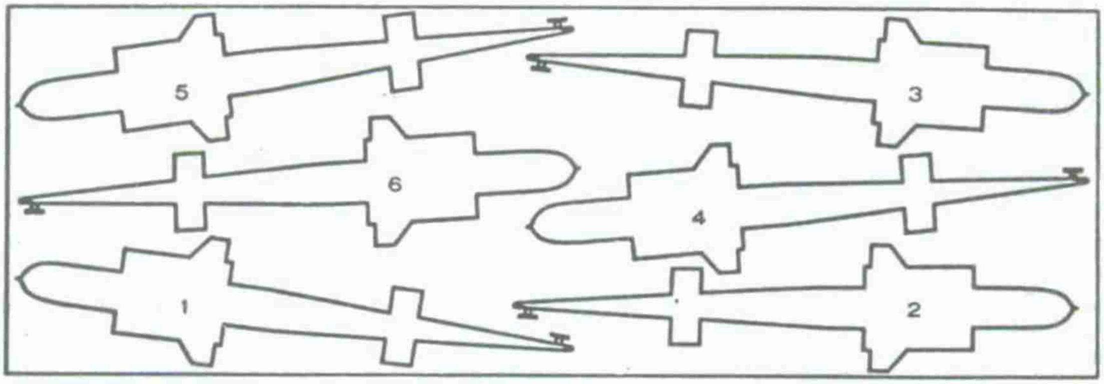

Figure 6. Stowage of 6 AH-1G Helicopters in SEABEE Barge.

the synchronized elevator on the tail boom it is possible to load 14 Cobras (Figure 7). The total disassembly time is now 6 man-hours

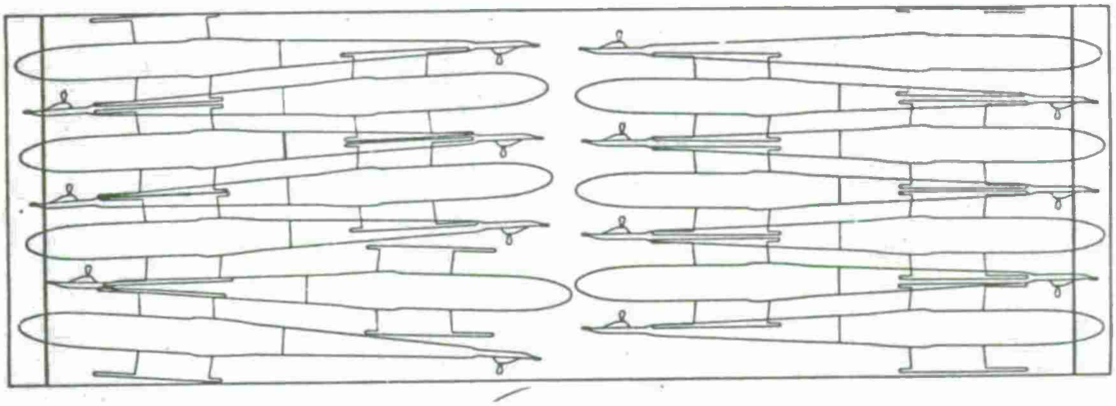

Figure 7. Stowage of 14 AH-1G Cobras in SEABEE Barge.

(three men working 2 hours), but only 5 man-hours would be required for reassembly to flyaway. The Cobra does not require the wings for flight under 110 knots; they are for carrying external stores, mainly ordnance. They could be reinstalled in 1 man-hour after the helicopters have reached their new base. Comparing reassembly times for flyaway, it is seen that the additional man-hour per helicopter when shipping 14 Cobras per barge is not much of a penalty over the 4 man-hours required when shipping only six per barge. Nine UH-1H/M helicopters can be loaded in a SEABEE barge when the synchronized elevator is removed (Figure 8). The

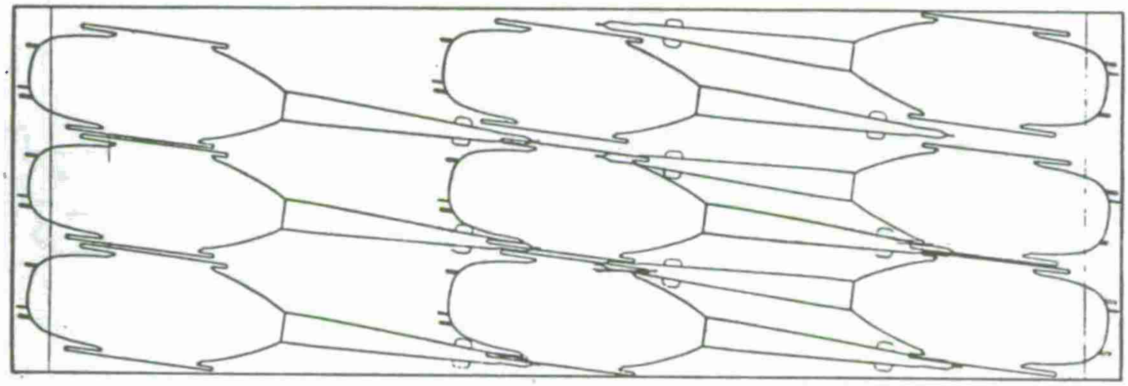

Figure 8. Stowage of 9 UH-1H/M Hueys in SEABEE Barge.

remaining helicopters, 88 OH-58A Kiowas, would be transported aboard the LASH ship. Eight of these scout helicopters can be stowed in the smaller LASH lighter with only the rotor blades removed (Figure 9).

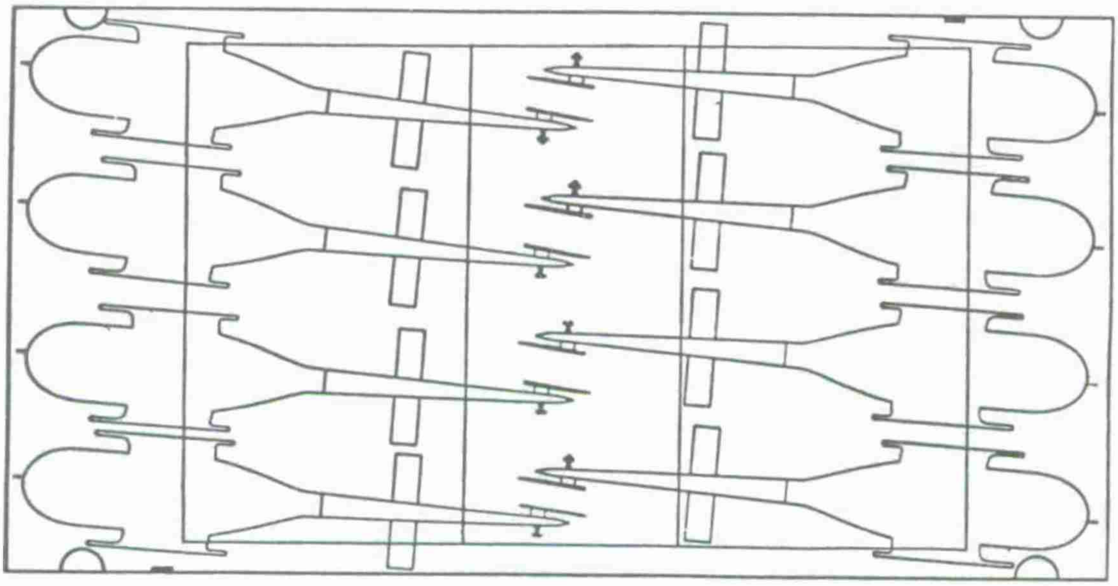

Figure 9. Stowage of 8 OH-58A Kiowas in LASH Lighter.

f. There is a wealth of historical information on the capabilities and time factors for loading unit equipment on break-bulk and RORO ships and for containerizable cargo on containerships. However, there has only been one unit move by the SEABEE system and that was only an aviation company with 5,331 MTON, approximately 6 percent of the airmobile division tonnage. There have been no unit moves using the LASH system although military equipment has been transported by LASH. Therefore, the notional information available on these systems for unit equipment has been evaluated and compared with the recent actual data collected. During the sea move of an attack helicopter company in 1973, 396 STON of unit equipment were sent to the POE on 27 railcars. This equipment, which equaled 1,891 MTON, was loaded in four SEABEE barges in exactly 8 hours with remaining space available. This equates to an average of 473 MTON per barge, which is about 48 percent utilization. This is in consonance with the MTMC-derived container-utilization factor of 50 percent for unit equipment.

g. Based on the shipping nominated by MSC it was determined that the first ship would arrive at the POD on D+14. MAC was requested to have all troops close in country 2 days prior to the first ship, on D+12. To move the 17,162 troops would require 134 sorties by C-141A aircraft; the C-5A normally will not be planned for a pure troop role.

h. On D-day for Sealift A, going to a developing country, Fort Campbell started outloading by rail and truck the cargo destined for the two break-bulk ships since they were the slowest vessels (Figure 10). Transit time to Jacksonville averaged 1 day. Ship loading commenced on D+1 and the ships sailed on D+3. Approximately 41 percent of the first ship's cargo were vehicles that generally load faster than bulk tonnage, and the remaining cargo was in a unitized or CONEX container configuration. Only about 77 percent of the cargo capacities were utilized, which,

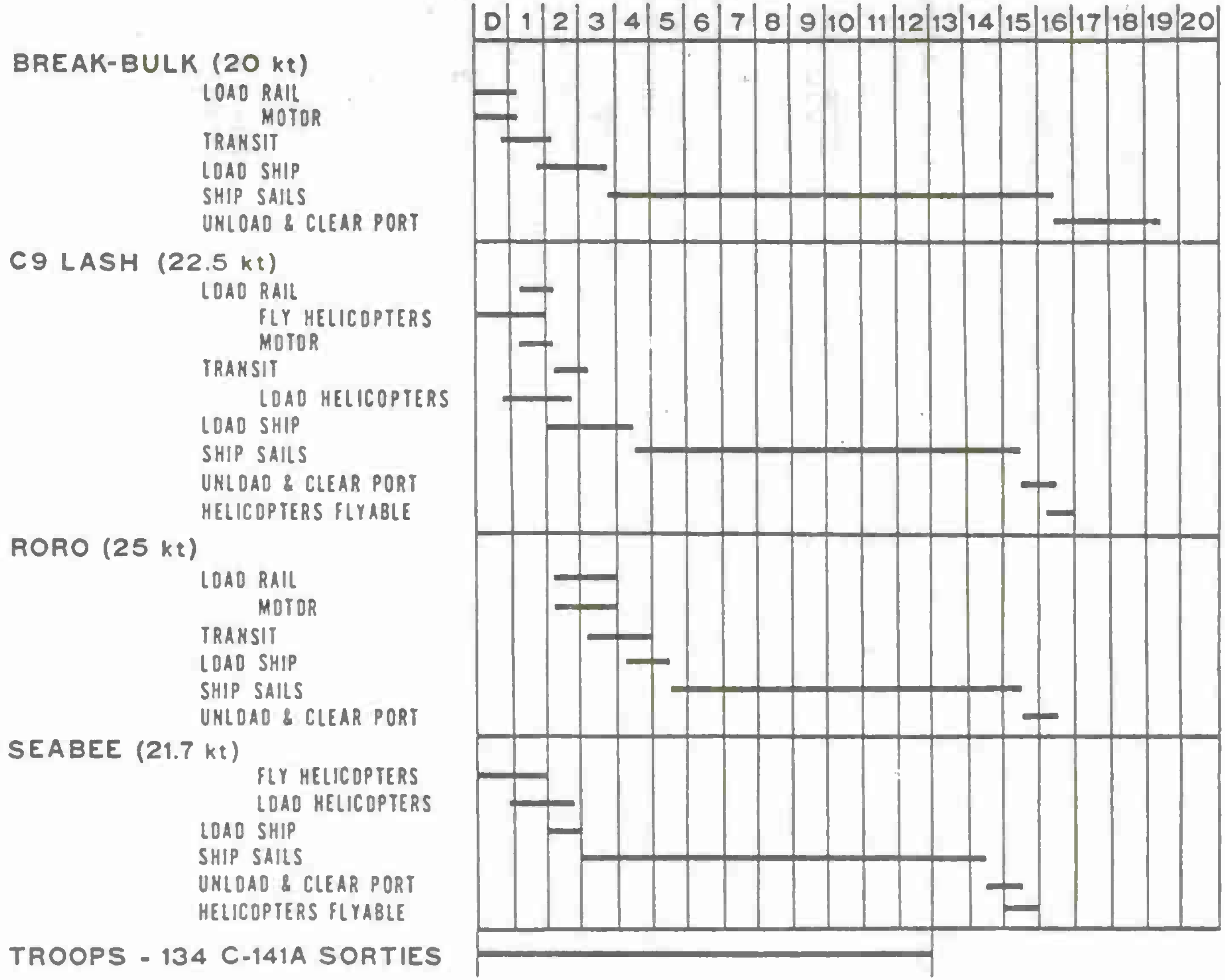

Figure 10. Sealift A, Developing Country.

when combined with a 24-hour workday, resulted in the relatively short loading time. Concurrently with the station outloading, the division's helicopters flew to Jacksonville for loading aboard the SEABEE and LASH ships. The SEABEE, carrying only 334 helicopters, sailed on D+3. The LASH carrying 88 helicopters, unit equipment, and supplies sailed on D+4. The latter had second priority on cargo outloading from Fort Campbell after the break-bulk ships. Large and medium size wheeled and tracked vehicles, approximately 58 percent of the total vehicle tonnage (STON), were outloaded from Fort Campbell last because they were loaded in less than 1 day on the fast (25 knot) RORO ship, which sailed on D+5. The break-bulk ships arrived last at the POD on D+16 and because of their longer unloading time, the division could not clear the POD and be fully operational until D+20.

i. In Sealift B, going to a developed country (Figure 11), the higher speed and faster loading ships were again programed to sail last. First priority for Fort Campbell outloading by rail and truck was 7,069 MTON of equipment and supplies that were containerized for the SEABEE. Next shipped were small and medium vehicles and some cargo for the LASH ship. Again, the RORO ship carried the bulk of the vehicles. The SL-7 containership carried the remaining containerizable vehicles and 7,643 MTON of equipment and supplies. The SEABEE and LASH carried all of the helicopters. The SEABEE sailed on D+3; the LASH on D+4; the RORO on D+5; and the speedy (33 knot) SL-7 containership on D+7. This deployment permitted the division to be operational on D+17.

j. A Sealift Special Option is worth mentioning even though it deviates slightly from the USREDCOM guidance of minimum helicopter disassembly. If the 88 small OH-58A scout helicopters are containerized in 44 of the 160 40-foot containers on the SEABEE ship, at a maintenance man-hour penalty of only 9 percent, all 422 helicopters could be carried on the SEABEE. Be elimination of the LASH lighter requirement for these helicopters and redistributing the LASH ship cargo to the RORO and a larger containership, the SL-7, it would be possible to deploy the division to a developed country such as Europe by D+16 using only 3 ships.

6. Airlift/Sealift Combination Deployment. Analyses were made to determine the best combination of air and sea assets capitalizing on the advantages of each mode and minimizing the disadvantages. The sealift was reduced to one SEABEE and one RORO vessel. As before, the SEABEE accommodated 334 helicopters. The remaining 88 OH-58A helicopters that had been transported on the LASH were shipped on C-5A aircraft. The RORO ship transported approximately 58 percent of the division's wheeled and tracked vehicles (STON). The preparation, deployment and reassembly factors used in this mixed air/sea movement of the division to a developed country permits readiness within the theater by D+16. Airlift utilization was spread throughout the entire time frame, again having the troops available the day before the ships arrive. To move the equipment of this division that had been moved on the LASH and the containership, plus all troops, would require 43 C-5A sorties

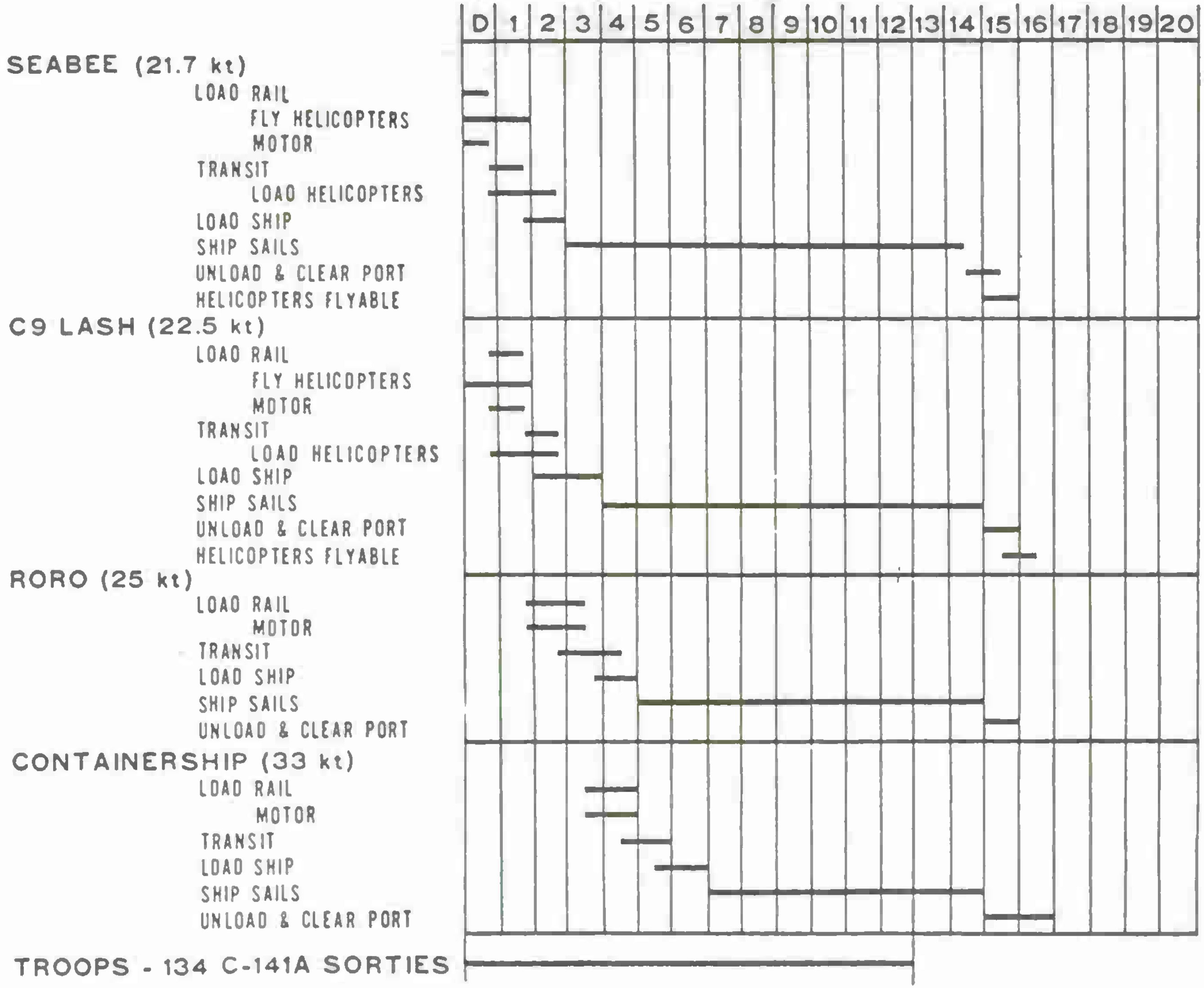

Figure 11. Sealift B, Developed Country.

and 325 C-141A sorties over this 13 day period. If deploying to a developing country, the airlift requirement would increase slightly to 58 C-5A and 400 C-141A in order to carry the 2,400 STON of cargo that had been stowed in the 160 40-foot containers on the SEABEE ship.

7. Summary of Deployments (Figure 12). The simulated deployments of the airmobile division are summarized as follows:

a. Movement totally by air, without mechanic or maintenance personnel augmentation at home station, can be accomplished by D+18. With augmentation at home station the closure and readiness times on the far shore are reduced by 3 days.

b. In developing countries, requiring some self-sustaining capability, the division can close by D+20 by using two break-bulk ships plus ships from the modern merchant fleet, and 134 sorties of C-141A for troops, with no C-5A aircraft required at all. In a developed country where the faster and larger containership can be used, the division can close by D+17.

c. If containerization of the 88 OH-58A helicopters on the SEABEE ship is permitted, sealift can deploy the division to a developed country by D+16 using only 3 ships.

d. By optimizing airlift and sealift assets in a combination deployment, the division could be OPRDY by D+16 in either type country.

8. Comparative Analysis of Deployments.

a. It is recognized that Army helicopters must be disassembled for intertheater use by both air and sea deployments; however, the requirements associated with airlift are significantly greater. An airlift deployment requires approximately 30,000 more man-hours of helicopter preparation than for either sealift or an air/sea move, due to the CH-47 disassembly for transport in the C-5A. This is an opportunity cost that, while not readily quantifiable in dollars, obviously would increase the cost of an airlift.

b. Closure time and operational readiness are normally paramount in force contingency deployments. However, when the operationally ready times are within a 3-day span, as in this simulation for a move to a developed country, transit costs might be considered along with other factors.

c. In the past, fuel requirements possibly may not have been a major consideration for force deployments. In view of the energy crisis, an analysis was made of the estimated fuel consumed for the selected simulated deployments. Only port-to-port aircraft and ship fuel consumption was considered since it would have been a major task to estimate truck and rail expenditures.

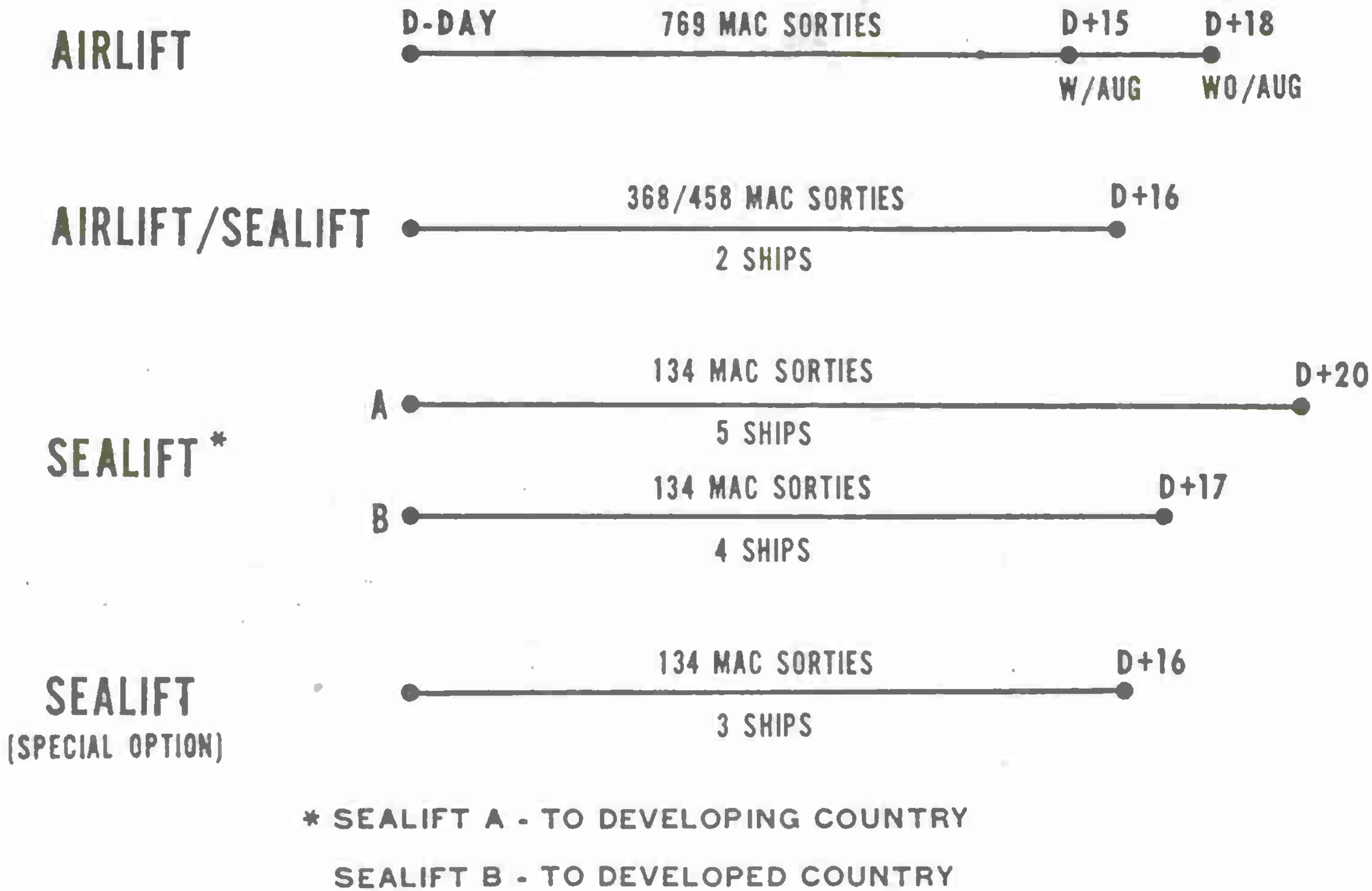

Figure 12. Summary of Deployments.

d. The types of deployments are listed by OPRDY time with the discussed considerations appropriate to each so that the possible trade offs may be determined (Table 3). The cost of the fuel required is included in the transit costs. The fuel consumed is shown for comparison purposes only.

TABLE 14
DEPLOYMENT TRADE OFFS

OPRDY	Hel Prep (Thousand Man-Hr)	Transit Cost (Million Dol)	Fuel Rqr (Million Gal)	Type of Deployment
		To Developing Country		
D+15	38.0	25.4	25.1	Airlift (Augmented)
D+16	7.5	15.8	16.3	Airlift/Sealift
D+18	38.0	25.4	25.1	Airlift (Unaugmented)
D+20	7.5	5.7	6.8	Sealift
		To Developed Country		
D+15	38.0	25.4	25.1	Airlift (Augmented)
D+16	8.2	5.2	6.7	Sealift (Special Option)
D+16	7.5	12.7	13.3	Airlift/Sealift
D+17	7.5	5.9	7.4	Sealift
D+18	38.0	25.4	25.1	Airlift (Unaugmented)

9. General Conclusions and Recommendations.

a. Conclusions.

(1) The strategic deployment capability of the US Army airmobile division could be significantly improved by implementing the proposed ship loading procedures with the modern ocean shipping presently available in the US Merchant Marine.

(2) Sealift deployment is competitive with airlift deployment of the airmobile division.

(3) The proposed helicopter loadings in the barge-ship systems represent a quantum jump in the state of the art and should be confirmed.

b. Recommendations. It is recommended that -

(1) The concepts proposed in this study be approved as a basis for the development of plans, procedures, and systems necessary to permit

the rapid deployment of the US Army airmobile division in a contingency situation and the optimum transportability of Army aircraft in peacetime.

(2) Expedited testing be conducted of the proposed helicopter loadings in the barge-ship systems.

10. Sensitivity Analysis. An analysis was performed to determine the sensitivity of the selected ship options to additional vessel variations, and of the airlift deployment to increased distances of the critical leg. It was found that sealift deployment time is not overly sensitive to the nonavailability of a SEABEE provided it is replaced with a LASH ship; however, it is very sensitive to the nonavailability of any barge-ship for the transport of helicopters. Also, the airlift deployment time is very sensitive to the length of the critical leg beyond 4,400 nautical miles and to the number of MAC aircraft available for deployment.

11. ORSA Applications.

Because this study was heavily oriented to operational methodology, such as aircraft disassembly and stowage, it was not amenable to the application of classical operations research techniques. A significant amount of the effort, however, was devoted to template loading of various transportation assets, and where this detailed loading was not done, cargo was allocated to available assets on the basis of either volume or loading area at a presumed level of space utilization. It would have been very useful, and would have enhanced the accuracy of the asset requirement determination, had there been an efficient way of loading individual cargo items, modeled as rectilinear blocks, into rectilinear cargo compartments. The problem can be stated as follows: suppose there exists a set of rectilinear blocks and a set of containers, possible of several different sizes. Then, does there exist an algorithm (preferably susceptible to computer implementation) for assigning the blocks to containers in such a way as to minimize the total number of containers used? Although an intuitive approach to the problem is obvious (sequence the blocks by size, possibly by a weighted average dimension, and load the items beginning with the largest), it is by no means clear that this method is optimal. Also, the question of the optimal physical arrangement of the blocks in each container remains open. The obvious computer-oriented approach to this aspect is to grid the container volume to some desired degree of resolution and do an array search to find available space for a cargo item, with loading indicated by turning on bits for each occupied grid cube. This method is extremely expensive, of course, and any more efficient approach would be a valuable contribution to the field. Formal answers to these questions do not appear to exist at present.

SYSTEM CAPABILITY-OVER-REQUIREMENT EVALUATION (SCORE)

A TECHNIQUE FOR SELECTING OPTIMAL AUTOMATIC DATA PROCESSING EQUIPMENT TO MEET FUTURE REQUIREMENTS

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I. INTRODUCTION. OR/SA, in contradiction to its name and origin, strays too frequently into the area of abstruse mathematical models. Many are never implemented. Significant benefits are possible through the use of inexpensive, simple, structured OR/SA techniques which address specific operational problems. The term MICRO-OR/SA has been used to aptly describe this type of analysis. Benefits accrue in three ways:

---Dollar savings are significant because the analyses address operational areas where large amounts of money are spent each day.

---The cost of analysis is a nominal percentage of the benefits.

---The probability of implementation is increased due to model simplicity and understandability which much improves its credibility and thus its acceptance by decision-makers.

The System Capabilities-Over-Requirement Evaluation (SCORE) planning process is such a technique applied to the planning of future ADP requirements. The technique is demonstrated for BASOPS, the Army installation management system located at 42 Army installations.

II. MODEL. The model, using statistical and empirical data, generates a description of both the requirement and capability stated in common units of computer power. In the illustration which follows the common units are "360/30 equivalent hours". The model is schematically portrayed in Figure 1.

A. Phase I uses empirical data from a number of sources to generate: (1) Installation Runtime Predictors (IRP's), and (2) Machine Conversion Factors (MCF's). Both parameters are stated in units of "360/30 equivalent hours". The IRP's allow generation of a BASOPS Runtime Matrix (BRM), which documents the requirement for each BASOPS sub-system at each Army installation. The BRM combined with extension schedules for each BASOPS sub-system completes the requirement statement. The MCF's applied to candidate hardware configurations, in units of "360/30 equivalent hours", are a statement of the capability available. The BASOPS Installation Analysis (BIA) performs the function of matching capability to requirement during each planning year, thus completing the Requirements Analysis (RA) phase of the plan. The RA determines those hardware configurations which will minimally satisfy the requirement.

B. Phase II, the Economic Analysis (EA), introduces cost and

SCORE
BASOPS HARDWARE PLAN
SCHEMATIC MODEL

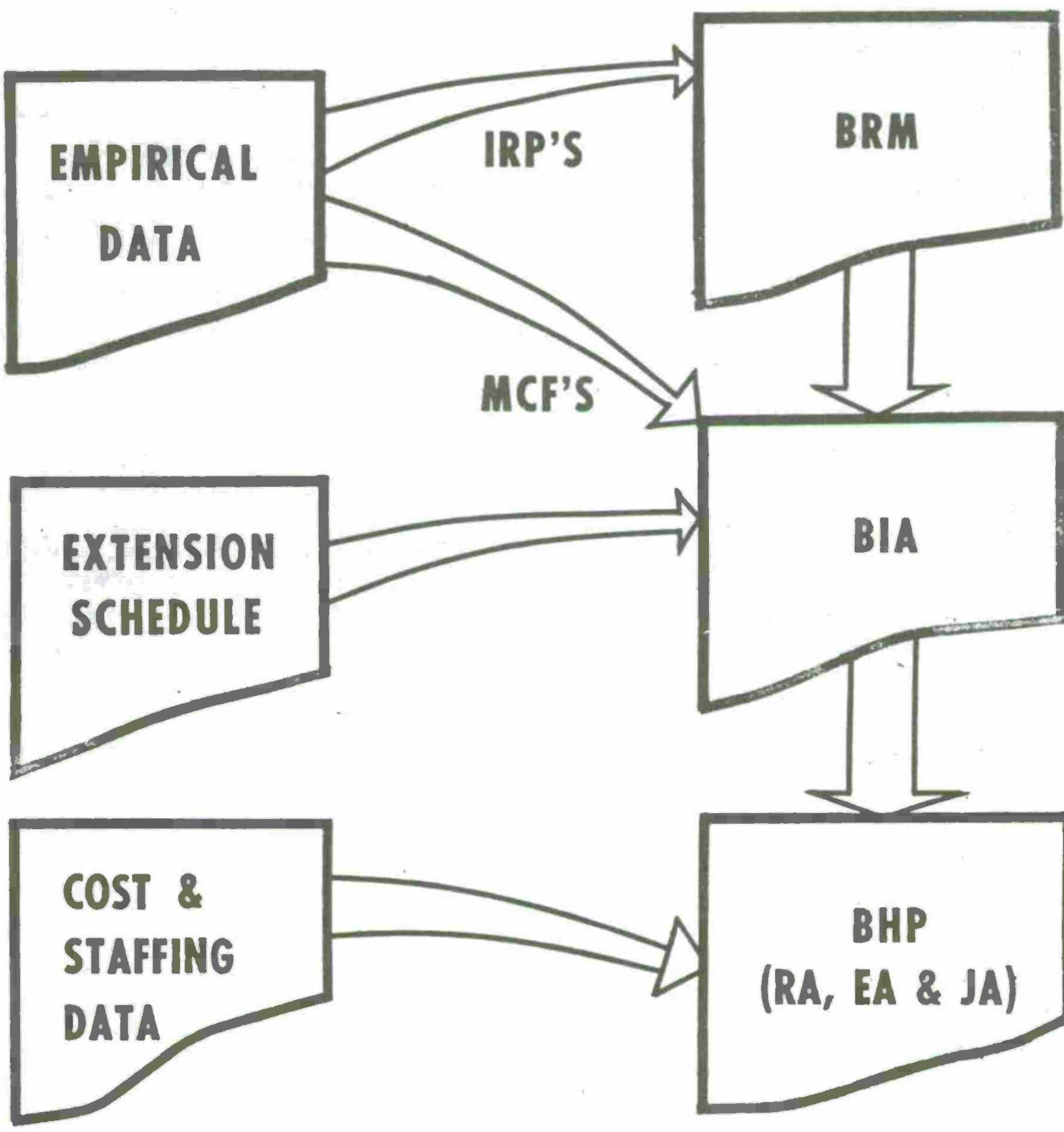


Figure 1

staffing data in order to perform a trade-off analysis between machine capability and operators required. The result is a list of configurations which will most cost-effectively satisfy the requirement.

C. Phase III, the Judgmental Analysis (JA), introduces factors not considered in the first two phases. For example, if two solutions are very close in cost, the slightly more expensive alternative which precludes weekend processing might be the preferred solution.

III. ILLUSTRATIVE EXAMPLE. The illustration which follows was developed during the past year in response to an increasingly critical problem. The problem was that of new versions of BASOPS sub-systems and planned additional systems would certainly exceed hardware capability at most BASOPS installations.

A. REQUIREMENTS ANALYSIS.

1. Empirical data included actual monthly runtimes (MRT) for the Standard Financial System (STANFINS), Major Command Standard Systems, and Installation Unique Systems.

2. Installation Runtime Predictors (IRP's) were developed to estimate sub-system runtime for SIDPERS and SAILS because these subsystems had not yet been fully extended to all BASOPS installations. The IRP's were developed as follows:

a. SIDPERS. A plot of SIDPERS cycle runtime versus number of transactions (Figure 2), combined with a subjective analysis produced a SIDPERS IRP of MRT = 3C + 7P, where MRT is monthly runtime, C is the number of cycles per month, and P is the supported population in thousands (based on 10 transactions per man per month). The IRP was validated data from Ft. Hood and Ft. Lee and later validated with more recent data (Figure 3). The IRP is applied using the DA approved 11 cycles per month. Single integer coefficients are used for purposes of simplicity.

b. SAILS. In April 1974 a regression analysis was performed on data from the four installations which had been operating SAILS on 360/30's for three or more months. An analysis similar to that for SIDPERS produced a SAILS IRP of MRT = 9C + 1.0T (Figure 4). The IRP was applied using 22 cycles per month since daily cycles are required.

3. The BASOPS Runtime Matrix (BRM) records estimated monthly runtime in "360/30 equivalent hours" for each BASOPS sub-system at each installation (Figure 5). Under column heading "POP" are current/projected populations (in thousands) which are used in the SIDPERS IRP. Those posts showing zero population will be satellited on other posts for SIDPERS purposes. Under column heading "TRANS" are the average/projected supply transactions (in thousands) which are used in the SAILS IRP. Actual hours reported are shown for STANFINS, Command Standards, and Post Uniques. If the post is using ADPE other than a 360/30, the reported hours are converted to "360/30 equivalent hours" using the Machine Conversion Factors discussed below. Runtimes for

SCORE

BASOPS HARDWARE PLAN

INSTALLATION RUNTIME PREDICTOR (IRP)-SIDPERS

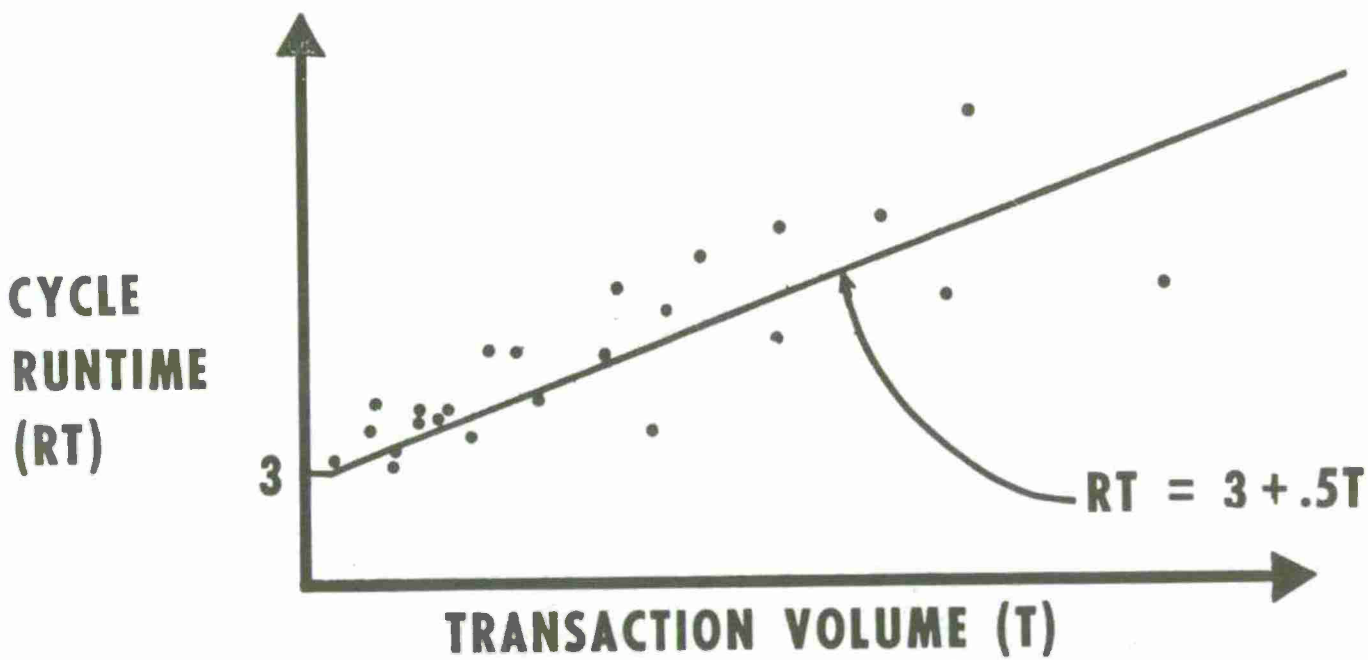


Figure 2

SIDPERS IRP

VALIDATION	INSTALLATION	MONTH	CYCLES	POP (1000)	MRT	
					PREDICTED 3C + 7P	ACTUAL
INITIAL	FT HOOD	May 73	18	2.9	74.3	72.5
		Jun 73	16	2.9	68.3	67.1
		Jul 73	15	2.9	65.3	59.1
	FT LEE	Jun 73	15	5.1	80.7	78.8
		Jul 73	12	5.1	71.0	70.1
FOLLOW-UP	FT McPHERSON	Apr 74	9	5.0	62.0	47.0
	FT BELVOIR	Apr 74	11	8.5	92.5	88.0
	FT BLISS	Jan 74	10	18.5	159.5	183.0
		Feb 74	11	18.5	162.5	135.0
		Mar 74	11	18.5	162.5	140.0
		Apr 74	11	18.5	162.5	134.0
	FT JACKSON	Jan 74	10	16.3	165.1	127.0
		Feb 74	8	16.3	159.1	123.0
		Mar 74	12	16.3	171.1	166.0
		Apr 74	12	16.3	171.1	145.0

Figure 3

SAILS IRP

INSTALLATION	MONTH	CYCLES	TRANS (1000)	MRT	
				PREDICTED 9C + 1.0T	ACTUAL
Ft Devens	Mar 74	9	61.2	142.2	143.5
Ft Lee	Feb 74	13	45.0	162.0	162.3
Camp McCoy	Mar 74	15	82.8	217.8	220.7
Ft L. Wood	Mar 74	12	72.5	180.5	183.0

Figure 4

FY 77

---------------RUNTIME MATRIX---------------

POST	POP	TRANS	SID	SAIL	STAN	STDS	UQS	VTS	STAR	MPS	IFS	TOTAL* +10%
BRAGG	23.7	243.7	199	442	155	110	15	8	20	10	40	1098
CAMPBELL	4.4	118.5	64	317	177	68	32	8	20	10	20	787
CARSON	25.0	190.5	208	389	200	213	82	8	20	10	20	1264
DEVENS	8.3	78.4	91	276	138	69	69	8	20	10	20	772
HAMILTON	0.0	30.0	0	228	144	104	38	8	20	0	20	618
HOMESTEAD	3.3	25.0	56	223	77	55	5	8	20	0	0	489
HOOD	3.0	299.0	54	497	143	92	114	8	20	10	40	1076
HOUSTON	16.0	94.5	145	293	273	194	170	47	20	10	20	1289
IGMR	7.7	35.1	87	233	32	22	20	8	20	0	20	486
LEWIS	25.0	181.5	208	380	252	161	85	8	20	10	40	1280
MACARTHUR	0.0	0.0	0	0	132	95	68	8	0	0	0	333
MCCOY	0.0	65.8	0	264	162	56	42	8	20	0	20	629
MCPHERSON	5.0	40.0	68	238	82	30	43	8	20	0	20	560

Figure 5

systems in development (VTAADS, STARCIPS, MPMIS, and IFS) were estimated by programer/analysts familiar with the systems. The "TOTAL" column is a summation of the MRT hours for each sub-system and includes an added 10% contingency/growth factor.

4. Machine Conversion Factors (MCF's) reflect relative capabilities of candidate hardware configurations. Carefully selected representative samples of actual cycles were assembled for SIDPERS, SAILS, STANFINS, Command Standards and Post Uniques. The "baseline" package was run on each of the appropriate hardware configurations. The 360/30 runtime was used as the baseline with the 360/30 MCF set at 1.0. MCF's for the other configurations indicate their increased throughput capability in relation to the 360/30. The 360/30 baseline capability was set at 600 hours per month. This represents a 30-day month, 7-day week, 3 shifts per day operation. It excludes the standard 4 hours per day for required maintenance, service, power outages, and other lost time. 360/30 "equivalent hours" of monthly capability are calculated by multiplying each MCF by 600. (See Figure 6).

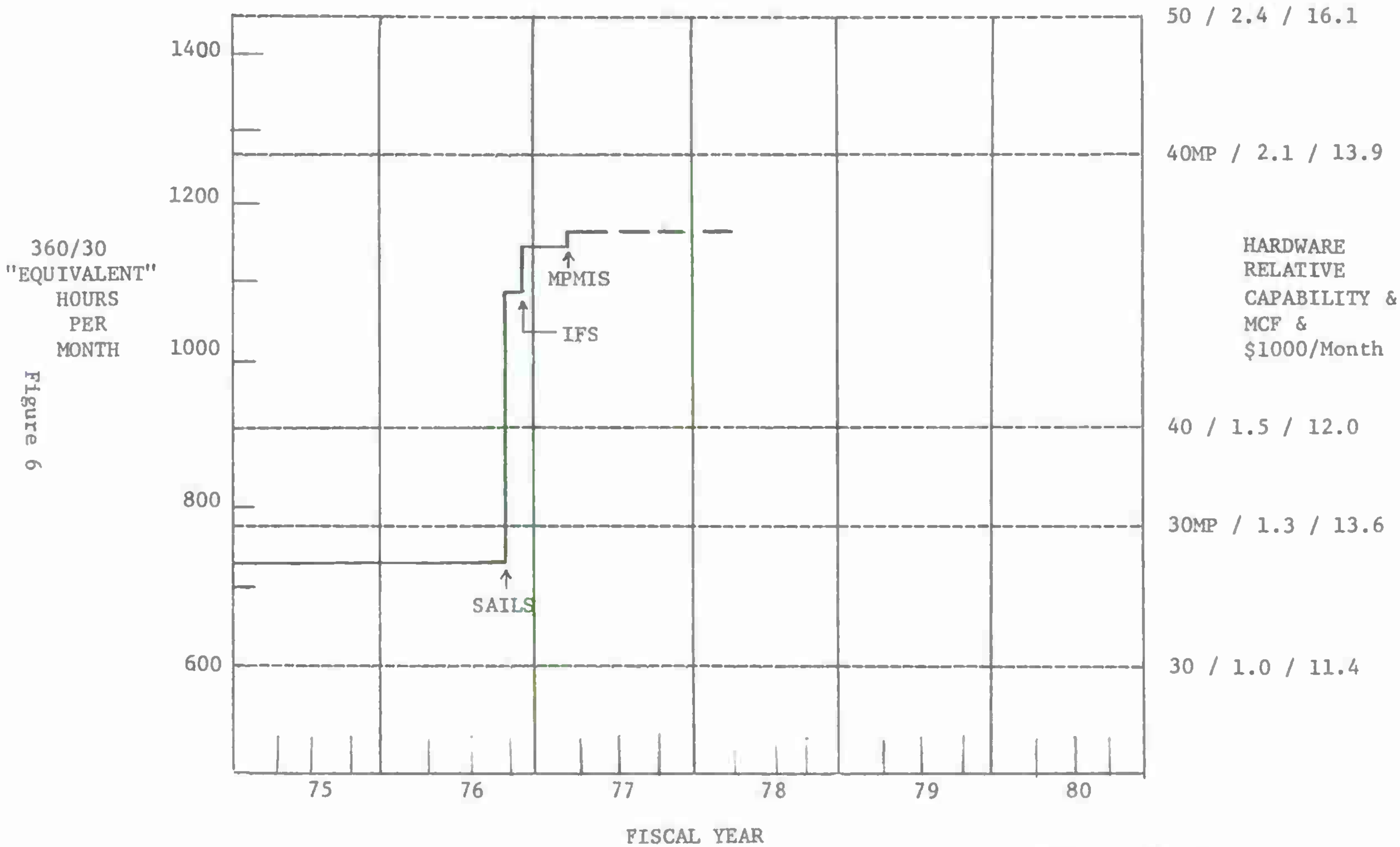
5. The BASOPS Installation Analysis (BIA) combines information from the BASOPS Runtime Matrix (BRM), the Machine Conversion Factors (MCF's), and the Extension Schedules. BIA's have been completed for each BASOPS installation. Figure 6 is an example. The right ordinate represents the relative hardware capability of each machine configuration as determined by the Machine Conversion Factors. The left ordinate converts relative hardware capability to 360/30 "equivalent hours" per month. At Ft. Lewis the FY 75 workload (734) includes SIDPERS (208), STANFINS (252), Command Standards (161), Post Uniques (85), VTAADS (8), and STARCIPS (20), as shown in the BRM (Figure 5). The SAILS arrow indicates sub-system extension in March 1976 and shows an incremental increase of 380 hours. At this point, the maximum capability of the 360/40 (900 hours) is exceeded and a machine configuration with greater capability will be required. Since Ft. Lewis currently has a 360/40, a machine upgrade will be necessary before SAILS is extended in March 1976. The aggregation of BIA's allows generation of a requirements summary for each planning year. Next, the results of the RA must be submitted to an Economic Analysis (EA) in order to determine the most cost-effective solution.

B. ECONOMIC ANALYSIS. The Requirements Analysis identified hardware configurations that would minimally satisfy the requirement at each installation. The purpose of the Economic Analysis is to determine the hardware configuration that is most cost-effective in meeting the requirement. The analysis includes both personnel and equipment costs and considers the fact that the use of ADPE with greater throughput capability will permit a reduction in the number of shifts employed per month and thus the total number of operators required. Machine parameters and costs are at Figure 6. The cost figures are based on existing contracts and current third-party ADPE market prices.

1. The basic tool for the Economic Analysis is the table shown at Figure 7. The table lists for each machine configuration the hours of capability and cost to provide a particular shift schedule. For example, one shift a day, five days a week on a 360/30, provides 145

SCORE

BASOPS INSTALLATION ANALYSIS (BIA)



SIDPERS POPULATION 25,000

SUPPLY TRANSACTIONS 181,500

INSTALLATION Ft Lewis

CURRENT ADPE 40

Figure 6

hours of capability at a cost of $15,400. The cost includes $11,400 for the hardware configuration (Figure 6) and $4,000 for the four operators required at $1,000 per man per month. The remaining hours of capability in the 360/30 column are based on the number of shift schedules run up to a maximum of 600 hours per month. Hourly capability of other machine configurations is proportional to their machine conversion factor. The following example demonstrates use of the table for a monthly requirement of 580 hours. A 580-hour capability can be attained on a 360/30 utilizing a 3x7 shift schedule costing $25,400 per month for operators and hardware. Or, 580 hours can be attained on a 360/30MP running a 3x6 shift schedule at a cost of $29,600. Or, 580 hours on a 360/40 with a 2x7 shift costs $22,000. A 360/40MP on a 2x5 shift costs $24,900 and 360/50 on a 2x5 shift costs $24,100. The 360/50MP on a 1x7 shift schedule costs $25,700. The lowest cost is $22,000 using a 360/40 on a 2x7 shift schedule. This was done for each BASOPS installation.

2. The Economic Analysis summary (Figure 8) is an automated output. The data under column heading "TOTAL MRT" is obtained from the BRM (Figure 5). "PRESENT ADPE" is obtained from the Requirement Analysis Summary (Figure 9). Two asterisks in the "MONTHLY COST" column for an ADPE configuration indicates that the particular configuration, at its maximum capacity (3x7 shift-schedule), cannot meet the requirement. Cost figures shown are the lowest cost shift-schedule which can meet the requirement on that particular machine. Using Ft. Bragg as an example, 1098 hours is beyond the capability of the 360/30, 360/30MP and 360/40. The 3x7 shift on a 360/40MP costs $31,900 and is the only schedule with sufficient capability. The 3x6 and 3x7 shifts on a 360/50 could meet the requirement but the 3x6 is less costly at $28,100. Under the "MIN-COST" columns the most cost-effective machine and shift selections are shown. The first "% UTIL" column is the percentage of available monthly runtime necessary to produce the required output for the selected hardware and shift-schedule. Again using Ft. Bragg as the example, the required output is 1098 hours. The maximum capability of a 360/50 on a 3x6 shift-schedule is 1248 hours (Figure 11). Therefore, 1098/1248 = 88%. The second "% UTIL" column is the percentage of the maximum capability of the selected hardware necessary to produce the required output. Thus, the capability of a 3x7 shift-schedule will always be used in this calculation. Therefore, 1098/1440 = 76%. These utilization percentages indicate the amount of flexibility available for peak loads and to absorb future growth or contingencies.

C. JUDGMENTAL ANALYSIS. The Judgmental Analysis considers intangible factors which impact on the selection of hardware. The following are illustrative examples:

1. Multiprograming. Running two sub-systems simultaneously on the same ADPE is more complicated than serial processing and greatly increases the probability of error such as mounting the wrong tape or generating an incorrect console operator response.

2. Ultimate configuration. If growth in requirement will necessitate an upgrade to a 360/40 this year and an upgrade to a 360/50 next

---------TOTAL MONTHLY COST/CAPABILITY ANALYSIS----------

SHIFT	PERS COSTS**		30		30MP		40		40MP		50		50MP	
SCHED	SER'L	MP	HRS	COST	HRS	COST	HRS	COST	HRS	COST	HRS	COST	HRS	COST
1X5	4	6	145	15.4	188	19.6	218	16.0	304	19.9	348	20.1	449	23.7
1X6	5	7	175	16.4	227	20.6	263	17.0	367	20.9	420	21.1	542	24.7
1X7	6	8	200	17.4	260	21.6	300	18.0	420	21.9	480	22.1	620	25.7
2X5	8	11	295	19.4	383	24.6	443	20.0	619	24.9	708	24.1	914	28.7
2X6	9	12	345	20.4	448	25.6	518	21.0	724	25.9	828	25.1	1069	29.7
2X7	10	13	400	21.4	520	26.6	600	22.0	840	26.9	960	26.1	1240	30.7
3X5	11	15	440	22.4	572	28.6	660	23.0	924	28.9	1056	27.1	1364	32.7
3X6	12	16	520	23.4	676	29.6	780	24.0	1092	29.9	1248	28.1	1612	33.7
3X7	14	18	600	25.4	780	31.6	900	26.0	1260	31.9	1440	30.1	1860	35.7

* ALL COSTS ARE EXPRESSED IN $1000.
** PERSONNEL COSTS ARE $1000 PER MAN PER MONTH.
*** MONTHLY EQUIPMENT COSTS ARE SHOWN IN THE MACHINE PARAMETERS TABLE.

Figure 7

---------------ECONOMIC ANALYSIS---------------

POST	TOTAL	PRESENT	--------MONTHLY COSTS(IN $1000)-------						MIN-COST		%	
	MRT	ADPE	30	30MP	40	40MP	50	50MP	ADPE	SHIFT	UTIL##	
BRAGG	1098	50MP	**	**	**	31.9	28.1	30.7	50	3X6	88	76
CAMPBELL	787	40	**	**	26.0	26.9	25.1	28.7	50	2X6	95	54
CARSON	1264	40MP	**	**	**	**	30.1	32.7	50	3X7	87	87
DEVENS	772	30	**	31.6	24.0	26.9	25.1	28.7	40	3X6	99	85
HAMILTON	618	30	**	29.6	23.0	24.9	24.1	25.7	40	3X5	93	68
HOMESTEAD	489	30	23.4	26.6	21.0	24.9	24.1	24.7	40	2X6	94	54
HOOD	1076	50MP	**	**	**	29.9	28.1	30.7	50	3X6	86	74
HOUSTON	1289	40MP	**	**	**	**	30.1	32.7	50	3X7	89	89
IGMR	486	30	23.4	26.6	21.0	24.9	24.1	24.7	40	2X6	94	54
LEWIS	1280	40	**	**	**	**	30.1	32.7	50	3X7	89	89
MACARTHUR	333	30	20.4	24.6	20.0	20.9	20.1	23.7	40	2X5	75	37
MCCOY	629	30	**	29.6	23.0	25.9	24.1	28.7	40	3X5	95	70
MCPHERSON	560	30	25.4	28.6	22.0	24.9	24.1	25.7	40	2X7	93	62

Figure 8

year, only one upgrade will be made, to the largest machine which will be required in the planning period.

3. Workdays. DPI managers prefer not to work weekends which costs overtime and decreased supervision.

4. Current Hardware. If the existing ADPE has the capability to meet future requirements, it may not be appropriate to upgrade even though another configuration may be more cost-effective. The amount of unused runtime available for future growth, cost of moving equipment, and size of the monthly operational cost savings must be considered.

5. Responsiveness. Selection of ADPE which permits shift reductions tends to improve responsiveness to user needs. If a customer request is delivered in late afternoon to a DPI operating on a 3-shift schedule, the output may not be available until late the next day, delaying output utilization until the second day. A DPI operating on a one or two shift-per-day schedule with a faster machine should be able to provide the needed output early the next morning.

6. Operator Quality. Selection of hardware which permits shift reductions also reduces the requirement for well-qualified operators.

Figure 9 is the Judgmental Analysis. Existing hardware, the Requirement Analysis (by FY), and the Economic Analysis provide the necessary input. Generally, the most cost-effective hardware configurations will be selected. However, the judgmental factors discussed above may sometimes indicate a different selection.

D. Cost Analysis.

1. Referring to the costs shown in Figure 6, upgrades from a 360/30 to a 360/40 cost $600 each and upgrades to a 360/50 cost $4700 each. The additional equipment costs = $104,600 per month.

2. Release of eight sets of peripherals from installations now multiprograming will save $68,000 per month.

3. Personnel Savings. The reduction in required operations personnel was calculated in the following manner. Installations whose current ADPE could support future requirements are assumed to be operating the shift schedules necessary to meet those requirements. The shift schedules are determined from Figure 7. Installations whose current ADPE could not support future requirements are assumed to be operating 3x7 shift-schedules on the current ADPE. These shift schedules were compared to those identified by the Judgmental Analysis. The difference, if any, is the personnel saving. The total number of personnel spaces saved under the upgraded BASOPS configurations is 121. Since the average cost of operators is $1,000 per month, the reduction of operator space requirements will save $121,000 monthly.

4. The net annual saving = $1.01M.

JUDGMENTAL ANALYSIS

		RA				
	CURRENT	FY 75	FY 76	FY 77**	EA	JA
FORSCOM						
Ft Bragg	50MP	40MP	40MP	40MP	50	50
Ft Campbell	40	30	30MP	40	50*	40
Ft Carson	40MP	40MP	40MP	50	50	50
Ft Devens	30	30MP	30MP	30MP	40	40
Ft Hamilton	30	30	30	30MP	40	40
Homestead	30	30	30	30	40	40
Ft Hood	50MP	40MP	40MP	40MP	50	50
Ft Sam Houston	40MP	40MP	40MP	50	50	50
IGMR	30	30	30	30	40	40
Ft Lewis	40	30MP	40MP	50	50	50
Ft McArthur	30	30	Closed	-	-	-
Camp McCoy	30	30	30	30MP	40	40
Ft McPherson	30	30	30	30	40	40
Ft Meade	40	40MP	40MP	40MP	50	50
Presidio of SF	40MP	40	40MP	40MP	50	50
Ft Riley	40MP	30MP	40MP	40MP	50	50
Ft Sheridan	30	30	30MP	30MP	40	40
Ft Stewart	30	30MP	30MP	30MP	40	40
Alaska	30	30	40	40	40*	50
Panama	30MP	40MP	40MP	40MP	50	50
TRADOC						
Ft Belvoir	30	30	30MP	30MP	40	40
Ft Benning	40	30	40MP	40MP	50	50
Ft Bliss	40	40MP	40MP	40MP	50	50
Ft Dix	30	30MP	30MP	40	40*	50
Ft Eustis	30	30	30MP	40	50	50
Ft Gordon	30	30	40	40	40*	50
Ft Ben Harrison	30	30	30	30	40	40
Ft Jackson	30	30MP	30MP	40	50	50
Ft Knox	40MP	40MP	40MP	50	50	50
Ft Leavenworth	30	30	30	30	40	40
Ft Lee	30MP	30MP	30MP	30MP	40	40
Ft McClellan	30	30	30MP	40	40*	50
Ft Ord	30	30MP	40	40MP	50	50
Ft Polk	40	30MP	30MP	40	40*	50
Ft Rucker	50	40MP	40MP	40MP	50	50
Ft Sill	40MP	40MP	50	50MP	50MP*	50
Ft Leonard Wood	40	30MP	40	40	40*	50
HEALTH SVCS CMD						
Ft Detrick	30	40MP	40MP	40MP	50	50
Fitzsimmons	30	30	30MP	30MP	40	40
Walter Reed	30	30	30MP	40	50*	40
OTHER						
Ft Huachuca	30	30MP	30MP	30MP	40	40
MDW	40	40	50	50	50	50

** Includes 10% Growth
* ADPE Selection modified by Judgmental Analysis

Figure 9

IV. SUMMARY. The SCORE procedure which has been described and illustrated is an example of MICRO-OR/SA. Conception to implementation time will be slightly more than a year. During this year data was gathered, tests were run, a short automated program developed, the model exercised, concurrences gained and final approval obtained from the Secretary of the Army. Resources expended at HQDA consisted of a single, full-time action officer and use of a time-sharing terminal. Benefits include:

---Upgrade of BASOPS hardware to meet all known future requirements.

---Annual cost savings of over $1 million.

---Increased effectiveness at installations due to fewer shifts required, thus generating more effective supervision and a shortened turn-around time.

TITLE: Programing Movement Requirements for Strategic Planning

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1. Introduction

The intent of this paper is to present a system for the development of movement requirements to support war plan scenarios. The procedures to determine these movement requirements were defined and automated by the author of this paper at the US Army Concepts Analysis Agency. The system is called the Computer Assisted Match Program (CAMP); its fundamental operation is the force matching of real units against plan requirements.

2. Planning Methodology

A typical war planning methodology includes the following steps:

a. Step 1 is to examine given major combat units and their availabilities against a postulated threat. The time of commitment of each unit in a scenario can either be input as a given parameter or obtained from the results of a movement analysis of the major forces and aggregated support tonnages. This step, of course, amounts to a war gaming of opposing combat forces.

b. Step 2 is to determine the type and number of combat support and combat service support units and when they are required by the war game. This traditionally is done according to a sequence of allocation algorithms and theater workload factors.

c. Step 3 is to correlate the time-phased requirements for combat, combat service, and combat service support units against a real world troop list and to program a complete deployment of the force needed to support the war game.

d. Step 4 is to conduct a detailed mobility analysis of the deployment requirement generated in Step 3. The mobility analysis is used to determine whether or not there exists sufficient lift to move and support the force and when units become available in theater.

If further refinements are needed, the four step methodology can be reiterated. The closure schedule of combat forces derived from the detailed movement analysis (Step 4) can be reintroduced into Step 1 and the warfighting capability regamed based on the revised unit availabilities. Such a methodology structures the force planning environment as an information feedback system. (See Figure 1)

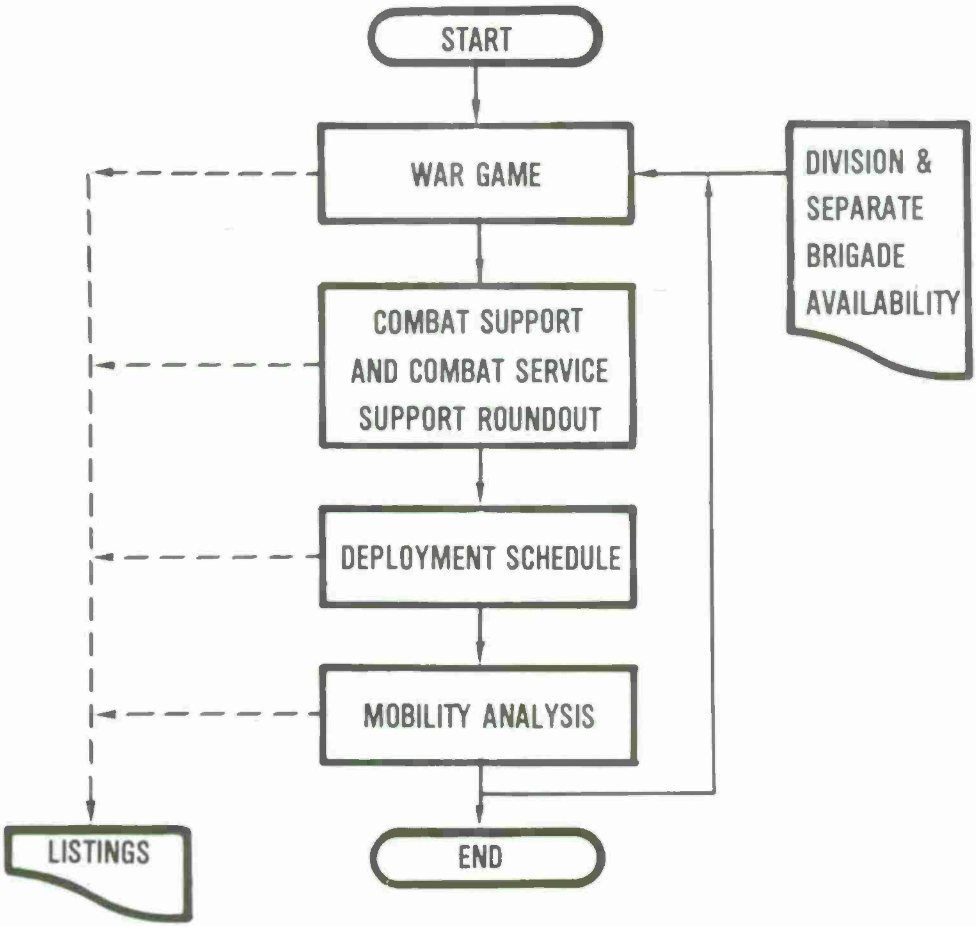

Figure 1, War Planning Methodology

3. <u>Background</u>

In past years, defense planners have focused on Steps 1 and 2 and given a lesser amount of attention to Steps 3 and 4. More recognition has been given to the areas of force structure and tactical wargaming than to the aspects of evaluating forces in terms of strategic mobility.

A valid requirement exists, however, to look at each war plan in terms of our ability to support the strategic movement of each force as well as its continuing resupply. How well, for example, could the United States support any deployment of US forces to the Middle East under non-mobilization conditions? The October/November, 1973, resupply of the Israeli Armed Forces in which 53,000 short tons of cargo were moved to Israel by sea and 22,395 short tons were moved by air was well executed and successful. Consider, however, that the airlift included 145 C5 sorties and 421 C141 sorties over a 33 day period. Two-thirds of the cargo shipment went by sea in nine Israeli ships. The capacity of those nine Israeli ships, "...approximated the total capacity of the MSC nucleus (government owned) dry cargo fleet. This fleet consists...of only 11 deep draft ships, six of which are World War II built victory ships."[1]

Consider also, that to move and support a typical US Army Corps for 60 days would require a lift of approximately 665,000 short tons. Such a realistic requirement is nearly nine times the tonnage lifted to Israel over a 33 day period. Increasing awareness of the need to evaluate our lift assets, therefore, has more recently resulted in a greater emphasis being placed on strategic mobility. Before a mobility analysis can be conducted in order to evaluate lift assets, or for any other reason, planners need to develop movement requirements. This is the type of problem that this paper addresses.

4. Discussion

A movement requirement is a stated movement mode and time-phased need for the transportation of units, personnel, and/or material from a specified origin to a specified destination. Because mobility analyses require great amounts of detailed data from differing functional areas: logistics, lift, force structure, mobilization, operations, etc, it has always been a difficult task to state the movement requirements to support a particular plan of action. Programing movement requirements comes under the development of the deployment schedule (Step 3) in the previously portrayed planning methodology.

Mobility analysts therefore have a need to know what is going where, from what origin, by what means, when it is required, and when it will be available for shipment. This problem becomes complex if one considers a full mobilization and deployment of the US Army. It is compounded because the problem of the tactician is knowing when units will become available on the battlefield so he can incorporate them in his tactical plan while the problem of the mobility people is knowing when the tactician requires the units so they can be scheduled to be available in the battle area when they are needed. Each would like to have the other's inputs before he begins his work. Responsive dialogue is achieved when the many data elements concerning each individual movement requirement are common knowledge to both of the planners.

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[1] "Promise and Problems", Brigadier General Garland A. Ludy, USA (Ret), TRANSLOG, September, 1974, Page 2.

5. Unit Requirements

As indicated in the typical planning methodology, the initial required delivery dates (RDD) for fighting forces can be stated by the tactician using professional judgment to begin the first iteration of the planning process. A wargame is then conducted based on the RDD's. Subsequently, support force unit requirements are generated through the use of allocation rules and according to the wargamed scenario.

The product at this point of the analysis is a time-phased list of requirements for type combat, combat service, and combat service support units. The requirements usually are stated in terms of so many battalions, companies, or teams, etc., of a given Table of Organization and Equipment (TOE) within specific time periods. The time periods, for example, are 30 days, excepting the first time period. The first time period is the period of mobilization and contains the number of each type TOE projected to already be in the destination theater on D-day. Hereafter, this composite list will be referred to as the "unit requirements file". It is sequenced by TOE.

6. Force Match

Once the unit requirements have been determined, the procedures to develop and deploy the force that will support the gamed scenario can begin. The initial task is to translate the type unit requirements to a real world environment. A force data file containing records for either the established and planned units of the entire Army or only a subset of the entire Army provides those units that can be allocated against the unit requirements file. The force file contains a record for each unit in the force. The entries in each record provide information of a type that one would need in force structure work: Standard Requirements Codes (SRC), Unit Identification Codes (UIC), Troop Program Sequence Number (TPSN), force planning codes, etc.

The allocation of real units to type requirements is called force matching. The first step in force matching is to organize the force file. The records in the force file are cross-referenced to records in other files that later are used to define the movement requirement parameters. The weight and cube of each unit are examples. Cross-referencing is accomplished by inserting pointers in the force file records.

Weights and cubes are described in terms of cargo categories to facilitate assignment of lift resources in the mobility analysis. These cargo caregories are typically:

a. Bulk. Cargo size less than 104" X 84" X 96".

b. Oversize. Cargo size exceeds 104" X 84" X 96". (C141 or C5A aircraft) C141 cargo cannot exceed 810" X 117" X 105".

c. Outsize. Cargo size exceeds 810" X 117" X 105". (C5A aircraft)

d. Non-Air Transportable Cargo. Too heavy/large for C5A -- cargo exceeds 1,453" X 144" X 145".

e. Non-self-deployable aircraft. Stated in square feet of aircraft.

f. Bulk petroleum, oils and lubricants (POL). Bulk Class III supply.

g. Ammunition/hazardous cargo.

h. Containerized cargo.

i. Special/security cargo.

j. Passengers (pax) requiring transportation operating agency transportation.

A second file to which the force file is referenced is a geolocation code file. Geolocation codes are identifiers of geographic locations at which military activities or personnel are situated or locations which have present or potential military significance. Origins, destinations, airports and seaports of embarkation (APOE, SPOE), debarkation (APOD, SPOD), and other transportation network nodes are referenced with geolocation codes.

The force file is also sorted according to alogrithmic rules that define the allocation process. The code on which all allocations are based is the Standard Requirements Code (SRC). This code (13 digits) identifies the unit TOE's. Most matches are made on the first five digits of the SRC, the portion that describes the unit's TOE branch of proponent, the organizational elements of the branch or major subdivision, and the type of organization. Certain SRC's, primarily those at team or section level and those specifically designated, are looked at in positions 8 and 9. These positions of the SRC describe TOE variations or type equipment changes. Medium truck companies, for example, all have the same first five positions in their SRC. Positions 8 and 9 indicate whether the trailer configuration of a particular medium truck company in flat bed, reefer, or tanker.

The fundamental selection procedure is to first try and fill unit requirements with those units already in the theater of operation. If the requirement cannot be filled with in-theater assets, units are looked at with the following priority:

a. Units belonging to a deployment package keyed to the destination theater, such as Reforger, 2 + 10 and MRLOGAEUR.

b. Units belonging to a major organization (division, armored cavalry regiment, or separate brigade) from which another unit has already been selected.

c. Active Army before Reserve or National Guard.

d. Those units programed to mobilize earlier according to force structure codes before those programed to mobilize later.

Designated units can be given a higher priority for selection than the basic allocation rules allow them or can be deleted from consideration by flagging them according to Unit Identification Code (UIC), Standard Requirements Code (SRC), Troop Program Sequence Number (TPSN), force planning codes, or any criteria the analyst may establish. Units in the 2nd Infantry Division in Korea for example, would probably be excluded as possible candidates to fill a European deployment.

The overriding prioritization is possible because the matching is accomplished by three passes through the unit requirements file and the force file. During the first pass, only those units given a selection priority are candidates for allocation. The basic allocation rules are followed on the second pass. On the last pass, units are allocated according to substitution criteria. Type substitutions are available and one or more units can be substituted for one or more TOE requirements.

The match produces four end products:

a. A listing of real units allocated to the force plan (the deployment force).

b. A listing of the requirements that could not be met.

c. A listing of real units that are in excess of the requirement.

d. A listing of those units that were not considered for possible allocation against the requirements.

7. Deployment Considerations

Once the match is complete, a number of deployment considerations are made. Units already in the destination theater and not allocated against a valid requirement are not likely to return to CONUS at the outbreak of hostilities. Those units are added to the deployment force. Units not allocated that belong to a division, armored cavalry regiment, separate brigade, etc., in the deployment force are also added to the deployment force. Other units might be added to or deleted from the deployment force on the basis of professional judgment.

8. Required Delivery Dates (RDD)

A force unit is entered into the deployment by flagging its record and by inserting into the unit record the time period, taken from the requirements file, in which the unit is required. The RDD for each unit is either specified or assigned according to the time period that unit is required. Each requirement time period, 30 days for example, is broken into a number of subperiod dates. Type units required within each time period are allocated to those subperiod dates either uniformly or skewed by some weighting factor.

9. Availability/Mode of Shipment

The date when a unit becomes available for shipment at its mobilization station is either specified, assumed, or computed based on when each unit is programed to be mobilized. Preferred modes of shipment are either specified or assumed optional.

10. Movement Requirements File

The units selected for inclusion in the force deployment, their RDD's, availabilities, and modes of shipment, are now fully determined. These units are put with the appropriate weights, cubes, and other deployment parameters into a movement requirements file and prioritized by the RDD's. The tonnages of dry bulk, POL, and ammunition associated with the Prepositioning of Material Configured to Unit Sets (POMCUS) and Prepositioned War Reserve Stocks (PWRS) are put at the front of the movement requirements in order to determine the initial theater stockages when computing the resupply requirements. Units already in theater have RDD's equal to Ø and precede the deployment schedule to determine the theater population used in the computation of filler, replacement, and resupply requirements.

11. Accompanying Supply

Accompanying supplies are computed for each unit in categories of dry bulk, ammunition, and POL. These supplies are those accompanying each unit to initially sustain it when it first arrives at destination. Accompanying supplies are added to the in-theater stockage levels when each unit is programed to arrive in theater (RDD). This is done to maintain a realistic environment for ascertaining resupply requirements. The tonnages in each category are computed using a pounds/man factor times unit TOE strength.

$$A = F \times S / 2000,$$

where A is short tons of accompanying supply, F is the pounds/man factor, and S is the unit TOE strength. The pounds/man factor can be restated in terms of days of supply. POMCUS units normally deploy with less accompanying supplies than do non-POMCUS units.

12. Resupply

Resupply and buildup of supply levels are also computed for the dry bulk, ammunition, and POL categories and phased into the movement requirements. The supply policies for each category are parametrically defined and may vary from scenario to scenario. A typical supply policy is described in the following manner:

a. The initial stockages of supplies in the destination theater are those in the Prepositioned War Reserve Stocks (PWRS).

b. The minimum acceptable levels of supply are 15 days dry bulk, 15 days ammunition, and 20 days POL.

c. No supplies are shipped before D+30 to prevent delay in the movement of combat units, unless the minimum supply levels are reached as a result of consuming theater stockages. If minimum levels are reached, only enough supplies are shipped to maintain those minimum levels until D+30.

d. At D+30, theater buildup begins. Supplies are shipped according to a straight objective line of constant slope over a period of time until an objective level of 45 days supply is reached on D+135. Thereafter a level of 45 days of supply is maintained in the theater for each of the categories of supply.

e. Resupply requirements are forecasted and programed to be shipped at five day intervals. Supply packages for each five day period are given an RDD of the first day of each forecasted period except no resupply is required before units are projected to be at their destination.

f. Class III, Class V and the dry cargo consumption rates are stated in terms of pounds/man/day and can be varied on a daily basis if required.

g. Those supplies accompanying and arriving with the units are taken into consideration in computing the resupply requirements. Accompanying unit supplies are computationally aggregated with the theater stockages. The unit strengths are considered for resupply computations as the separate units are projected to arrive at their destination. Computations are based on the RDD's and are tied to TOE strengths. Figure 2 shows two typical theater supply profiles. It is a graph of days of supply on hand versus day of the war after mobilization or after D-day.

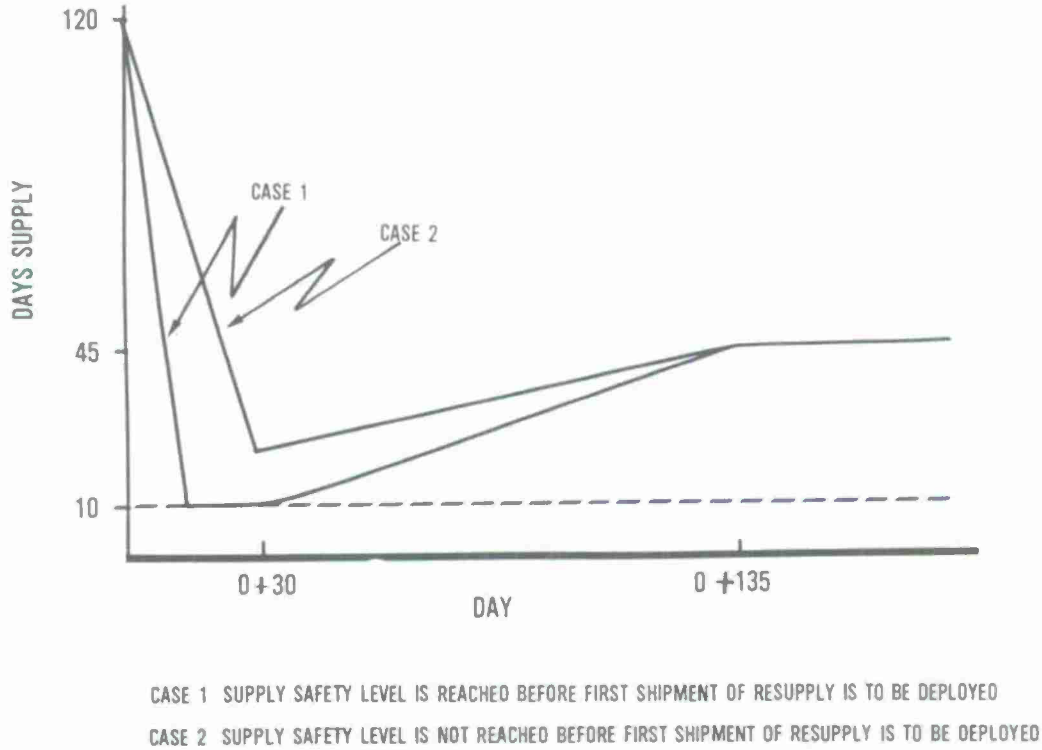

Figure 2, Resupply Profiles

13. Replacements

Replacement packages are developed using a similar procedure:

a. Replacement requirements are forecasted and required at five day intervals.

b. Packages for each five day period are given RDD's reflecting the first day of each forecasted period, except no replacements are required before units are programed to be at their destination.

c. Unit TOE personnel strengths are scheduled to arrive at destination on the RDD specified for the unit.

d. Personnel replacement factors are in terms of number/1,000 theater strength/day.

$$R = (S \times F)/1000,$$

where R is the number of replacements, S is the theater strength and F is the replacement factor.

14. Fillers

Filler requirements are computed in accordance with some established policy. Units already at destination are assumed to have a certain fill, 90 percent for example. The number of personnel needed to fill the in-theater units is computed and filler requirement packages are phased into the movement requirements.

$$N = S \times (1 - F/100)$$

where N is the number of required fillers, S is the theater strength at mobilization, and F is the percent fill of in-theater units.

15. Packaging

Movement models, when operating in an optional mode, consider available airlift and sealift assets to determine whether it is quicker to deploy a unit by air or sea. Then the available lift is type-loaded and deployed a number of ways to select the desired alternative. This process, particularly for very small detachments, might result in a very inefficient utilization of lift if shipments that could be shipped together are not collected and shipped as a movement package. Ships should sail and aircraft should take off fully loaded. Units, therefore, that can logically be grouped together for shipment considerations are packaged without losing their individual identifies. More than one unit is loaded aboard available lift using this technique.

The algorithmic constraints used to logically group units for packaging are stated in the following manner: Those units required at the same destination, in the same time frame, coming from the same origin, available at the same time, and deploying by the same mode of shipment are logically grouped together for shipment purposes.

Subsequently, priorities of movement are established for those sets of units having the same RDD. Combat units, as a rule, have priority for allocation of lift assets over combat support and combat service support units, which in turn, have priority over resupply, replacement, and filler packages.

16. CAMP

Transportation people can conduct detailed mobility analyses only when some procedures such as those just outlined are completed. This is the purpose for the Computer Assisted Match Program (CAMP). It builds and packages movement requirements in a semi-automated environment.

The CAMP system is both versatile and flexible because the program routines have been structured as a translator. Tasking instructions, along with associated data elements which represent policy decisions, are read by the program, translated and executed. The resupply instruction, for example, tells the CAMP system to compute resupply for the force located in the movement requirements file. The Commander's resupply policy is in the data field following the resupply instruction.

Analysts, in this manner, can view selected outputs and adjust accordingly at each step of the building process. After the force match is completed, the deployment force can be examined to determine its acceptability and adjustment made before any support considerations are identified.

An overview of what types of information the CAMP system operates with and what it does with that information is shown in Figure 3.

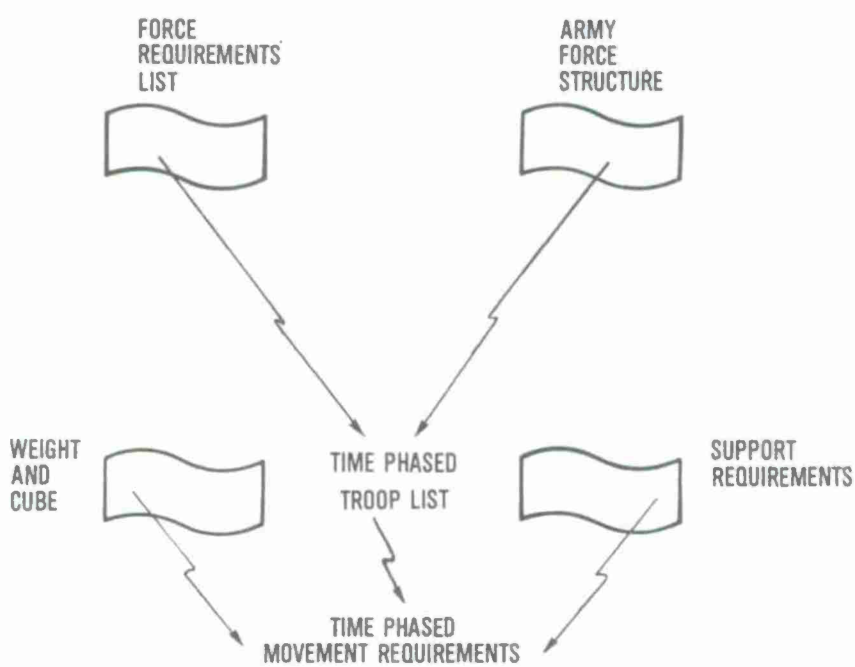

Figure 3, CAMP Functional Areas

17. Applications

The deployment of programed and objective US Army forces in a planning environment is the main application of the CAMP system. Some other uses for the CAMP, however, have presented themselves since its inception.

Because it addresses the real world problems of force structure and logistics, portions of the CAMP system have been used to look at the Army force structure. In addition, CAMP procedures have been used to establish and evaluate the impact that certain plans have on appropriate lines of communication.

Selected examples where CAMP has been utilized include the Army movement requirements input to the Joint Strategic Capabilities Plan (JSCP), and the Joint Strategic Objectives Plan (JSOP), Book VI, Mobility Forces, Volume II, Analysis and Force Tabulations; also the Air Force Lift Enhancement Program, a Strategic Mobility Analysis of Movement of a Modified Corps to the Middle East, and the Total Force Study.

One may conclude then that the CAMP system extends the Army's ability to look at force structure as well as to investigate force deployments. Of particular importance is the fact that the CAMP methodologies do this in great detail and are particularly helpful in addressing problems concerning the below the line or support forces.

TITLE: Procedures for Predicting Bridging Requirements In Theaters Of Operation

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Introduction

The U. S. Army's tactical requirement to cross terrain gaps has been evaluated in numerous studies and field exercises. The British, Germans, and Russians have long been active in developing new bridging equipment and gap crossing techniques. These combined efforts have produced a wealth of technology and resulted in continual improvement in gap-crossing capabilities.

In the past 5 to 10 years the U. S. has put considerable emphasis on applying modern "know how" of operations simulation on large computers to the study and evaluation of the Army's gap-crossing operational needs. This approach provides a means of bringing to bear the composite of latest technology and military doctrine in determining the most cost-effective manpower-equipment mixes to meet gap-crossing requirements anywhere in the world.

This paper describes a comprehensive computer simulation for evaluating gap-crossing operations of a division force structure. The simulation is designated STAFFGAP (Simulated Terrain And Force For Gaps) and is designed to do the following:

a. Identify shortages in existing bridge stocks and engineer forces in a theater of operations as related to performing known contingency operational functions.

b. Determine the most cost-effective additions of bridge equipment and force levels required to meet shortfalls in a theater of operations.

c. Provide guidance for establishing criteria and specifications for new materiel design and procurement.

General Description of STAFFGAP

The division gap-crossing operations are simulated on a terrain of "real" gaps. As the division advances, each assault column encounters gaps of varying widths, bank geometries, and hydrologic conditions. The gaps are crossed by placing earthfill in the gap, fording, rafting, or bridging.*

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*The option of swimming gaps is not included in STAFFGAP, since many vehicles in the assault columns cannot swim (as of 1974). Inclusion of the swim capability would require separation of the division columns into units such as amphibious vehicles, personnel light equipment, and heavy vehicles. The performance of amphibious vehicles would then be evaluated for each gap, and crossing of personnel light equipment would be evaluated for foot bridges and light rafts or bridges. The merits of adding this complexity to the existing gap-crossing operations simulation will be considered in the near future.

One main supply route (MSR) is established as a follow-on action to the initial assault phase. All equipment and personnel for constructing gap crossings on the MSR are obtained from a supply depot inventory in the rear area. Equipment and personnel required for gap crossings by the assault and follow-on columns are obtained either from the columns' own resources or from the supply depot or both. The main elements of STAFFGAP are illustrated in fig. 1.

The different methods used in crossing gaps result in differences in the amount of time required for crossings, which affects the rate of advance of each column and total mission time.

Available gap-crossing methods are evaluated for each gap, and fixed bridges are evaluated for three different construction design configurations. A choice of the three designs can be made on the basis of minimum construction time, minimum costs, minimum manpower, or any weighted combination of these. Data from the evaluations are stored for each gap separately and used as input data for the division gap-crossing simulation. Selection of a single gap-crossing method for a gap encountered in STAFFGAP is made on the basis of minimum response time (shortest time to provide a crossing). STAFFGAP also is organized to allow the user any choice of personnel-equipment mix and quantities, and a choice of force structure organization, terrain gap types, and tactical doctrine (operational strategy).

Terrain Gap Data Base

To determine the kinds and quantities of bridging systems needed in an operations area, the nature and frequency of gaps in that area must first be known. Since water flows in the majority of gaps to be crossed, details regarding changes with time in depth of water, water width, and current velocity must also be known.

As a result of previous studies[1] related to tactical bridging, basic gap data for 651 sites in West Germany have been compiled and stored on magnetic tape. An example of that portion of data available for hydrologic geometry factors for mean high stage conditions on a monthly basis is illustrated for a single gap in fig. 2. The same type of data is available for mean mean and mean low hydrologic stages. Examples of numerical class ranges used to describe gap factors are shown in fig. 3 for gap width and water width. Also shown in fig. 3 is a generalized gap profile indicating the relations among the profile geometry, the water stage, and the descriptive factors. On retrieval of gap data from magnetic tape or disk files, the factor class numbers are converted to class ranges, and commonly the mid-point of the class range is used as the value to describe a factor. For example, the water depth class given for January in fig. 2 is 4, which is equivalent to >200-500 cm (see fig. 3). The mid-point of the class range is 350 cm.

Gap width and other factors described in terms of factor classes that are also available for each gap are listed in fig. 4. Since cone index varies with changes in soil moisture, and since soil moisture changes seasonally (and even with each rainstorm), the minimum cone index (soil strength) that would occur in the 0- to 15-cm soil layer during the year was selected to be included in the gap data base for the top-of-bank position. For guidance on use and interpretation of soil strength and soil type gap data see references 1 and 2. The procedures used in deriving the gap data base are described briefly in the following paragraphs.

A portion of a base map prepared for a selected east-west sample band in West Germany is shown in fig. 5. Three such sample bands approximately 5.4 km wide were selected for mapping in an area of West Germany roughly contained within the 49th and 50th parallels, extending from France to Czechoslovakia. The irregular lines on the map in fig. 5 represent the spatial distribution of "tactical gaps" traced from topographic maps and aerial photographs. Linear gap segments having relatively uniform characteristics are numbered (gap No.) and defined by a set of factor class numbers representing ranges of factor values (see fig. 3).

A body of statistical gap data was obtained from the mapped area by a simple procedure. Templates were made just long enough to fit across the width of sample bands. On each template a set of randomly placed tick marks was drawn parallel to the long axis of a sample band. A randomly selected template was then moved from left to right, and each intercept between any of the eight tick marks and a gap segment was counted. It will be noted in fig. 5 that the fifth line from the top crosses gap segment type 207 (indicated by a dashed circle) three times because the gap segment makes a large S-curve. In this situation the gap segment was counted only once, because such a loop projected against a normal line would in effect be only as long as the double line shown in the dashed circle in fig. 5. When a military column moves across country, it for all practical purposes crosses each gap only once: The column always "sees" a gap as if it were oriented at right angles to its paths. Basic data formats derived from this sampling process are those illustrated in figs. 2 and 4.

A computer program is required to retrieve data from the basic gap data storage files and transform them as required for input to other computer programs that (a) evaluate crossing methods for each gap to develop a gap-crossing capabilities inventory, and (b) that construct a statistical planimetric gap distribution simulating the operational terrain environment.

Gap-Crossing Operations

When a tactical commander encounters a gap, a relatively complex set of decisions is required during the process of evaluating the situation for the best gap crossing strategy. The commander must first decide whether to fill in the gap, ford, bridge, or raft. Swimming has been excluded for reasons previously stated. The commander will usually use the means involving the least expenditure of time. However, the time required is strongly influenced by the nature of the gap. Thus, all decisions are constrained by the physical relations between the characteristics of the gap and the various gap-crossing methods available to the force. If a gap is wide and the water is deep, so that rafting is a reasonable solution, the commander must decide on which of the available floating systems (MAB or ribbon) to use. If however, the gap is such that it can be bridged, the commander will decide whether to use a fixed or floating system, and having made that decision, determine which one would be most appropriate. Again, all other things being equal, the decision will be based on the time required to obtain a useable crossing.

Since time appears to be the most generally useful measure of gap-crossing capability, it was decided at the outset to develop the division gap-crossing operations simulator in such a way that the total response time (delivery time and construction time) to obtain a useable crossing could be determined.

The principal parts of the division gap-crossing operations simulator are the input data formats, the subroutine for selecting the gap-crossing method, and the subroutine for outputting the results of the operations analysis in summary form.

Input data requirements

The input data requirements for the gap-crossing operations simulator are as follows:

a. Inventory assignment of manpower and equipment to depot and force structure elements.

b. Average rate of advance of columns between gaps.

c. Maximum longitudinal separation distance for assault columns.

d. Average speed of transporters.

e. Specification that assault columns advance along a straight line or within a band width.

f. Time interval allowed for inventory make-up.

g. Gap-crossing capabilities matrix.

h. Description of force structure composition and dimensions.

i. Statistical terrain gap data files.

Item a requires that an available inventory be specified. Also specified should be whether all, none, or part, is in depot behind the line of departure for the assault, and what assets if any are organic to the assault and follow-on columns. An unlimited inventory can be specified. There are currently 111 items in the inventory and most of these are identified in figs. 6 and 7. Manpower, weight, length, and cost are set up for each bridge type and also fording, since mats are available for fording. At this time the inventory is structured to include six of the nine bridge types listed in fig. 8. These are the Bailey, MGB, MAB, ribbon, AVLB 18.3 m, and AVLB 27.4 m. The inventory distinguishes between single span, multi-span, and cable reinforcing kit for the Bailey and MGB. MAB and ribbon rafts also are identified separately. The Bailey bridge parts inventory includes transoms, button ramps, plain ramps, and panels. The MGB parts inventory includes top panels, bottom panels, and bank seat beams.

Item b is a single constant specifying the maximum rate of advance for all column elements over intergap distances.

Item c allows the option to adjust the speed of columns during the advance so that all column fronts are within a specified distance of the slowest column.

Item d is a single value for average speed to be maintained by all vehicle transports delivering equipment from depot inventory to crossing sites. Transport of equipment from supply depot to crossing sites can be excluded from consideration if desired.

Item e permits the option of having the columns cross those gaps encountered along a straight line of advance or within a band width, and choosing that gap crossing in the band width requiring the least time.

Item f is a time interval that is used to increase the response time to permit a wider consideration of gap-crossing methods to reduce on-site construction time (see section on selection of gap-crossing method for further explanation of the impact of this input variable).

Items g, h, and i are discussed in some detail as to their nature and derivation in the following paragraphs.

Gap-crossing capabilities matrix. This capabilities matrix is prepared in advance of using the division gap-crossing operations simulation and consists of calculating manpower and equipment requirements, costs, and construction time for designated gap crossing methods and each gap type selected from the terrain gap data base. The end product is a matrix of inventory requirements for crossing individual gaps. A detailed listing of gap crossing methods for which gaps may be evaluated is given in fig. 8.

Gap data required by the gap-crossing evaluation subroutine consist of those factors given in fig. 2, plus gap width and soil cone index of the gap bottom. Programs are available to retrieve gap data for a specific month, for those months having the highest water stage, or for average conditions for a 12-month period.

A summary of inventory requirements and other data produced for each crossing method and gap type combination are given in fig. 6. A detailed listing of requirements for certain inventory categories is given in fig. 7.

When it is physically impossible to use one of the crossing methods for a particular gap, a failure code replaces the configuration code. Examples of failure code descriptions are: (a) no bridge of sufficient length, (b) water too shallow for ribbon bridge, and (c) water velocity too great to raft.

The gap-crossing capabilities matrix can be derived so that fixed bridging design is optimized for each gap to achieve either minimum construction time, costs, manpower requirements, or some weighted combination of these three parameters.

To approximate reality in bridge design and estimation, all operations in building a bridge were accounted for and included survey and site layout, bridge unloading, site preparation, abutment construction, bridge construction, and bridge finishing. A logical scheduling (critical path method) of these operations was devised to simulate the actual bridge construction process making the time, manpower, and equipment utilization more realistic.

The three different bridge construction designs evaluated for fixed bridging are illustrated in fig. 9. These configurations involve: (a) building a bridge atop the banks with the support points far enough back from the edge to preclude bank failure, (b) building a shorter bridge just above the water stage in which site preparation may be required if the bank angle exceeds 10 deg, and (c) building a shorter bridge with abutments. Class 60 loads, the expected division load maximum, are used as the design loading for all bridges.

From the feasible construction designs a best configuration is chosen, and a configuration code and associated bridge construction data are then stored on magnetic tape to provide the gap-crossing capabilities inventory requirements. These data files form part of the input to the division gap-crossing operations simulation. For details on the bridge construction simulation see references 3 and 4. Work is in progress on an improved scheme to optimize bridge length and site grading on the basis of construction time.

Force structure. To simulate a division-size force advancing over a given terrain gap distribution, an idealized representation of the force must be developed. The force structure developed for the European theater is shown on fig. 10.

To represent the division units in a manner more suitable to a study on tactical gap crossing, the concept of unit columns was developed. Basically this concept recognizes that even though combat units will normally be widely dispersed on the battlefield, they must converge on available bridge or rafting sites unless the gap can be forded by the force. To bridge or raft, therefore, all units may be considered as columns of a certain length depending on the number of vehicles. Troops to a depth of 11 km on fig. 10 are considered assault forces and all others as follow-on troops, except the division support command (DISCOM). This entire unit is considered a follow-on column.

The number of follow-on columns decreases toward the rear of the division and also toward the Corps support areas. The columns converge toward the rear because fewer gap crossings will be used to maintain the rate of advance with logistical vehicles that generally cannot move cross country with the same agility and ease as tracked and wheeled combat vehicles. Fewer columns crossing, of course, results in reduced requirements for bridges.

Any force structure configuration similar to the design in fig. 10 can be used as input to the force movement simulation by specifying the number of assault columns, depth of columns, positions of follow-on troop columns, and the MSR with respect to the lead assault column positions.

Statistical gap type distribution of operational environment. Procedures used for constructing a statistical analog of real world gap type occurrence and planimetric distribution are those presented in reference 1. The statistical terrain gap environment is designed to present the same number of gaps of each kind to a hypothetical military force as would be encountered by a real military force operating in the real area from which the statistics were derived. Construction of the statistical gap distribution analog is described briefly in the following narrative.

The example table at the top of fig. 11 illustrates the data format retrieved from the basic terrain gap data base. Gaps are grouped into width classes, as illustrated by the hypothetical example for gap width class 2 at the top of fig. 11.

Since there is a fixed relation between the number of template lines and the area through which they are moved, the number of intercepts of any gap type can be equated to the length of gap type that has to be displayed at right angles to the axis of movement of an assault column. This synthetic length (or statistical length) is called the "normalized segment length."

Statistically, each intercept of a template line and gap is a "count" and represents a projected gap segment equal to the reciprocal of the number of lines on a template times the width of the sample band. This relation leads directly to an equation that defines the total projected length of each gap type stated as a percentage of the "front" of a selected force structure. The equation is given in fig. 11. Terms of the equation are defined as follows:

- P = percentage of "front" of the force structure occupied by the selected gap type.
- N = total number of occurrences (intercepts) for any one gap type.
- TL = length of sampling template in cm.
- SM = the denominator of the representative fraction defining the scale of maps on photographs that constitute the sample base.
- TN = the number of tick marks per template.
- AM = the area of the geographic region selected for sampling, e.g. operational theater.
- AS = the area of the sample.
- W = the width (or front) of the selected force structure.

A value for P is obtained for each type retrieved from the gap data base. After a P value is calculated for each gap in a gap width class, the factor class number arrays for current velocity, water width, water depth, bank angles, and bank height are used to sort the gaps so that the individual columns of factor class numbers are in order of increasing values to the extent possible. The end result of these data manipulations is illustrated by the table shown on the bottom of fig. 11.

The next step is to place the gap types into a rectangular area of a width equal to that of the force structure front width and a length suitable for the operations scenario. Let us assume a width of 23 km and a length of 200 km. Since a test of the sample area indicated that, on any selected random line, the gap type intercepts were essentially randomly distributed, a procedure can be used that places the gap type segments into the rectangle by random processes. In practice, the selection of random distances between 0 and 200 km is performed by a random number generating computer program. Values are generated one at a time with each value being an equivalent distance measured on the horizontal axis of the rectangle. The first random value is generated and the rectangle width is multiplied by the percentage (P) value given for the first gap number in gap width class 1. The resulting normalized segment length is placed along a line perpendicular to the horizontal axis at the first randomly selected position. The normalized segment length is calculated for the next gap number in gap width class 1 and added to that of the preceding segment. This process is continued until the line has been extended completely across the rectangle. The entire process is then repeated until all the gaps in all gap width classes taken in order have been positioned on "gap lines" in the rectangle. Any remainder of gap segment from the first line position is simply the first segment placed at the second random line position selected, and so on. Because of the way in which the gaps are ordered and selected for placement in the rectangle, abrupt changes in gap width will not occur along a single line, and to some extent this will be true for the other gap characteristics.

The product is a "map" (fig. 1), which has essentially the same statistical properties, from the special point of view of tactical bridge construction, as that portion of the real world used as the data base.

Selection of gap-crossing method

Forces in the assault will attempt to cross a gap by any means available with the greatest possible speed; whereas, follow-on units may be required to provide temporary replacement bridging along routes other than the MSR. Semipermanent replacement bridging that will reliably and rapidly carry large volumes of traffic over an extended period of time is required on the MSR.

Bridge replacement and upgrading of earthfill, ford, and raft sites with bridging by follow-on columns are decided on the basis of the force structure composition, inventory assets of bridging and other equipment, type of conflict, time of year, and the scenario of events relating to the conflict. Decisions made about bridge utilization by follow-on columns may affect the type of gap-crossing capabilities data that is used, i.e. selection of the gap-crossing capabilities data from among those calculated on the basis of the optimization criteria of time or cost, or manpower, and the hydrologic stage conditions of mean low, mean mean, or mean high. For example, in performing a bridge inventory evaluation study one may want to use the gap-crossing capabilities data optimized on construction time for mean low hydrologic stage for assault crossings, and the data optimzed on time, but for mean high stage for MSR bridge construction. It is possible also, for example, to use gap-crossing capabilities data optimized on the basis of least cost for MSR bridge construction. It is obvious there are many combinations possible.

As the gap-crossing operations simulation now functions, response time is the basis on which gap-crossing methods are selected, regardless of the type optimization used to derive the gap-crossing capabilities data. Response time is equal to the sum of delivery time and construction time. Delivery time accounts for waiting time due to temporary shortages in inventory and transport time from depot inventory to the crossing site. The selection process is concerned with finding the shortest time in which all necessary bridge parts or other gap-crossing materiel, construction equipment, and manpower can be collected at the crossing site and construction completed.

When a column encounters a gap, the availability of resources for each gap-crossing method possible for that gap is evaluated by the scheme shown on fig. 12. The simulation actually allows for the requirements of any type of personnel or equipment (e.g. support skills, construction equipment) to be obtained in any combination from the columns resources and the depot inventory that gives the shortest response time.

Once the minimum response time is determined for each possible gap-crossing method, the times are compared and the gap-crossing method with the shortest response time is selected. Equipment and manpower are then taken from the available inventory and dispatched to the appropriate crossing site. The exception to this selection procedure arises in those cases for which a time interval allowed for inventory make-up (item f of input data requirements) is included in the input data for the simulation "run." For such cases a gap-crossing method is selected in the manner just described. The time interval for inventory make-up is then added to the response time of the crossing method selected to obtain an extended response time. All crossing methods with response times equal to or less than the extended response time are considered, and the method having the shortest on-site construction time is selected for use. This allows the selection of a crossing method that will expose a fewer number of men for a shorter time to enemy attack, thereby, minimizing the number of casualties and wounded. Release times are assigned to the items removed from inventory. The release time is the sum of the delivery time, construction time, column crossing time, and bridge or raft dismantling time (if applicable). Column crossing time depends solely on the depth of the echelon that a bridge or raft supports. When the release time expires for manpower or equipment items in use, they are put back into inventory for reissue.

In the process of determining response times for gap-crossing methods, the status of release times is checked for any item needed but not in inventory. The shortest release time on record for the item needed at the time of a check is used in computing response time.

The division gap-crossing simulator is currently programmed to cycle for any given run until the variation in the cummulative average of peak usage for each inventory item does not exceed 5 percent. Of course, any item in inventory can be excluded from this criterion, or other statistical criteria for monitoring inventory usage can be specified.

Prior to each cycle the gap lines are redistributed randomly within the rectangular terrain area selected for the operations scenario. This means that each column will encounter the same number of gaps on each cycle, but in a different sequence. This will cause different peak usages to occur.

Output data summary of operations analysis

A wide variety of output data types and formats can be obtained from the output data storage file obtained for each run of the gap-crossing operations simulator. Output data found to be most appropriate for studies conducted thus far are as follows:

a. Mission time - maximum, minimum, and average values for the number of cycles completed for:

(1) Assault columns
(2) Follow-on columns
(3) MSR

b. Peak usage of inventory items from available inventory for:

(1) Assault columns
(2) Follow-on columns
(3) MSR

c. Peak usage of manpower for each gap-crossing method.

d. Weight and hardware investment costs for peak usage of bridges, rafts, and mats (these outputs are required to compute systems cost).

e. Systems 10-year life cycle costs for peak usages of manpower and equipment.

Peak usage or demand is the maximum number of an item needed at any one time during the assault operations. This is, of course, a far more critical number than a simple count of the total number of bridge parts or other equipment items and personnel. The latter gives a false estimate of the number required, since it does not account for the fact that the same bridge can be picked up and used again on another gap farther along.

Conclusions

The current version of the division gap-crossing operations simulator costs approximately $25.00 at day rates and $12.50 at night rates per run of 25 cycles on a Honeywell G-635 computer.

This capability provides the Army with a method of evaluating the most cost-effective gap-crossing systems to use in theaters of operations. Once the theater assets are established, the operations simulation can be used to optimize and plan gap-crossing operations for specific missions in the theaters. This is possible since the gap data base contains hydrologic geometry data for 12 months of the year.

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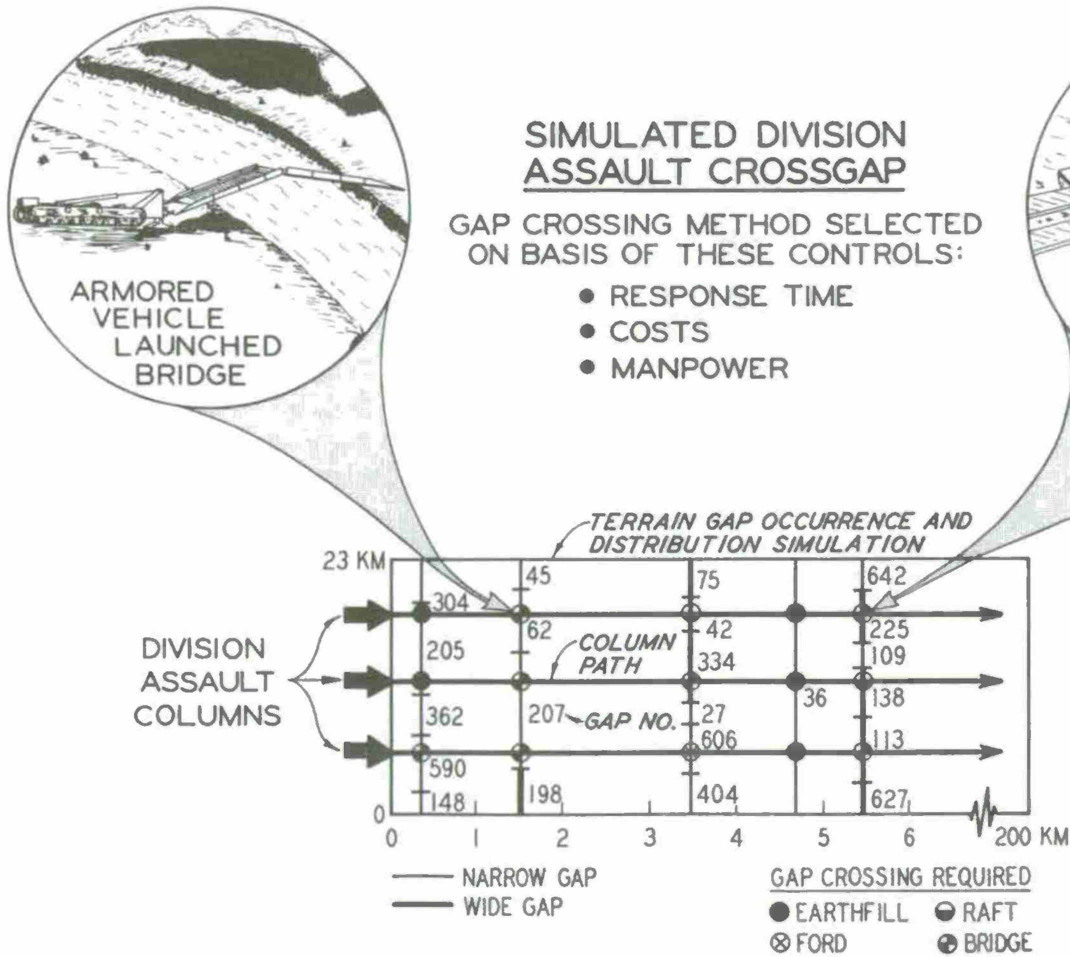


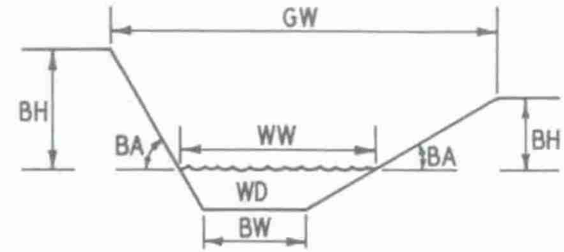
Figure 1. Computer scenario to study the effects of bridging equipment quantities and mixes on mission time, force structure, and costs

GAP NO. 25

MONTH	FACTOR CLASS NUMBERS FOR MEAN HIGH STAGE*: WATER DEPTH	WATER WIDTH	BANK HEIGHT – LEFT	BANK HEIGHT – RIGHT	BANK ANGLE – LEFT	BANK ANGLE – RIGHT	CURRENT VELOCITY
JAN	4	2	2	4	3	5	2
FEB	4	2	2	4	5	5	2
MAR	4	2	2	4	5	5	2
APR	3	2	3	4	5	5	2
MAY	3	2	3	4	5	5	2
JUN	3	2	3	4	5	5	2
JUL	3	2	3	4	5	5	2
AUG	3	2	4	4	4	5	2
SEP	3	2	3	4	4	5	2
OCT	3	2	3	4	5	5	2
NOV	3	2	3	4	5	5	2
DEC	4	2	2	4	3	5	2

* DATA AVAILABLE ALSO FOR: MEAN MEAN STAGE; MEAN LOW STAGE.

Figure 2. Example of data available for three hydrogic stages for gaps in West Germany



GW – GAP WIDTH
BW – BOTTOM WIDTH
WW – WATER WIDTH
WD – WATER DEPTH
BH – BANK HEIGHT
BA – BANK ANGLE

EXAMPLES OF CLASS RANGES USED TO DESCRIBE GAP FEATURES

GAP WIDTH: CLASS NO.	GAP WIDTH: CLASS RANGES, M	WATER DEPTH: CLASS NO.	WATER DEPTH: CLASS RANGES, CM
1	>0-3	1	No water
2	>3-6	2	0-100
3	>6-9	3	>100-200
4	>9-12	4	>200-500
5	>12-15	5	>500
etc.			

Figure 3. Generalized gap profile and examples of gap factor class ranges

GAP NO. 25

GAP WIDTH
VEGETATION BANDWIDTH LEFT BANK
STEM DIAMETER AND DENSITY LEFT BANK
VEGETATION BANDWIDTH RIGHT BANK
STEM DIAMETER AND DENSITY RIGHT BANK
CONE INDEX TOP LEFT BANK*
CONE INDEX WATER LEVEL LEFT BANK
CONE INDEX BOTTOM
CONE INDEX WATER LEVEL RIGHT BANK
CONE INDEX TOP RIGHT BANK
BOTTOM WIDTH
SOIL TYPE CODE (USCS)**
NO. OF OCCURRENCES†

* CONE INDEX IS A MEASURE OF SOIL STRENGTH AND CORRELATES WITH VEHICLE TRAFFICABILITY.

** UNIFIED SOIL CLASSIFICATION SYSTEM (UPPER BANK).

† NUMBER OF TIMES GAP NO. WAS ENCOUNTERED IN STATISTICAL SAMPLING OF WEST GERMAN TERRAIN.

Figure 4. Example of additional data available for gaps in West Germany

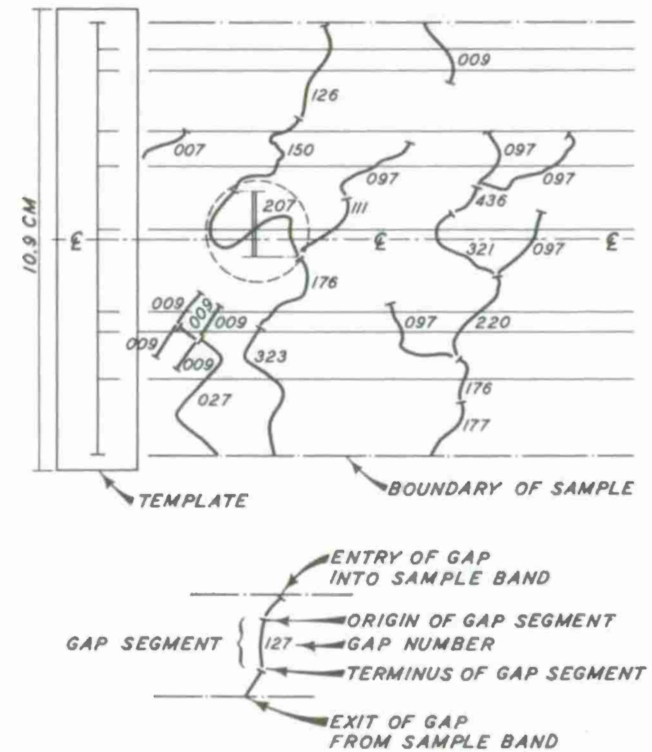


Figure 5. Method of sampling gap segment types mapped from stereo aerial photography and topographic maps

GAP NO.

CONFIGURATION CODE

CONSTRUCTION TIME

FY 73 HARDWARE INVESTMENT COST-FOB MANUFACTURER'S PLANT

MANPOWER CODE

WEIGHT

CONSTRUCTION EQUIPMENT CODE

TRANSPORTATION EQUIPMENT CODE

RIBBON BRIDGE RAMP BAYS

RIBBON BRIDGE INTERIOR BAYS

MAB RAMP BAYS

MAB INTERIOR BAYS

HYDROLOGIC STAGE

GAP CROSSING METHOD

Figure 6. Summary of gap crossing capabilities matrix

CONFIGURATION CODE

- BRIDGE/RAFT TYPE
- TOTAL BRIDGE LENGTH OR LENGTH OF MATTING
- BRIDGE END DATA (GRADING AND ABUTMENTS)
- NUMBER OF SPANS/NUMBER OF RAFT BAYS
- SPAN TYPE
- NUMBER OF PIERS
- PIER TYPE
- TRUSS TYPE
- PIER FOUNDATION TYPE

MANPOWER CODE

- P1 - SUPERVISORY OR SPECIAL SKILLS (3 TYPES)
- P2 - ROUTINE BRIDGE CONSTRUCTION SKILLS (4 TYPES)
- P3 - SUPPORT SKILLS (4 TYPES)

CONSTRUCTION EQUIPMENT CODE

- HAMMER
- ERECTION BOAT
- BAILEY BRIDGE CONVERSION SET
- MGB ERECTION SET
- BAILEY BRIDGE ERECTION SET
- RIBBON BRIDGE ERECTION SET
- CABLE SET
- CRANE
- TRUSS-TRUSS ERECTION SET
- DOZER
- SCOOP LOADER
- AVLB LAUNCHER

TRANSPORTION EQUIPMENT CODE

- BOLSTER TRAILER
- BRIDGE TRUCKS
- RIBBON TRANSPORTERS
- DUMP TRUCKS
- 25-TON TRACTOR TRAILERS

Figure 7. Detailed listing of requirements for capabilities matrix categories

- EARTH FILL
- FORD (INCLUDES MAT LAYING ON SOFT BOTTOM SOILS)
- RAFT
  - MOBILE ASSAULT BRIDGE UNITS
  - RIBBON BRIDGE UNITS
- BRIDGE
  - FIXED
    - BAILEY M2 PANEL
      - SINGLE AND MULTISPAN
      - CABLE REINFORCING KIT
    - MEDIUM GIRDER BRIDGE (MGB)
      - SINGLE AND MULTISPAN
      - CABLE REINFORCING KIT
    - ARMORED VEHICLE LAUNCHED BRIDGE (AVLB)
      - 18.3 M (60 FT)
      - 27.4 M (90 FT)
    - TRUSS TRUSS
    - ARMY FACILITIES COMPONENT SYSTEMS (AFCS) BRIDGE
    - TIMBER TRESTLE
    - PRESTRESSED CONCRETE
  - FLOAT
    - MOBILE ASSAULT BRIDGE UNITS
    - RIBBON BRIDGE UNITS

Figure 8. Detailed listing of gap crossing methods

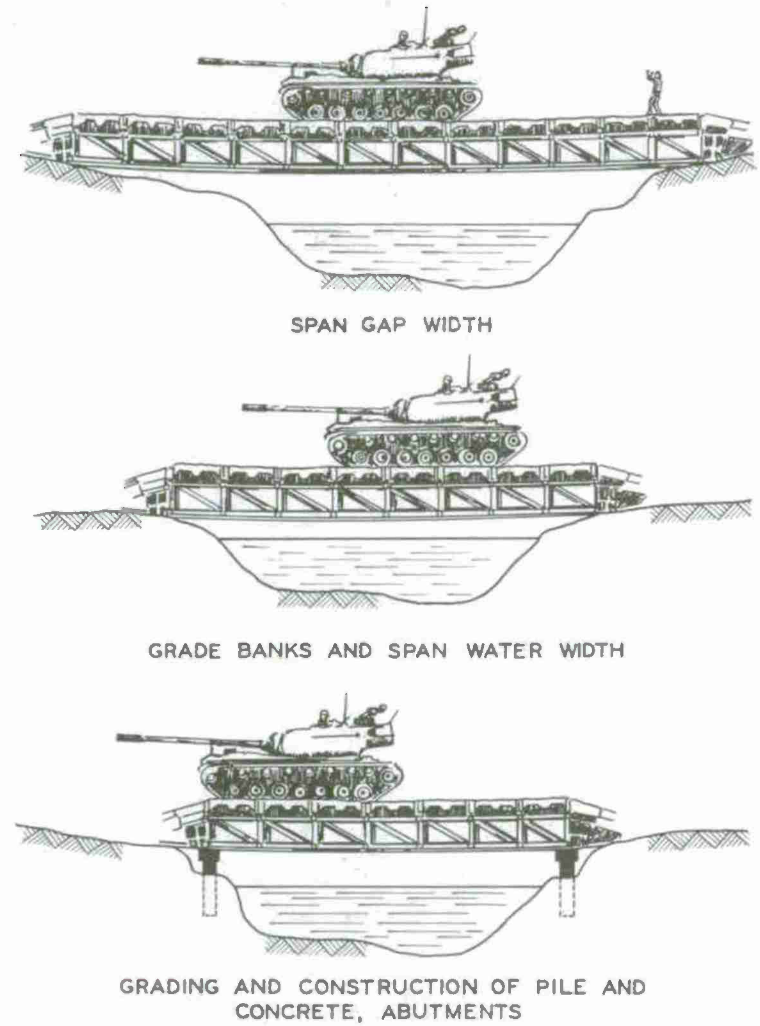


Figure 9. Bridge/gap configurations evaluated for each fixed bridge type and each gap

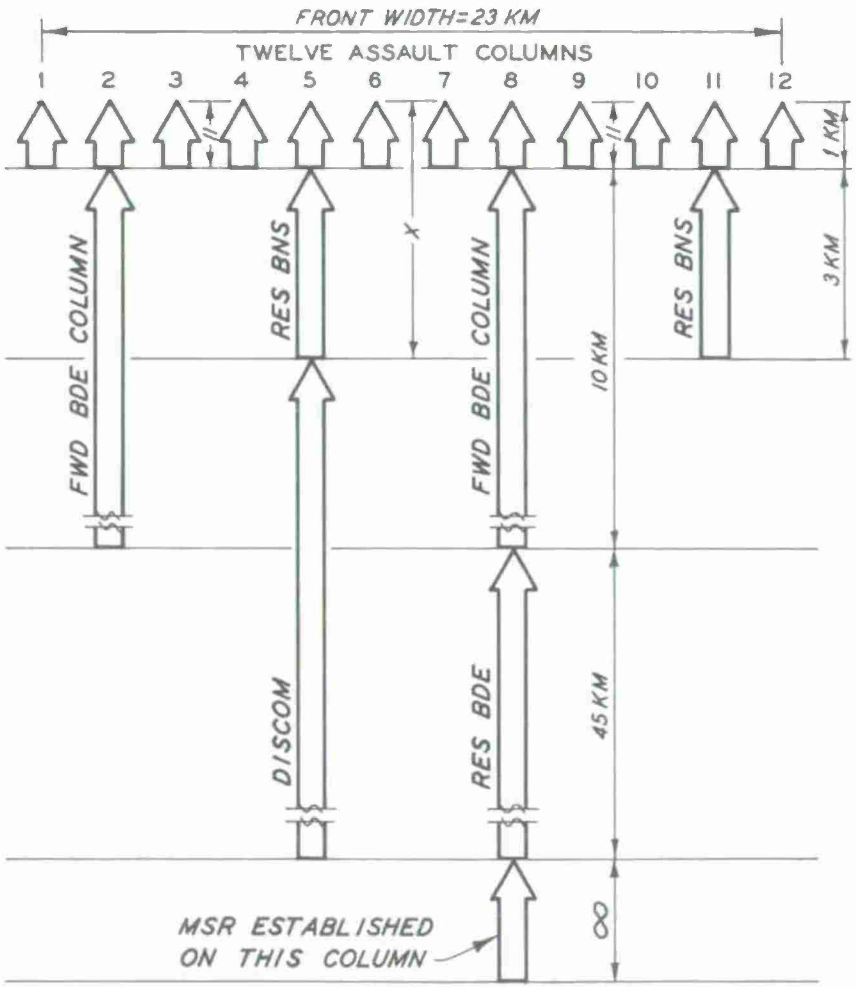


Figure 10. Division force structure for European theater

GAP NO.	NO. OF OCCUR. (N)	GAP WIDTH	VELOCITY	BK ANGLE-R	BK ANGLE-L	BK HEIGHT-R	BK HEIGHT-L	WATER WIDTH	WATER DEPTH
25	4	2	2	2	3	2	3	3	2
26	6	2	3	2	4	2	4	3	1
27	3	2	2	2	3	3	3	2	1

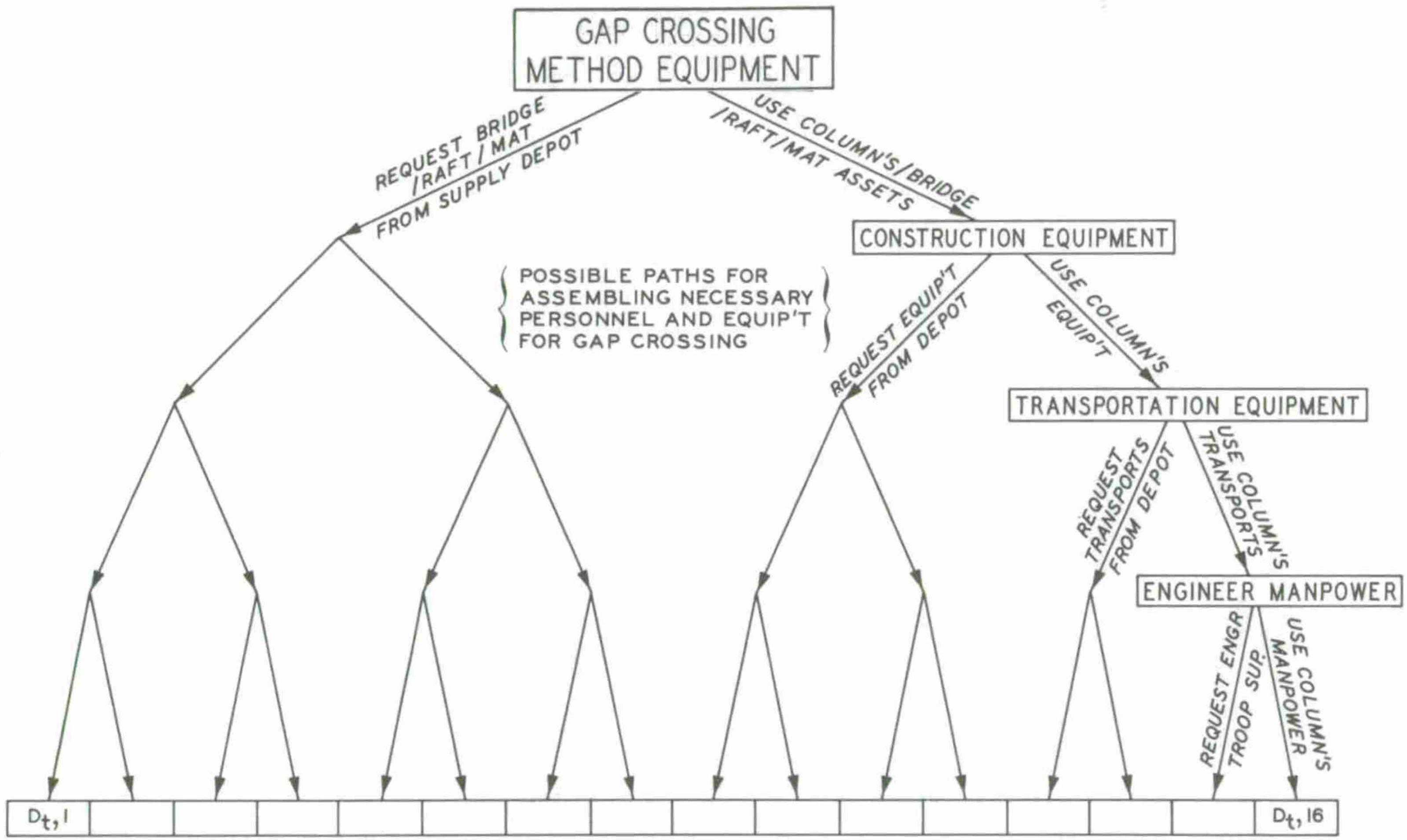
$$P = \left[\frac{N \times \frac{TL \times SM}{TN} \times \frac{AM}{AS}}{W} \right] \times 100$$

GAP WIDTH CLASS - 2

GAP NO.*	TOTAL LENGTH OF GAP IN PERCENT (P) OF FRONT WIDTH
25	80
26	55
27	130

* ARRANGED IN INCREASING ORDER OF FACTOR CLASS RANGES.

Figure 11. Data preparation for simulation of gap occurrence and distribution



DELIVERY TIME, D_t

RESPONSE TIME, R_t = DELIVERY TIME, D_t + CONSTRUCTION TIME, C_t

Figure 12. Personnel/equipment inventory availability determination

A REAL TIME DECISION MODEL FOR THE ARMY COMMUNICATIONS COMMAND

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1. Introduction.

The present and future environment of Army communications systems managed by the U.S. Army Communications Command is such that major operational and maintenance decisions must be made in a timeframe increasingly more in coincidence with the earliest and faintest signal of a potential need for decision. Otherwise, the Command will tend toward an increasing posture of a reaction, corrective type decision process rather than an action, creative decision orientation.

In order to assist the Command decision making organization in continuing to move in the direction of the action, creative decision orientation, a decision analysis model is being developed which will in real time, on demand, signal the potential need for decision, identify alternatives available at that moment and project the relative impacts of the alternatives on computerized video display devices. A computerized up-to-date model of USACC's operations, the heart of the system, will be available through remote terminals for USACC decision makers to investigate "what if" type questions, and communications technology will be available to issue command decisions and directives resulting from the real time analysis.

The design of this communications decision/intelligence system (CDISTM) is being approached by means of the tricotyledon theory of system design. Since this approach to system design is not as yet widely known, Section 2 gives a short exposition of the theory. Section 3 then reports the current state of the project applying this theory to the design of CDISTM. The model of USACC's operations upon which the design of CDISTM must be based is discussed in Section 4.

2. The Tricotyledon Theory of System Design.

The tricotyledon theory of system design [4,5] is based on mathematical system theory [1, 2, 3] and, as such, is a rigorous mathematical theory. The concept, however, and in particular the language dealing with systems manipulation, can be discussed and used at a more practical level of abstraction than the mathematical. In other words, almost all of the concepts involved in the tricotyledon theory of system design are more or less easily explained at a common language level and can be used at that level.

That interdisciplinary teams are necessary to specify comprehensively and precisely complex, large-scale, man-machine system problems is almost a truism. That is, in order to see all points of view, organizational, individual, governmental, physical, and biological aspects of a given large-scale, complex man-machine system design problem, it is necessary to have several disciplines represented on the team looking at such a problem. The first problem of such a team is that of language. Everyone seems to talk past one another. The jargon of each individual discipline is inadequate to talk about the phenomenological aspects of other disciplines. The second worst problem of interdisciplinary teams is that of problem definition. Many interdisciplinary teams spend a great deal of time worrying about "what is the problem" simply because they lack an adequate language. The tricotyledon theory of system design is an attempt to solve both of the problems.

In the first place, the tricotyledon theory of system design provides a common language in which to speak about systems phenomena and the manipulation of systems phenomena. Secondly, the principal thrust of the tricotyledon theory of system design is to provide a structure within which any large-scale, complex, man-machine system design problem can be stated as precisely, yet as comprehensively, as possible without limitations of any kind and without unconsciously specifying the solution. For example, linear programing could be considered to be a system design methodology, but the limitations of linear programing are such that very few large-scale, complex, man-machine system problems can be expressed within the methodology presented by linear programing. On the other hand, a common approach to the definition of any system design problem is to assume a solution to the problem. For example, instead of stating a problem as the design of a system, one typically asks for a new piece of hardware. Both of these approaches tend, on the one hand, to eliminate from consideration some very important aspects, and on the other hand, to over-simplify the problem. Over-simplification is one of the greatest dangers in the approach to large-scale, complex, man-machine system design or analysis problems.

The tricotyledon theory encourages independent considerations of input/output specification and of available technology. These considerations actually lead to the three cotyledons involved in the tricotyledon theory system design. The first cotyledon is composed of all systems that satisfy a given input/output specification. We attempt to identify what the system is fundamentally supposed to do in terms of inputs and outputs. These considerations are independent of what or how the system will ultimately produce the output from the inputs. Then we attempt to define a merit ordering of the systems that satisfy the input/output specification on the basis of how well they perform that input/output relationship. On the other side, in the second cotyledon, we consider the various means of producing the systems that could be involved in the solution. That is, we look at all the technologies available at the time of the system design exercise, or in the foreseeable future, that are available for solving the problem. This defines the cotyledon of all systems that are implementable in the given technology. We then attempt to define an ordering on this set of systems that describes in some sense which of these are best, in terms of how well we have used our resources. In other words, in the input/output cotyledon we looked at performance. In the technology cotyledon we look at costs, reliability, availability, vulnerability, and all of those factors that are involved in the appraisal of technological systems. Eventually these two independent considerations come together in the feasibility cotyledon which consists of all systems that both satisfy the input/output specification and are implementable in the technology. These systems eventually must be ordered by a trade-off merit ordering that involves the relationship between benefits, or performance, and costs and technological implementation. Finally, in order to complete the statement of a system design problem comprehensively, yet precisely, a system test plan must be defined by means of which the final, end-item system will be tested. This test plan must be consistent with the trade-off merit ordering in a precise way. The abstractions which went into the definition of the three cotyledons are made precise through operational procedures involving statistical sampling and hypothesis testing, as part of the definition of the system test plan.

Thus, the statement of any system design problem involves definition of six system theoretic artifacts: (1) an input/output specification, (2) a merit ordering over the input/output cotyledon, (3) a technology, (4) a merit ordering over the technology cotyledon, (5) a trade-off merit ordering over the feasibility cotyledon, and (6) a system test plan.

Definitions of those six artifacts are developed out of negotiations between the interdisciplinary systems engineering team and the client or his representatives. This negotiation between the interdisciplinary team and the client is crucial. The negotiation with the client could follow the format roughly indicated by the block diagram in Exhibit 1. The six basic artifacts that must be defined in order to state a system design problem comprehensively yet precisely are embodied in the six basic questions as indicated in the Problem Definition block. The interdisciplinary team works with the client, or clients, and asks them each of these six questions. Their answers result in documents that are called there the "literary formulation" in order that the client may see how the interdisciplinary team has interpreted his answers to the six basic questions. This is a feedback negotiation that must be iterated several times, finally to result in the six system theoretic artifacts: the input/output specification, the input/output merit ordering, the technolgoy, the technology merit ordering, the trade-off merit ordering, and the system test plan.

A merit ordering is a mathematical construct generalizing the arithmetical notion of "less than or equal to" and defined over a set of systems. Hence, a merit ordering is said to be defined over a set of systems when, given any two systems in the set, it can be determined whether one of the systems is "less than or equal to" the other system. Of course, when we speak of merit orderings of systems we are dealing with a vastly more complex subject than the usual arithmetic ordering. A great deal of effort in the system design project will be devoted to the discovering of the criteria on the basis of which such merit ordering will be defined.

The actual definition of a merit ordering is based typically, though not necessarily, on more primitive constructs. The most primitive of such constructs is the performance index. A performance index is a way of evaluating the performance of a specific system with respect to one specific, simple criterion under specific, dynamic conditions and on the basis of a finite period of time. A performance index is defined for each system in the set of systems for which a merit ordering is required and for each identificable performance criterion discovered by the design team. The next step, typically, is the development of a figure of merit over the set of systems. A figure of merit is usually

EXHIBIT 1

PROBLEM DEFINITION

BASIC QUESTION	LITERARY FORMULATION	SYSTEM THEORETIC FORMULATION
What is the system Supposed to do, Basically?	Statement of Need	Input/Output Specification $\mathcal{S}$
How is the system's Performance to be Judged?	Statement of Need Satisfaction Criteria	Merit Ordering over the I/O Cotyledon α
What can be used To Build the system?	Statement of Available Resources	Technology τ
How is the use of Resources to be Judged?	Statement of Resource Utilization Criteria	Merit Ordering over the Tech Cotyledon β
How are Performance/ Resource Conflicts to be resolved?	Statement of Trades-off Criteria	Merit Ordering over the Feasibility Cotyledon γ
How ought the system be tested?	Statement of System Test Plan Requirement	System Test Plan δ

defined as the expected values, or the distributions of values, of the performance indices. Such a figure of merit, therefore, depends on the development of a probability distribution over the set of all specific, dynamic conditions under which the performance indices are defined. In the development of this probability distribution, historical data is invaluable. Given a figure of merit defined over a set of systems, the problem of comparing systems is transformed into a problem of comparing symbols of merit. Such a method of comparing symbols of merit is called an ordering of merit. The ordering of merit is typically defined in terms of negotiated importance weightings for comparison to a "standard" symbol of merit representing the present, existing system or minimally acceptable values of performance criteria, and so forth. The merit ordering for systems is finally defined in terms of the ordering of merit for symbols of merit.

In a system design project based on the tricotyledon theory of system design, three merit orderings are required to be defined over three distinct, but related, sets of systems.

The first step in defining a system design problem within the tricotyledon theory of system design is to define an input/output specification which is essentially a statement of what the system to be designed is supposed to do, independent of the way in which the system will accomplish the doing. The first set of systems for which a merit ordering is required is the set (the input/output cotyledon) of systems that "satisfy" the input/output specification. Hence, the input/output merit ordering is based on performance criteria relating strictly to the input/output behavior of the system.

The next step in defining a system design problem within the tricotyledon theory of system design is to identify the technology of hardware, software, and personnel available to build systems to solve the problem. Definition of the technology determines the set (the technology cotyledon) of systems buildable in the technology, and it is over this set of systems that the technology merit ordering will be defined. The performance criteria upon which the technology merit ordering will be based will undoubtedly include capital costs, operating costs, time to build and deploy the system, reliability, availability, maintainability, flexibility, and so forth.

Given the input/output merit ordering and the technology merit ordering, it is necessary to define the tradeoff merit ordering over the set (the feasibility cotyledon) of systems that both satisfy the input/output specification and one implementable in the technology, consistent with the input/output merit ordering and the technology merit ordering. This is the point at which cost/benefit and cost/effectiveness criteria enter the problem definition.

When the six system theoretic artifacts, required by the tricotyledon theory of system design--the input/output specification, the technology, the input/output merit ordering, the technology merit ordering, the tradeoff merit ordering, and the system test plan--have been defined, comprehensive and rigorous evaluation of various alternative approaches to the design of the system is assured, and a framework will have been provided within which other design decisions can be made with confidence and precision. Once the problem has been thus precisely stated, there are a number of mathematical, computer, scientific, even heuristic, and empirical techniques that might be used to actually design the system. And, if an optimum solution exists within the feasibility cotyledon, it can be found.

3. The Communications Decision/Intelligence System.- CDISTM

Exhibit 2 displays the first step in the application of the tricotyledon theory of system design to the design of the communications decision/intelligence system CDISTM. In Exhibit 2, the design problem itself is given a name CDIDSN, and the six system theoretic artifacts necessary to define the problem according to the tricotyledon theory of system design are identified, and references given to documents where each artifact is defined in detail. None of these documents are given here; they have not yet been finalized. Exhibit 2, then, is only an example of the type of documentation that will be presented eventually to record the statement of the system design problem.

After generating the document represented by Exhibit 2, the next step is to generate the document defining in detail the input/output specification CDISPC, which must be satisfied by the system CDISTM to be designed. In order to generate the input/output specification CDISPC, the following situation was visualized: There exists a large-scale, far-flung, complex military communication system; call it ACSTM. The system CDISTM is to be designed to manage and control this system ACSTM. Therefore, the set of inputs for the system CDISTM includes but is not limited to the following types: information about the state of the system ACSTM, requirements to increase the capability of ACSTM to include new users or to decrease the capability of ACSTM in response to a decrease in funding, information about new hardware, software, or communication techniques, information concerning the obsolescence of hardware, software, or techniques, changing value judgments with respect to the performance of the system ACSTM, and so forth, in greater detail. The output of the system CDISTM would be essentially, orders that would result in the modification, expansion, contraction, or adaptation of the system ACSTM; new equipment would be installed, old equipment replaced, policies updated or initiated, and so forth. In other words, the system ACSTM would be, essentially, at least partly, redesigned; the essential function of the system CDISTM, then, can be characterized as the dynamic redesign of the system ACSTM. In order to know how to design the system CDISTM, one must know how to design the system ACSTM.

Therefore, in order to define the input/output specification CDISPC for the system design problem CDIDSN for the design of the system CDISTM, we must be able to develop a system design problem definition for the system ACSTM itself. The potentially variable and dynamic parts of this design problem definition are the inputs to the system CDISTM that will be specified as part of the input/output specification CDISPC.

4. The Army Communications System.

The Army Communications System design problem for the design of the

EXHIBIT 2

THE COMMUNICATIONS DECISION/INTELLIGENCE SYSTEM DESIGN PROBLEM

1. Let CDIDSN be a system design problem. (The format governing this definition is that given in Exhibit 2.1 of [5].

2. The input/output specification of the system design problem CDIDSN is denoted CDISPC and is defined in Exhibit 1.10.

3. The technology of the system design problem CDIDSN is denoted CDITEK and is defined in Exhibit 2.10.

4. The input/output merit ordering of the system design problem CDIDSN is denoted CDIMO and is defined in Exhibit 3.10.

5. The technology merit ordering of the system design problem CDIDSN is denoted CDIKMO and is defined in Exhibit 4.10.

6. The tradeoff merit ordering of the system design problem CDIDSN is denoted CDITMO and is defined in Exhibit 6.10.

7. The system test plan of the system design problem CDIDSN is denoted CDITST and is defined in Exhibit 6.10.

system ACSTM is named ACSDSN in Exhibit 3, and the six artifacts necessary for the complete definition of the design problem ACSDSN are identified. The references are not included here; some of them can be found in [5].

In order to develop the input/output specification ACSPC that the system ACSTM is to be designed to satisfy, a set of users is postulated, each user is to be represented by a system theoretic model. Each user, at each instant of time, depending on his state, for each of the other users, might have a message to communicate. These users, conjunctively coupled in the system theoretic sense, constitute the market that the system ACSTM is to be designed to serve. Each of the users has a communication input port and an environmental input port. At his environmental input port, each user receives information about his environment; at his communication input port each user receives messages distributed by the communication system, presumably generated for him by other users.

Thus, the input for the system ACSTM at each instant of time is demand for communication, that is, a statement that gives the message that a given user would communicate to another user, for all possible pairs of users in the market. The output of the system ACSTM is a distribution of messages, each message distributed, presumably, to the appropriate input port of the appropriate user.

These relationships are caricatured in Exhibit 4. There, two coupling recipes are portrayed: a conjunctive coupling recipe of which the system MARKET is the resultant and the systems USER1, USER2, . . . USERn, are the components and a coupling recipe whose components are the system MARKET and ACSTM and of which the resultant is denoted ACSIEM. Coupling recipes are the system theoretic constructs discussed in [1, 2, 3, 5].

In Exhibit 5, a formal input/output specification ACSPC is defined reflecting these intuitive notions. The input/output specification ACSPC, however, is defined without reference to the fact that the system ACSTM to be designed will be coupled to the system MARKET. That coupling arrangement will be used to <u>evaluate</u> the system ACSTM. As stated in Exhibit 5, the only function of the system ACSTM is to accept demand for communication among the users and to distribute messages to the users as output. These are Statements 2 and 4, respectively, of Exhibit 5. Statements 3 and 5 simply assert that these inputs can arrive, and these outputs can be produced, in time, in any manner whatsoever. Step 5 of Exhibit 5 says that a system can be considered to be a communication system provided only that it accepts demand for communication among users as input and produces distributions of messages to users as output <u>regardless whether there is any relationship between the inputted demand for communication and the outputted distributions of messages to users!</u> Of course, the output of a "good" communication system will be highly correlated with the input. But the issue of what constitutes a "good" system and what constitutes a "bad" system is being ignored here purposely and conscientitously. The point is, there seems to be no natural or physical laws that <u>require</u> a correlation between the input and the output of a communications system. By defining the input/output specification thus so permissively, we assure ourselves that the input/output cotyledon will be as large as possible, that we haven't arbitrarily eliminated, through prejudice and preconceived notions, any innovative solutions

EXHIBIT 3

THE ARMY COMMUNICATION SYSTEM DESIGN PROBLEM

1. Let ACSDSN be a system design problem. (The format governing this definition is that given in Exhibit 2.1 of [5].

2. The input/output specification of the system design problem ACSDSN is denoted ACSPC and is defined in Exhibit 18 of [6].

3. The technology of the system design problem ACSDSN is denoted ACSTEK and is defined in Exhibit 3.9.

4. The input/output merit ordering of the system design problem ACSDSN is denoted ACSIMO and is defined in Exhibit 2.11 of [6].

5. The technology merit ordering of the system design problem ACSDSN is denoted ACSKMO and is defined in Exhibit 4.9.

6. The tradeoff merit ordering of the system design problem ACSDSN is denoted ACSTMO and is defined in Exhibit 5.9.

7. The system test plan of the system design problem ACSDSN is denoted ACSTST and is defined in Exhibit 6.9.

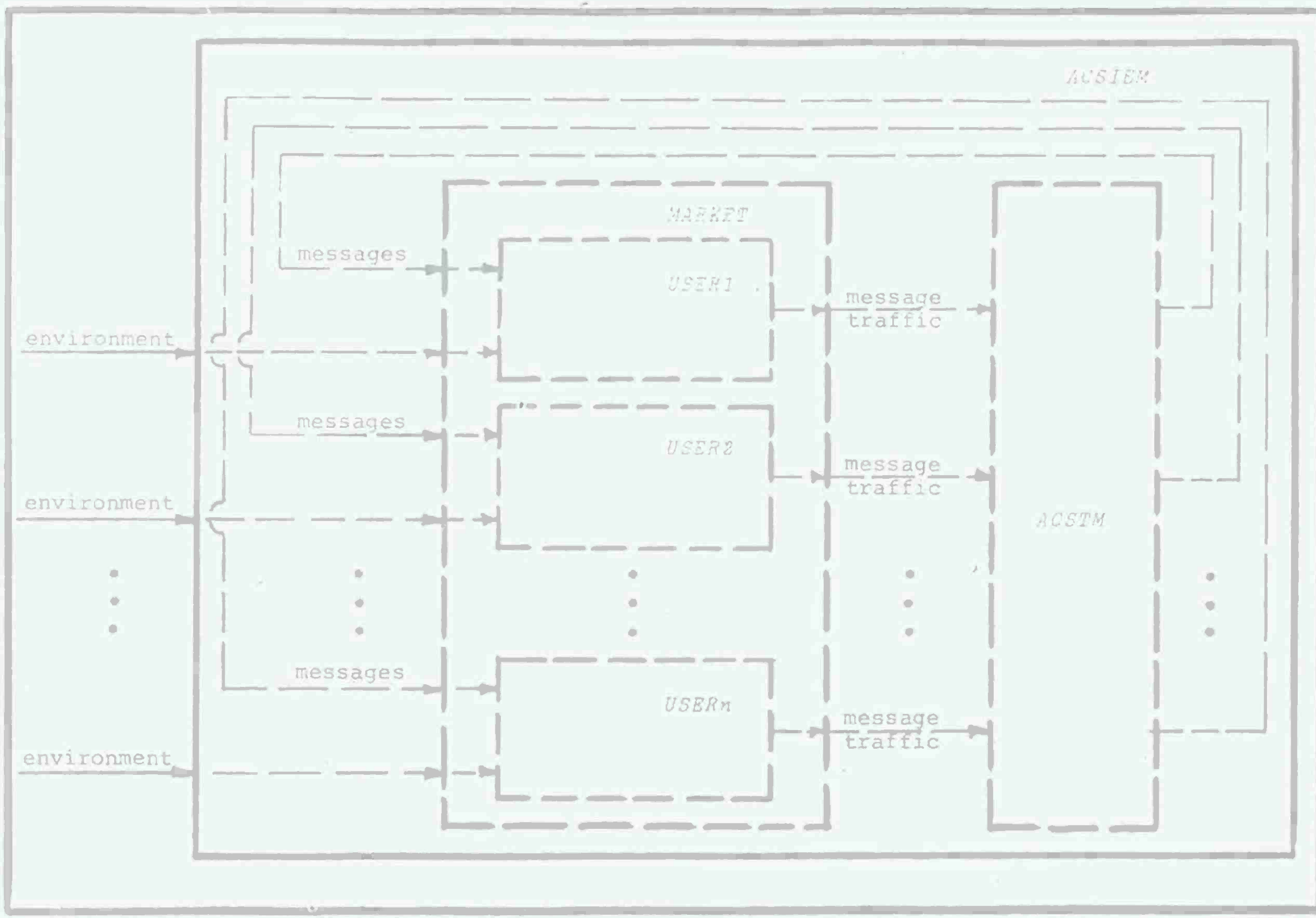

Exhibit 4

Caricature of the System *ACSIEM* within which the System *ACSTM* will be Evaluated

EXHIBIT 5

THE ARMY COMMUNICATION SYSTEM I/O SPECIFICATION

1. Let ACSPC be an input/output specification. (The format governing this definition is that given in Exhibit 2.2 of [5].

2. The set of inputs of the input/output specification ACSPC consists of all possible statements of demand for communication. A statement of demand for communication consists of a list, each entry on the list is an ordered pair of users together with a message that the first user would communicate to the second user of the pair or else an indication, NO NEED, that the first user of the pair has no need to communicate to the second user of the pair. Every possible pair of users from the set USERS must appear in any list that is a statement of demand for communication.

3. The set of input trajectories of the input/output specification ACSPC consists of every function of time which, at any time value, gives a statement of demand for communication.

4. The set of outputs of the input/output specification ACSPC consists of all possible distributions of messages. A distribution of messages is a list, each entry on the list consists of the name of a user, together with either a message or an indication, NOXMTL, that no message has been distributed to the user. The name of every user in the set USERS must appear in any list that is a distribution of messages.

5. The set of output trajectories of the input/output specification ACSPC consists of every function of time which, at any time value, gives a distribution of messages.

6. The matching function of the input/output specification ACSPC matches with any input trajectory the set of all output trajectories.

to our problem, that we have retained as many as possible of our options at this stage.

But now we must turn to the definition of an algorithm by which any two systems in the input/output cotyledon can be compared. Such an algorithm is required in Step 4 of the definition of a system design problem; it is called the input/output merit ordering and identified in Step 4 of Exhibit 3 by the symbol ACSIMO. We will not go into the definition of this merit ordering in detail. The technical detail will be found in Reference [5]. The development of the merit ordering ACSIMO is sketched herein, however, in Exhibit 6.

The first step in the development of the input/output merit ordering ACSIMO, as indicated in Exhibit 6, is to define a set of performance indices. A performance index is a number or other symbol assigned to a specific system experiment for a specific system. Thus, performance indices are operationally defined so that given a system and a system experiment, we know exactly how to compute the performance index. We define performance indices for every system in the input/output cotyledon generated by the input/output specification ACSPC. And, in defining these performance indices, we use only the characteristics of the system deducible from the fact that the system is in the input/output cotyledon generated by the input/output specification ACSPC. As indicated by Exhibit 6, we define four general performance indices: average time of message transmission, estimated lost call probability, estimated spurious call probability, and average quality of message transmission. Then we define two other performance indices for each priority class of messages: maximum transmission time and minimum transmission quality. The details of the definitions are given in Reference [5]. These are not the only performance indices that could be defined nor are they necessarily the most important. They are merely examples of indices that have been used. A thorough-going negotiation exercise might bring others to light or might result in discarding or modifying some of these.

But a performance index assigns a symbol to, and hence can be thought to summarize, the behavior of a system only under one specific set of experimental conditions. Two systems cannot be satisfactorily compared on that basis. We must somehow summarize the behavior of a system over all possible experimental conditions. In other words, we want to define a figure of merit by which we can assign a number or other symbol to every <u>system</u> in the whole input/output cotyledon generated by the input/output specification ACSPC. The approach usually taken is to use for the figure of merit the expected values, over all system experiments, of the performance indices. For this purpose we need a probability distribution over the set of all system experiments for each system in the input/output cotyledon generated by the input/output specification ACSPC. This probability distribution is identified in Step 2 of Exhibit 6 as ACSIRM.

The development of the probability distribution ACSIRM is accomplished within the structure caricatured in Exhibit 4. We assume that the system being evaluated, identified as ACSTM in Exhibit 4, is coupled to the MARKET system of users. Then, the distribution of messages by the system

EXHIBIT 6

DEVELOPMENT OF THE I/O MERIT ORDERING ACSIMO

1. I/O Performance Indices:

   . Average time of message transmission

   . Estimated lost call probability

   . Estimated spurious call probability

   . Average quality of message transmission

   . Maximum transmission time for messages of priority P.

   . Minimum transmission quality for messages of priority P.

2. The I/O scenario probability distribution ACSIRM.

3. The I/O figure of merit ACSIFM is the expected values of the performance indices with respect to the I/O scenario probability distribution.

4. The I/O ordering of merit:

   . Compares symbols of merit on the basis of importance weightings and a reference symbol.

5. The I/O merit ordering.

ACSTM will affect the states of the users which, in turn, determined the demand for communication inputted to the communication system ACSTM. This phenomenon embodies the essence of communication: demand for communication is determined, partly at least, by accomplished communication. Of course, the state of each user is determined not only by messages received but also by information received about the environment. Hence, a probability distribution is postulated on the environmental inputs, the states and the time scales of the users; in other words, a probability distribution is postulated on the set of system experiments of the system ACSIEM caricatured in Exhibit 4 as the resultant of coupling the communications system ACSTM with the system MARKET. This probability distribution, then, determines a probability distribution on the inputs to the system ACSTM. It is this probability distribution that is denoted ACSIRM, and that is used to compute the expected values of the performance indices, as suggested in Step 3 of Exhibit 6, that define the figure of merit ACSIFM.

Thus, the figure of merit ACSIFM assigns to each system in the input/output cotyledon generated by the input/output specification ACSPC, a symbol consisting of the expected values of the four general performance indices and the expected values of two additional performance indices for each priority class of message. These expected values, then, represent performance with respect to performance criteria. In order to compare two systems, then, we compute their figures of merit and compare the figures or symbols of merit.

As suggested in Step 4 of Exhibit 6, the comparison of symbols of merit can be accomplished by means of importance weightings negotiated for each performance criterion and a standard reference symbol of merit representing the present system or the ideal system. Each symbol of merit is then scored by comparing it, performance criteria by performance criteria, to the standard symbol of merit, and awarding to the symbol being scored a proportion of the total importance weighting for that performance criteria according to improvement represented by the symbol being scored to the standard symbol with respect to that performance criteria. The details of this comparison are given in Reference [5]. This method of comparison is not the only one possible, nor is it necessarily being recommended as desirable; it is a method that is fairly easy to understand and one, at least, that raises appropriate questions for this discussion.

Finally, as suggested in Step 5 of Exhibit 6, the input/output merit ordering ACSIMO for comparing systems is defined in terms of the ordering of merit just defined for comparing symbols of merit.

This completes a version of the considerations necessary to define the system design problem ACSDSN (Exhibit 5) from the input/output point of view. The next step is to record similar considerations from the technology point of view and then go on to the tradeoff merit ordering and the system test plan as indicated in Exhibit 3. When the system design problem ACSDSN (Exhibit 3) is completely defined, then we will be able to return to the definition of the system design problem CDIDSN (Exhibit 2).

In conclusion, then, the initial problem to design a real time decision intelligence system which can accurately sense the earliest and faintest signal of the potential need for decision and display the panorama of feasible alternatives with appropriate merit orderings, must be preceded by a clear understanding of the design of a large, far-flung, complex military communications system. The tricotyledon theory of system design, therefore, is first being applied to this secondary design problem. Once this is accomplished, and we understand more completely the nuances of military communications systems design, we can apply the tricotyledon theory to the design of a more effective system of control, the real time decision system.

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MOVANAID: AN ANALYTIC AID FOR ARMY INTELLIGENCE PROCESSING

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The Intelligence Systems Program at the Army Research Institute is exploring ways of utilizing tactical data systems such as the Tactical Operations System (TOS) to support information processing. MOVANAID, an analytic aid for tactical intelligence processing recently developed under this program, is described in this paper. MOVANAID is an on-line, interactive aid primarily intended for use by division-level staff intelligence officers (G2 Section) in the analysis of enemy movement capabilities. The aid computes fastest travel times and paths through road networks for military units of various types and, in addition, fastest times within which simultaneous maneuvers can be completed. In the following two sections the movement analysis problem is briefly discussed and the capabilities of the present form of MOVANAID are outlined. These sections are followed by a description of the mathematical algorithms built into the aid and the manner in which users will interact with MOVANAID. Then, the planned program of evaluation of MOVANAID is discussed in some detail. This evaluation will involve the analysis of user reactions to and user performance with the aid relative to current manual procedures. In the final section, ways in which the capabilities of the present MOVANAID might be extended are briefly mentioned.

The Movement Analysis Problem

One of the continuing responsibilities of a division G2 (Assistant Chief of Staff, Intelligence) in a tactical situation is the preparation of periodic intelligence estimates[1] which include a discussion of significant enemy capabilities and probable courses of action. Estimates of enemy "mobility" are frequently necessary for such estimates. It is plain, for example, that if an enemy is not physically capable of maneuvering a force of strength S to location P in time T, he will then not have the capability to attack in strength S at point P in time T. Similarly, the enemy's capability to reinforce front-line units by time T with other units reserved in the rear for that purpose depends strongly on whether or not the necessary maneuvers can be completed by time T.

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[1] Intelligence estimates are discussed in detail in Department of the Army Field Manual 30-5 (Combat Intelligence, Ch. 6 and appendix J) and in Department of the Army Field Manual 101-5 (Staff Officer's Field Manual: Staff Organization and Procedures, appendix B).

For an example involving the determination of enemy probable courses of action, suppose that it is known or suspected that an enemy attack is imminent and that the friendly G2 wishes to identify the avenue or avenues of approach which the enemy is likely to select. It may be possible for the G2 to eliminate some of the alternative avenues in this case on the basis of mobility considerations alone, since the enemy would be unlikely to select an avenue along which his movement would be too slow to meet the requirements of the tactical situation.[2]

Thus, while the estimation of order of battle factors, such as enemy strength, composition and disposition, requires the integration and correlation of many fragmentary pieces of information, the ability of a given enemy unit to move from one location to another involves a much more straightforward analysis. As will soon become apparent, however, a thorough movement analysis requires extensive computation; indeed, it is doubtful that such an analysis could be conducted by intelligence processors within a time consistent with the needs of a dynamic tactical environment without using a computer-based aid. Thus MOVANAID has the potential for not only reducing the burden on the G2 staff, but also for an improved intelligence product.

An Overview of MOVANAID

The ARI test facility (TISF -- Training and Information Systems Facility) consists of a large laboratory space containing various relocatable computer interface devices and other equipment. One portion of the TISF is currently configured to accommodate SIMTOS, a Simulated Tactical Operations System. A SIMTOS G2 player is tasked with the preparation of an Intelligence Estimate and other tasks within the context of a division-level planning exercise; the scenario involves preparation for a likely Aggressor attack against the 20th (U.S.) Mech. Div. positions in southeastern Germany. The SIMTOS player is provided with appropriate maps and overlays, and is connected to a computerized data base via an alpha-numeric CRT screen and keyboard, and a teletypewriter. While MOVANAID as described here has not been integrated into SIMTOS, the development of the aid was directed toward its use within SIMTOS, and it has been implemented on the TISF computer. Also, the road network is from the SIMTOS area, and all examples of its use are based on questions facing the SIMTOS player. All interaction between MOVANAID and the user utilizes the CRT screen (MOVANAID output and requests for input) and CRT keyboard (user input).

Users may call on MOVANAID to assist them in answering two basic types of questions about enemy movement capabilities:

(1) How soon, and by what path, can a unit of type x now located in location y maneuver to destination z?

[2]Mobility factors frequently are a primary consideration in the choice of avenue of approach (see Department of the Army Field Manual 30-102 (Handbook on Aggressor, Chapter 5).

(2) How soon, and by what paths, can units of types $x_1,\ldots,x_n$, now located in locations $y_1,\ldots,y_n$, complete a simultaneous maneuver to destinations $z_1,\ldots,z_n$?

Variations on each of these types of questions are possible, but MOVANAID is not presently configured to treat them all. For questions of the second type, it is understood that it is not required for any $1 \leq i \leq n$ that the i^{th} unit travel to the i^{th} destination z_i; rather, a unit may maneuver through the network to any destination so long as each unit travels to some destination and each destination is the recipient of some unit. Such a question, therefore, asks for the assignment of units to destinations such that the largest travel time is a minimum.

At present, the interface between user and aid is on-line and inter-active. Users interact with the aid in hands-on fashion, with information being transmitted from aid to user via a cathode ray tube (CRT), and from user to aid via a keyboard.[3] Users need input only a small fraction of the data required by the aid in determining an answer to any eligible question. The bulk of the data (including all information about the network of roads to be considered by MOVANAID) has been made available to the aid in advance. It is expected that any operational use of MOVANAID would necessarily involve a similar prior preparation of network information.

To make inputs to (and interpret outputs from) MOVANAID, users must be familiar with certain conventions which have been adopted for identifying nodes and classifying arcs of the SIMTOS network. Nodes are defined as any point of interest, such as a crossroads, unit location, or key terrain feature, which is given a coordinate label and connected to the network. For purposes of quickly and easily identifying nodes of the network, a coordinate scheme resembling the usual Cartesian system has been adopted. First, a convenient origin of coordinates is selected at the time of data collection, thus establishing (imaginary) horizontal and vertical reference axes. Next, the area of operations is divided into square subareas (which we call "sectors") of side-length 10 kilometers. Next, each sector is subdivided into 100 squares (called "sub-sectors") of side-length 1 kilometer. Nodes of the network are numbered with a five-digit number. The first two digits and the second two digits of a node number indicate, respectively, the horizontal and vertical coordinates of the lower left corner of the sub-sector within which the node lies. The last digit of the node number is always taken to be "0" unless two or more nodes of the network lie in the same sub-sector; in the latter case, as many as necessary of the digits "1",..., "9" are also used. Thus, for example, if two nodes of the network were found to lie in a subsector whose coordinates were (18,54), one of the nodes would be numbered 18540 and the other would be numbered 18541[4].

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[3]Information is transmitted in the form of written text. Graphic displays are not presently used.

[4] It is immaterial which node receives which number. An acetate overlay of the SIMTOS network on a 1:50,000 map showing the node numbers as they exist in the MOVANAID data base is made available to users.

Arcs of the network are interpreted to be paths of travel which connect two, and only two nodes. In computing travel times, the aid uses internally-stored information about each arc of the SIMTOS network as follows:

(1) Length,
(2) Type of arc classified as one of five types --
   (a) major highway (e.g., autobahn),
   (b) main all-weather road (road with hard surface and two or more lanes),
   (c) other all-weather roads (hard surface and two lanes or less),
   (d) artificial route (travelled in zero time, used by the aid for computational purposes), and
   (e) cross-country route.
(3) Speed capability, classified as --
   (a) highway speeds (travelled at speeds typical of non-urban areas);
   (b) city speeds (travelled at speeds typical of urban areas), and
   (c) cross-country speeds, classified as one of three types - -
      1. speeds typical of easy cross-country routes,
      2. speeds typical of cross-country routes of medium difficulty, and
      3. speeds typical of difficult cross-country routes.

Although the above information is part of the permanent data input to the aid prior to use, the user may amend any of it on a temporary basis by entering new data on an interactive basis with the aid. These interactions are discussed in detail in a later section.

The remainder of the information used to determine travel times is selected by the user from a set of data input prior to use. This data may not be amended on-line. The information is comprised of the unit type (e.g., foot, tracked vehicle, or truck), and environmental conditions (light and weather). Selected by the user (from a composite unit type/speed table), this data, in conjunction with the defined speed capability of an arc, is used by the aid to determine the speed travelled on each arc. This, with the arc length, results in the arc travel time.

The Analytic Foundation of MOVANAID

As we have mentioned, MOVANAID is designed to solve two types of movement analysis problems. One of these is to find the fastest path between two user-specified nodes in a network. The other is to assign units to destinations such that the time for completion of a simultaneous maneuver is minimized. The former will be referred to here as the fastest path problem while the latter will be called the assignment problem.

Several algorithms for finding fastest paths in a network have been discussed in the literature. One such algorithm has been selected for adaptation in MOVANAID. Alghough there are reasonable grounds for attributing this algorithm to Dantzig (see Dantzig (1960) and also Dantzig (1963, pp. 363-366), it must be admitted that the origin of it is now obscure. There are several similar fastest-path algorithms which predate Dantzig's (see, for example, Bellman (1958) and Moore (1957) and still another algorithm due to Minty (1957). Like these others, the algorithm selected requires as data the travel times for the individual areas of the network. As has already been pointed out, the computation of these arc travel times is straightforward. Combining certain user-specified data with prestored data, the aid is able to determine an appropriate rate of travel for each arc. Then, the arc length is divided by this rate to determine the traveltime. Using these travel times, the algorithm seeks to determine the fastest path to the destination by a "fanning-out" search technique beginning at the moving unit's origin.

To solve the assignment problem, it is first necessary to employ the fastest path algorithm for each origin/destination pair so that the fastest travel time from each unit to each destination is known. Given this information and the added assumption that units do not interfere with each other's movement, it is possible in principle to determine an assignment scheme which minimizes the maximum simultaneous maneuver time by simply examining all possible assignments. This method, called solution by enumeration, requires the examination of an enormous number of assignments for problems of even moderate size. A problem of size ten, for example, which is about as large a problem as users are likely to pose to MOVANAID, would require examination of 10! or 362880 assignments.

To avoid the time-consuming enumeration method, an iterative algorithm for rapidly solving the assignment problem has been adopted from Gross (1959). Gross' algorithm draws heavily on earlier work by Konig (1950) and Egevary (1931). Briefly, the Konig-Egevary theorem shows that the assignment problem is equivalent to a problem in network flows. Based on this theorem, the algorithm uses a labelling technique, normally used to optimize flows in networks, to solve the assignment problem. A full account of this technique is given by Ford and Fulkerson (1962, pp. 53-58).

User Interaction with MOVANAID

There are three distinguishable levels of development for a tool like MOVANAID. The existing aid, developed primarily for demonstration purposes, will be different in detail and perhaps character from a version structured for laboratory testing and evaluation. The laboratory version, in turn, will differ from any final version which may be implemented on a TOS or other system. Changes in the aid will be made from one level of development to the next to take account of experience with the aid to that point. Since the laboratory version is not yet fully developed, the following discussion of the interactions between user and aid is limited to the aid as it exists in the first level of development.[5]

To initiate the MOVANAID program, a user makes a simple entry on the input keyboard. Once this is done, a single problem-solving session with the aid will proceed through a series of six steps. For each step in the sequence, instructions to users about what to do next are provided by MOVANAID itself, via the CRT.

In the first two steps the user is given the opportunity to make temporary changes in the network. He may, for example, wish to delete an arc which he knows will be impassable at the time the proposed movement is being made. Or, he may simply wish to change the speed type of the arc to reflect changing road conditions. It may also be desirable to create a cross-country arc between two nodes where such travel is feasible. In any case, network modifications can be made on a piecemeal basis, or in a more sweeping fashion through the specification of sub-networks.

Piecemeal changes are specified in the first step of the problem-solving sequence. By piecemeal, we mean that individual nodes or arcs may be added or deleted, and that the speed type or length of individual arcs may be modified. The user first specifies the number of such changes that he would like to make. Then, MOVANAID prompts the user to specify the required information for each change. For any given node the required information, called the linkage information, consists of the node number of each connected node, the speed type, and the length of each connecting arc. The linkage information for any node is specified by eleven digits per connected node. Thus, the entering of data for a large number of piecemeal changes would be somewhat time consuming. As a consequence, this method of making network modifications is reasonable only if there are relatively few changes to be made. Extensive additions to the network are better accomplished through a permanent redefinition of the data base of the aid before its use in problem solving. Extensive deletions, on the other hand, are possible through the choice of other options in the next sequential step in the problem-solving experience.

In step two, the user may delete from consideration large portions of the network by specifying subnetworks in one of two ways. First, he may limit the attention of the aid to whatever portions of the network lie in certain map sectors. These he designates by simply entering the coordinates of these sectors on the keyboard. Second, a user may limit the attention to the aid to a "swath" by specifying the swath width and a series of "turning points." The subnetwork defined by a swath of, for example, 10 km contains all nodes within 5 km on either

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[5]The existing mode of interaction between aid and user requires users to be familiar with the rudiments of computer programming. This situation will be modified prior to laboratory evaluation.

side of a line constructed by connecting the specified turning points. The use of either the swath or sector option will reduce the computation time for MOVANAID while allowing the user to limit the possible solutions to those which fall within a specified area of interest. For example, it may be the case in some situation that a route which is clearly the fastest between two nodes may be highly unlikely to be followed for some tactical reasons. This route can be eliminated by specifying a subnetwork. Also, in certain cases, the user may find it necessary to know the travel time along a specified route. This is easily done by specifying a narrow swath-type of subnetwork along the avenue of interest.

In the third step of the sequence MOVANAID prompts the user for the initial locations, destinations, and types of units to be considered. For each origin/destination pair specified in this step the aid will compute the minimum time and path. The type of the unit specified in this step is used in conjunction with the prestored data base to determine the speed with which a unit may traverse any arc in the network.

Having specified the data for his problem, the user selects in the remainder of the steps a set of options which tell the aid how to proceed. Thus, in step four, the method by which computational results are displayed is selected. Then, in step five, the user indicates whether or not his problem involves the simultaneous movement of several units through the network. If so, the aid will compute the possible time for simultaneous completion of the multiple maneuver specified in step three. Minimum paths between all origin/destination pairs are, as we have noted, computed regardless of the user's choice at this step. In step six the aid displays the results as requested, and prompts the user to specify the next step. At this point the user has the choice of working another problem with the same network (including any modifications he has made), working another problem requiring new network modifications (or the elimination of the previous ones), or terminating the session.

It should be noted that throughout this sequence MOVANAID may generate error messages when necessary to alert users to three major types of errors which may prevent successful solution of a problem. The first type of error occurs if the user gives an origin or destination outside a previously-specified subnetwork. If so, the aid signals this fact and allows the user to respecify the data. The second error condition occurs when a user has specified, either intentionally or unintentionally, a subnetwork in which not every node can be reached from the origin. This is not necessarily a fatal condition for the user's problem as long as the destination itself can be reached. In any case, the user is warned of its occurrence so that he may determine if his results are satisfactory. If, in fact, no path can be formed between an origin/destination pair, the third error type is said to have occurred. This fact is displayed and the aid restarts.

Evaluation of MOVANAID

As described earlier, MOVANAID was developed to provide a division G2 staff with an aid to assist them in their analysis of enemy capabilities. The problem of movement analysis is one which is well suited for the use of computer based aids, involving as it does numerous straightforward computations. The issue which we will discuss in this section concerns the adequacy of MOVANAID as a solution to the movement analysis problem.

The evaluation of a computational computer program such as MOVANAID can be a simple matter of inputting a few sample problems with known solutions and examining the validity of the output. Indeed, this approach has been taken and, to nobody's surprise, the algorithms work as they are supposed to. However, this provides only a partial answer to the question "does MOVANAID function well?"

Besides accuracy, a second major concern with computer programs such as MOVANAID is the speed with which they operate. In its current configuration, MOVANAID takes approximately 1.5 minutes of CPU time (using a CDC 3300) to solve a problem involving the movement of a unit from one position to another within a network of approximately 600 modes. However, this time could be greatly reduced either by increasing the amount of core storage allocated to MOVANAID or by changing the computational approach. The former solution would make it more difficult to integrate MOVANAID into SIMTOS or a comparable system, and the latter would reduce the flexibility of the system. How may we evaluate whether the current system, which is a result of many such tradeoffs, does operate "fast enough" or "too slowly"? This question is actually irrelevant to MOVANAID in its current stage of development, and can be adequately addressed only by the designers and users of an operational system who are in a better position to determine the relative costs of inaccurate information versus untimely information.

Having discarded speed and accuracy as factors to be evaluated, we are left with the question of the adequacy of the <u>concept</u> of MOVANAID. Will MOVANAID help the intended user to do his job better? Will the user fully and appropriately take advantage of various MOVANAID capabilities? If the answer to either of these questions is "no", what are the characteristics of MOVANAID and of the interaction between MOVANAID and the user which interfere with its proper use? Can we redesign the system and/or train the user in order to increase MOVANAID's usefulness?

Our approach to this evaluation is to develop a laboratory version of MOVANAID, implement that version in the ARI test facility (TISF), and study the behavior of a number of G2 staff officers using MOVANAID to solve problems encountered in intelligence analysis. Two issues immediately arise: first, what are the characteristics of the population of potential users from which we want to sample? Second, what are the characteristics of the situations in which MOVANAID might be used?

MOVANAID was not developed in a vacuum; extensive discussions with the intelligence community, in particular with individuals at the US Army Intelligence Center and School, and extensive analysis of current intelligence processing doctrine as represented in the appropriate field manuals led to the original concept of a computer-based aid for analysis of enemy movement capabilities. Nevertheless, having developed MOVANAID, we still find ourselves in the position of a man who has just invented the wheel but cannot find anybody who wants anything moved. Since the evaluation of enemy movement capabilities has been so limited in the past, no doctrine or body of experience exists to suggest who the potential user is or how and when he would use MOVANAID. Thus, in order to evaluate MOVANAID, we first have to expand the definition of the concept to include a description of the context of its use.

Given the redefined concept, we now prepare a set of problems within a tactical scenario. These problems include direct requests for analysis of enemy movement capabilities as well as requests for other intelligence analyses which may be supported by a movement analysis. Intelligence officers are brought to ARI and are presented with the problems under one of three conditions:(1) they are given a standard 1:50,000 map of the relevant area as well as appropriate speed tables, etc., from the Handbook on Agressor (Department of the Army, 1973); (2) they are given an additional map overlay highlighting the road network and a capability for accessing a computerized data base to determine the length of any given road segment; or, (3) they are given full use of MOVANAID.

Three aspects of the user interaction with MOVANAID are examined. First, it is of course interesting to know the extent to which MOVANAID improves (or leads to a decrement) in the users' ability to produce intelligence analyses. It should be noted that "improvement" here refers to accuracy and not speed; as mentioned earlier, the adequacy or appropriateness of a speed/accuracy trade-off can only be evaluated in a specific operational context where the cost of the different types of errors can be estimated. Thus, if the users working only with the map and using standard procedures are able to accurately describe enemy capabilities but take five hours to do so, a MOVANAID user's ability to achieve the same result in 30 minutes would not constitute, in and of itself, a sufficient argument for the implementation of MOVANAID.

A more critical questionis the extent to which an analyst provided with MOVANAID will take advantage of the aid's capabilities to produce answers to questions which would not be asked in a manual system. We might expect that an analyst following standard procedures would make a rough estimate of likely travel times for enemy units on the most obvious routes. We would hope that, with MOVANAID, an analyst would evaluate enemy capabilities using several well defined alternative routes developed through interaction with the aid.

A third area of concern is the users' subjective reaction to MOVANAID. At the lowest level, this would include whether or not they find it convenient to input data or to choose among MOVANAID options. At a higher level, this would include whether or not the users trusted the output from the aid (Halpin, Johnson, and Thornberry, 1973). While many of the factors affecting such subjective reactions may be manipulated, it is necessary to determine whether or not the basic concept is acceptable to the intended user, apart from questions of procedural matters affecting the convenience of use.

Extensions to MOVANAID

The primary purpose of MOVANAID in its present form is simply to determine whether such an analytic aid for intelligence processing in a TOS environment is reasonable and feasible. Clearly, it is not in its present form capable of solving the most complex problems which can be imagined. To enhance the capability of the aid as it might be implemented in the TOS, many generalizations and extensions are possible for both the fastest path and the assignment algorithms. Also, many enhancements of the interface between user and aid are possible.

The fastest path algorithm could, for example, be expanded to identify not only the fastest path, but the second fastest path, third fastest path, and so on. A more interesting direction for generalization would involve relaxing the (heretofore implicit) assumption that a military unit can move along a road <u>en masse</u>. Normally, this does not occur for at least two reasons. First, the tactical situation may dictate that movement be accomplished in a columnar formation of gap-separated segments or "serials". Second, columnar movement along a road may be forced on a unit whose size is large compared to the capacity of the road. Treatment of the latter phenomenon would, of course, require the expansion of the algorithm to treat route capacities.

The assignment problem can also be generalized in several ways. One of these is to allow the possibility that two or more units moving simultaneously through the network might interfere with each other by occupying the same arc or node at the same time. Delays resulting from this interference would then affect the choice of fastest path as well as the minimum travel time. Another useful extension to the algorithm would be the provision that some or all of the destinations could be recipients of more than one traveling unit. An enriched model of this type would be applicable, for example, in cases where it was thought that the enemy would like to reinforce frontline units with more than one reinforcement unit with some frontline units perhaps being more heavily reinforced than others.

Finally, the aid/user interface could be modified, in particular through the addition of graphic CRT terminals as input/output devices, to facilitate and encourage the full use of MOVANAID capabilities. If the user were able to indicate start points, destinations, and map sectors of interest with a simple wave of a light-pen, and if the output were displayed as a highlighted route through a graphic network display rather than as a string of node lables, then we would expect that utilization might be increased.

Summary

An analytic aid for the evaluation of enemy movement capabilities has been developed. MOVANAID can currently handle minimum path and assignment problems on the basis of pre-loaded data and information input in real-time by the user. The ARI evaluation of MOVANAID will focus on issues of the user interaction with the aid. In this way the concept of an on-line aid in support of intelligence analysts may be evaluated and the value to the Army user of the operational research techniques incorporated in MOVANAID may be determined.

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Simulation of Assault Tactics in an Urban Area

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INTRODUCTION

The purpose of this paper is to describe an urban warfare modeling and analysis effort being performed at the Rodman Laboratory, Rock Island Arsenal.

The subject of urban warfare has been receiving increased attention in the last few years because of the accelerated urbanization of the world and the decrease in the amount of open spaces. This development has caused concern about the effectiveness of present weapons and tactics in an urban environment.

For our purposes, urban warfare is defined as combat that takes place within built-up areas, such as; hamlets, villages, suburbs of large cities, and within the cities themselves. The level of combat can vary from riot control to full scale conventional non-nuclear warfare. In general, urban warfare develops into small unit actions which place maximum responsibility on the squad and platoon leaders. With this in mind, we have developed a stochastic, event-sequenced, squad level, URBan WARfare computer simulation (URBWAR) with the intended purpose of evaluating the effectiveness of both existing and conceptual weapons in an urban environment. Currently, the scenario being employed describes an assault squad attacking a defended building.

SCENARIO

One squad is defending a face of a two-story brick building (commercial) approximately 20 X 20 meters (see Figure 1). For the analysis documented in this report, this squad consists of eight riflemen armed with AKMs and a light machine gunner armed with an RPK. One of the riflemen is designated the squad leader, and in the defense he is on the second floor. In theory, this position would allow him to communicate with his elements on the roof and first floor.

The other squad is located in an identical building directly across the street. The mission of this squad is to attack the defended building. In the attack, a rush team attempts to cross the street in preparation for entering the building and eliminating its occupants. This squad consists of nine riflemen armed with M16s, one of which is the squad leader, and two grenadiers armed with M16/M203s. For this preliminary scenario, the offensive squad doesn't have a machine gun because in the future we are going to compare the effectiveness of this squad with one that has a machine gun.

The defending squad is located on the roof, in the rooms, and in a front hallway on the first floor is the machine gun emplacement. The assaulting squad has a cover team providing fire, from the roof and rooms in the form of grenade and rifle fire. The rush team is located outside of its building and attempts to rush across the street to the same side of the opposing building; they do not fire on the move.

This is the basic scenario for which the first component of the math model was written.

MODEL

Within the model, there are presently three decision making routines: detection, movement, and fire.

Main control assigns uniform random detection and movement times between 0 and 1 second depending on the input intelligence scheme; (a) Neither side knows the other exists or both know that each exists; (b) Offense only knows; (c) Defense only knows.

When one side begins firing the opposite reacts to this with detection, self-defense, and firing events.

Sectors which are believed to be unique with this model are used for detection and fire delivery events. These sectors result in a form of fire control, in that, an element is resticted to detection and fire only within his assigned sector. A sector is defined as a parallelepiped, referenced by four vectors, and corresponding to one "chunk" of built up area. Some sectors contain streets, and others contain parts of a building. The "scanning" of these sectors is measured in time and is used to determine the time of firing should a target be detected.

The detection controller checks to see if the element N already has a target, if not, information on potential targets for N is sought by checking presented areas, whether the enemy is in the street, and mobility aspects of the opposing force. Based on this, a decision is made whether a target exists. If it does exist, a fire clock is set. If no targets exist, a future detection event is scheduled.

The main controller selects the next event by locating the smallest event time in the time arrays. Should the next event be a movement event for N, the following is currently considered: (a) is N suppressed? If so, release him, give him a detection time and once more make him vulnerable to enemy fire; (b) is N on an assault team? If so, is his team waiting to cross the street. If the time to rush is now, objectives are set up, mobility flags are set, and velocity direction vectors are established. Another move event for N is scheduled. In addition to the rush movement, the model allows for movement when an element takes cover. It is assumed he has moved to a position where he cannot be detected, such as behind a wall.

The fire controller, which is used when N has a target, is primarily responsible for determining the type of fire which N will employ. The following types of fire are currently simulated: Quick Fire, Personal Protection, Grenade (M79 Type), and Sweep or Area Fire. These fires are for such weapons as pistols, semi-automatic rifles, automatic rifles, machine-guns and grenade launchers.

Assuming fire will be made on a target, aiming error and ballistic error are loaded into the firing model. In addition, a check is made to see whether ammunition is available. If ammunition is available and the weapon is empty, a time delay for reload is signaled. After we are assured the weapon is loaded, a target check is made to see if our target is still available, if it is, a call to the firing model is made.

The fire model takes projectile mass, velocity, height and width of visible target and computes a probability of a kill. Lethality is then checked for casualties comparing a random number against calculated probability of a kill. There is no other form of incapacitation at the present in this model, hence no wound characteristics.

If the target has survived, a self-defense routine is retrieved for the target to determine what action, if any, should be taken. Available actions include: take cover, return fire, continue fire at current target, or fire at someone crossing the street if this situation presented itself.

A decision by the firer whether to continue fire at the same target or another target is made, clocks are updated, and the next event is selected. In the current model, the defense is encouraged to stop street assaults at all cost, thereby exposing themselves to more than the usual fire.

The other routines do bookkeeping, create data, make decisions, and perform vector operations.

ANALYSIS

Employing this model and the scenario, an investigation into the dynamics of attacking across a street has been conducted. For this investigation it was assumed both sides have intelligence of the other side. That is, both sides are aware of each other. The offense consisting of eleven men armed with M16s and M16/M203s open fire first, defense react shortly thereafter. Four rush tactics were considered in the investigation:

a. All at once (base case)

b. 3 rush, then 2 rush

c. Rushing elements go one at a time

d. Alternation of rushers at opposite corners, 3 at one, 2 at the other

The defended building and its features (walls, hallways, floors, doors, and "holes") are shown in Figure 2, with the initial defense positions. Windows and doors are assumed to be open and are referred to as "holes".

For the purpose of this investigation, the following conditions were established:

CONSTANTS

a. Rush velocity @ 6.1 m/sec

b. Weapon mix

c. Intelligence, i.e. both sides know

d. Time to cross street (i.e. begin the crossing)

e. Machine gun fires automatically, rifles fire semi-automatically.

Continuing investigation will include automatic rifle fire.

VARIABLES

a. Rush tactics (the four enumerated earlier)

b. Street widths (7m, 15m, 30m, and 40m)

CALCULATIONS

a. Casualties in rush team as a function of street width & tactics

b. Casualties of cover team as a function of street width & tactics

c. Casualties of defense as a function of street width & tactics

d. Force ratio=alive offense/alive defense, a function of street width, tactics, and battle time.

The results of the preliminary investigation into the effects of rush team tactics and street width on the casualties produced by the offense and defense are shown in Figures 3 - 6. Figure 3 shows expected rush team casualties, Figure 4 expected cover team casualties, Figure 5 expected defense casualties and Figure 6 expected force ratio (live offense/live defense) at the end of the battle.

The rush team casualties, as shown in Figure 3, are sensitive to type of tactic and street width. Of the four tactics checked; (1) rush all at once from the same location, (2) rush three then two from the same location, (3) rush one at a time from the same location and (4) rush three then two in alternation from different locations.

The best tactic appears to be the one presently employed, i.e. tactic number one. The worst tactic is number four with very little to choose between two and three. All four tactics are sensitive to street width. Number four is the most sensitive and little difference is seen between two and three. There is very little difference between one, two and three up to a street width of approximately sixteen meters, in fact, the expected casualties is almost constant. Between sixteen and thirty meters, these three tactics show an increase in casualties with tactics two and three having a greater increase than tactic one. Between thirty and forty meters, all tactics show a slight decline in expected casualties, the least decline being shown by tactic four. It is believed that the reason for this decline is due to the use of firing sectors which by their very nature force a form of fire discipline on the battle. For tactics one, two and three, only the defensive elements on the side of the building being rushed can fire at the rush team and as the street width increases the chances that these defensive elements, whose responsiblity it is to engage the rush team, are suppressed or killed, increases. For tactic four, where the rush team is split, the defense from both sides of the building can engage the rush team and basically negate the affects of defensive suppression and incapacitation and increase the affect of the fire discipline enforced by the firing sectors.

Another way of looking at these results, is that, for tactics one, two, and three, approximately four of the five rush team elements will be alive to initiate building clearing operations, as long as the street width is sixteen meters or less. At thirty meters, approximately two elements will be alive for the first three tactics and only one for tactic number four.

Figure 4 indicates that the cover team casualties are basically insensitive to type of tactic employed by the rush team and street width. This could have been expected because the cover team performs the same functions regardless of the type of tactic employed by the rush team. Again the casualties appear to be approximately constant up to a street width of sixteen meters and then they increase between sixteen and thirty meters and are approximately constant between thirty and forty meters.

The defensive casualties shown in Figure 5 show the same insensitivity to rush tactic as the cover team casualties, again a result that could have been expected. The defensive casualties are more sensitive to street width, than are the cover teams. As the street width increases, the defensive casualties decrease at least up to a street width of thirty meters at which point a slight increase in casualties is evident, which is inverse to the decrease shown in Figures 3 and 4.

The expected force ratio at the end of the battle, Figure 6, shows more sensitivity to rush team tactics than either Figures 4 and 5 and also more sensitivity to street width. It also shows that tactic four, which is the worst tactic for the rush team results in a higher force ratio for street width up to approximately ten meters and from that point on it is the poorest tactic. Tactics one, two and three result in almost the same force ratio with two being the best up to a twenty-eight meter street width and one for street widths greater than twenty-eight meters. Tactic three is always equal to or less than either of these tactics and could be considered to be dominated by one and two.

FUTURE CONSIDERATIONS

A simulation in its infancy always has a need for expansion. The following are some of the areas that will be included in the simulation.

a. Sniper fire

b. Optical contrast (day & night) against a variety of objects

c. Increased mobility by both sides

d. Entering a building

e. Room to room search

f. Reflexive actions

g. Weapon retrieval and combat assistance to wounded "friendlies"

h. Hand signal communications

i. Hand delivered grenades

j. Non-lethal weapons

Interaction is a by-word these days in simulation work. Therefore after considering and studying the results of the "restricted" environment, more buildings and more difficult conditions will be added. Structures placed between buildings (trees, cars) will hinder detection capabilities. Several elements "holing up" in a rubble pile will add interest and problems. One of the greatest handicaps of all, will eventually involve the placement of the local citizens in the scenario and how they can help, hinder, or remain indifferent and the problems we have to solve their presence.

In the present stage of the problem, continued sensitivity will be studied in the area of different weapon mixes, different soldier emplacements, different numbers of men on the cover and rush squad. Changing the opening fire strategy and intelligence situations will also be analysed.

ACKNOWLEDGEMENTS

I would like to thank Mr. Jack Manata for guidance and assistance on this study.

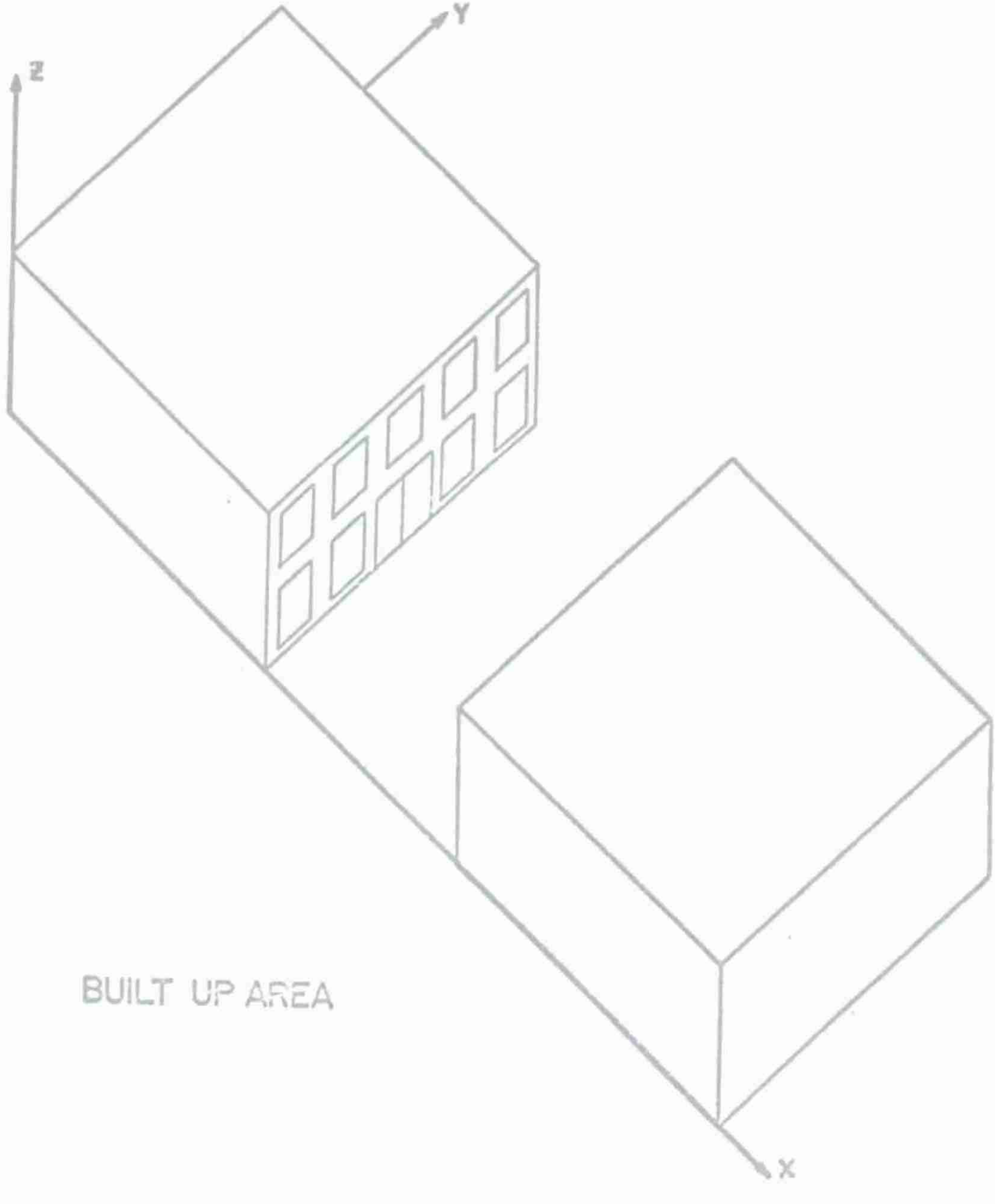

Figure 1 Scenario Built-Up Area

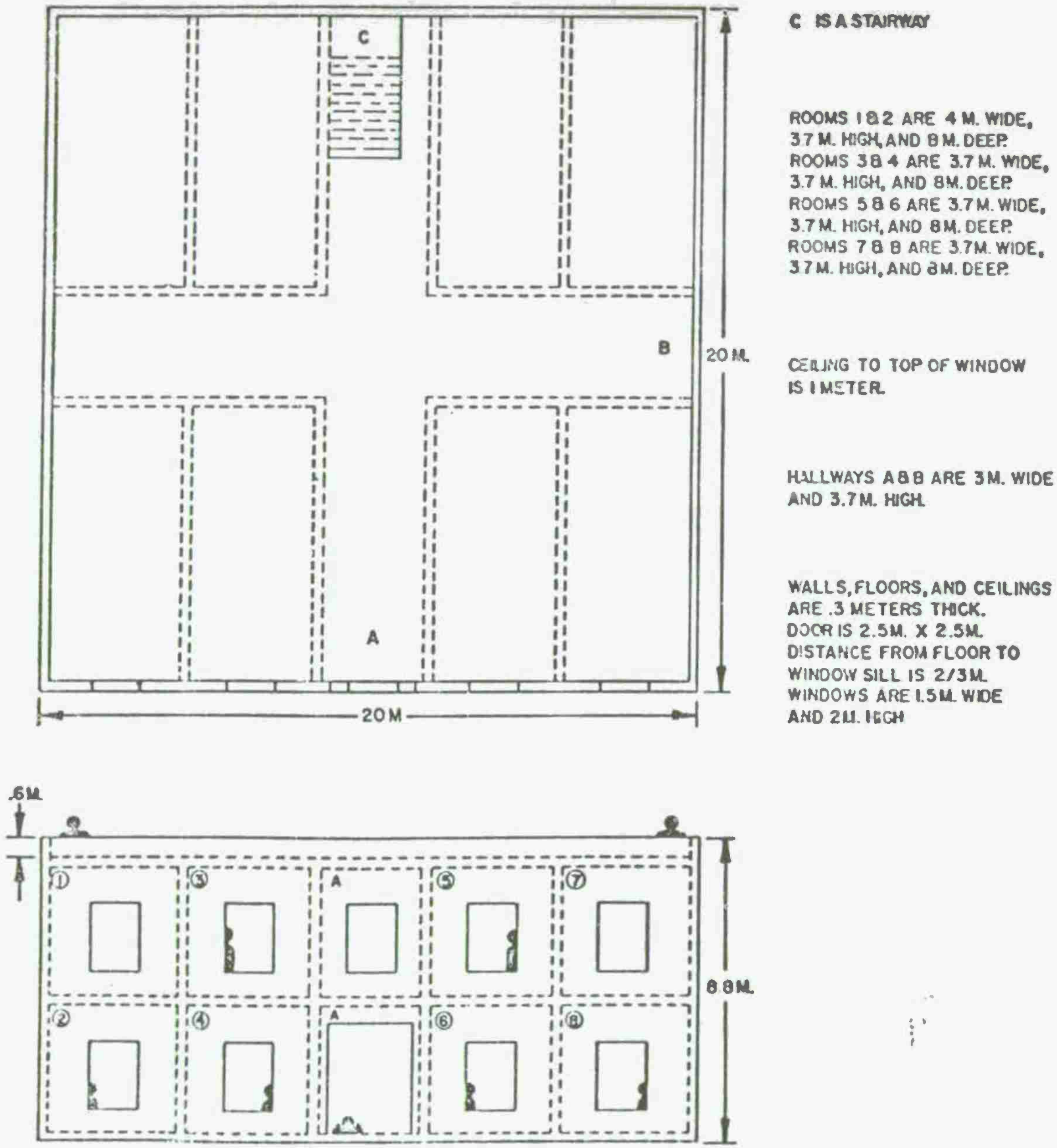

Figure 2 Building Layout and Location of Defensive Elements

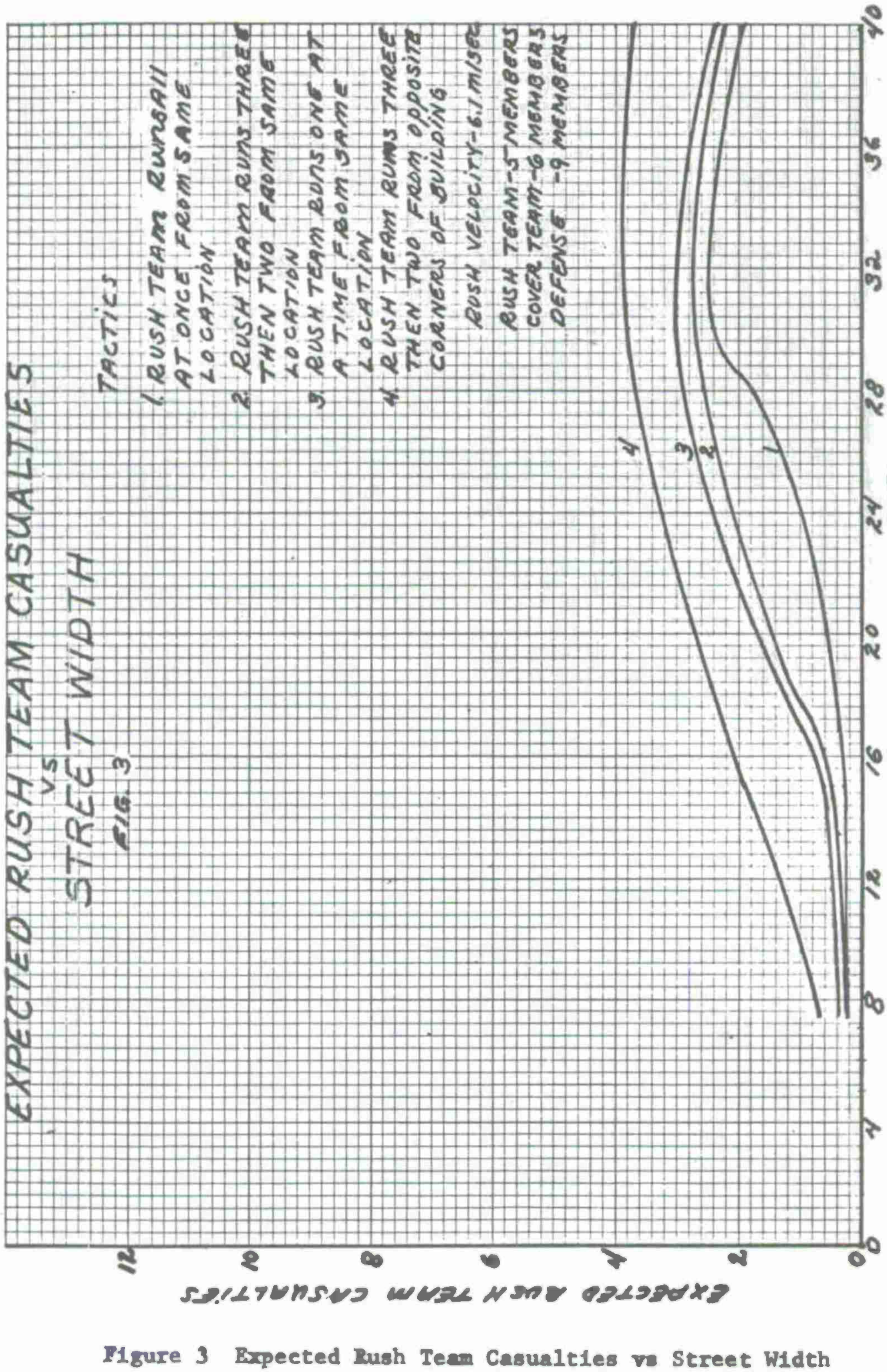

Figure 3 Expected Rush Team Casualties vs Street Width

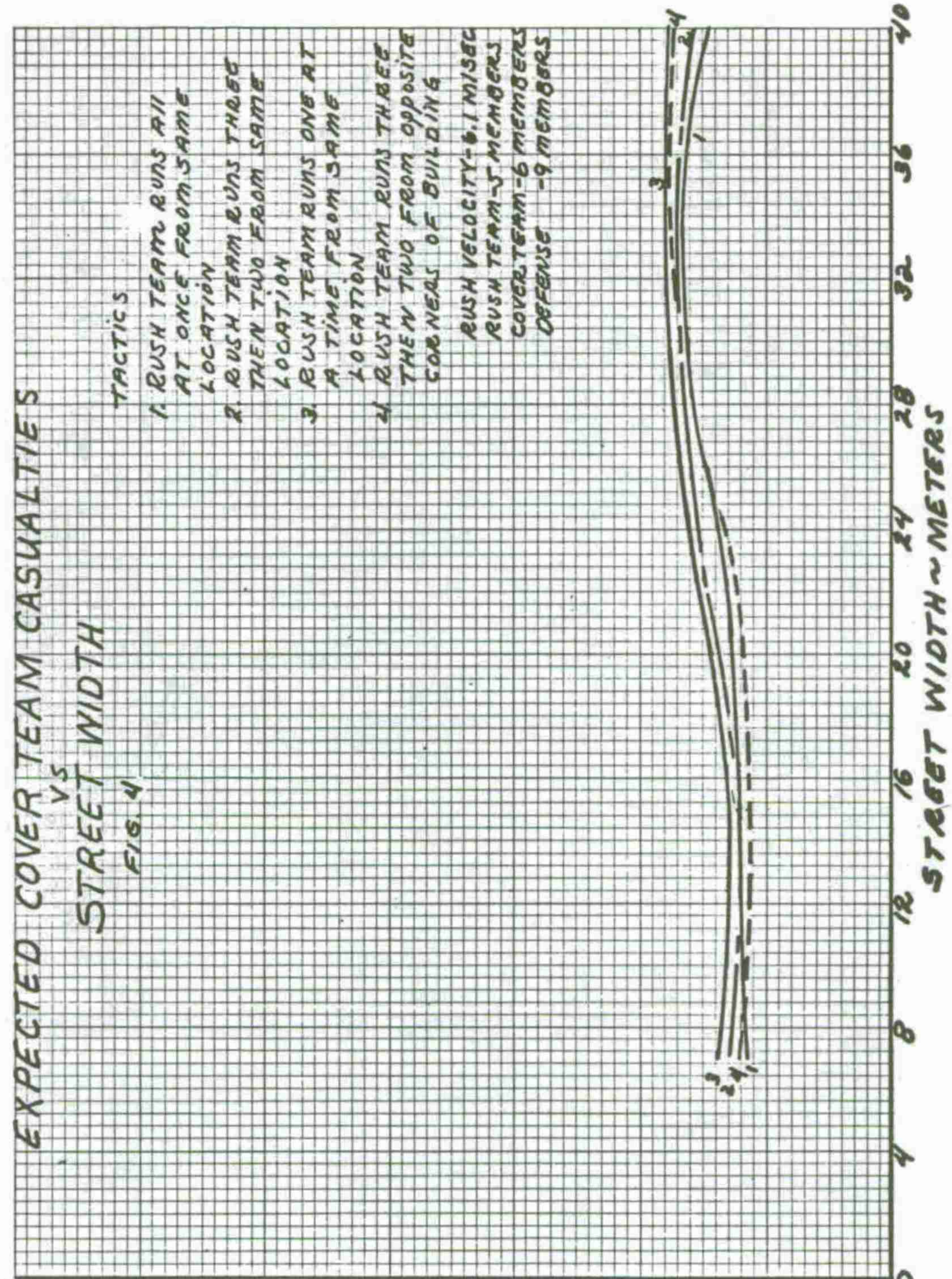

Figure 4 Expected Cover Team Casualties vs Street Width

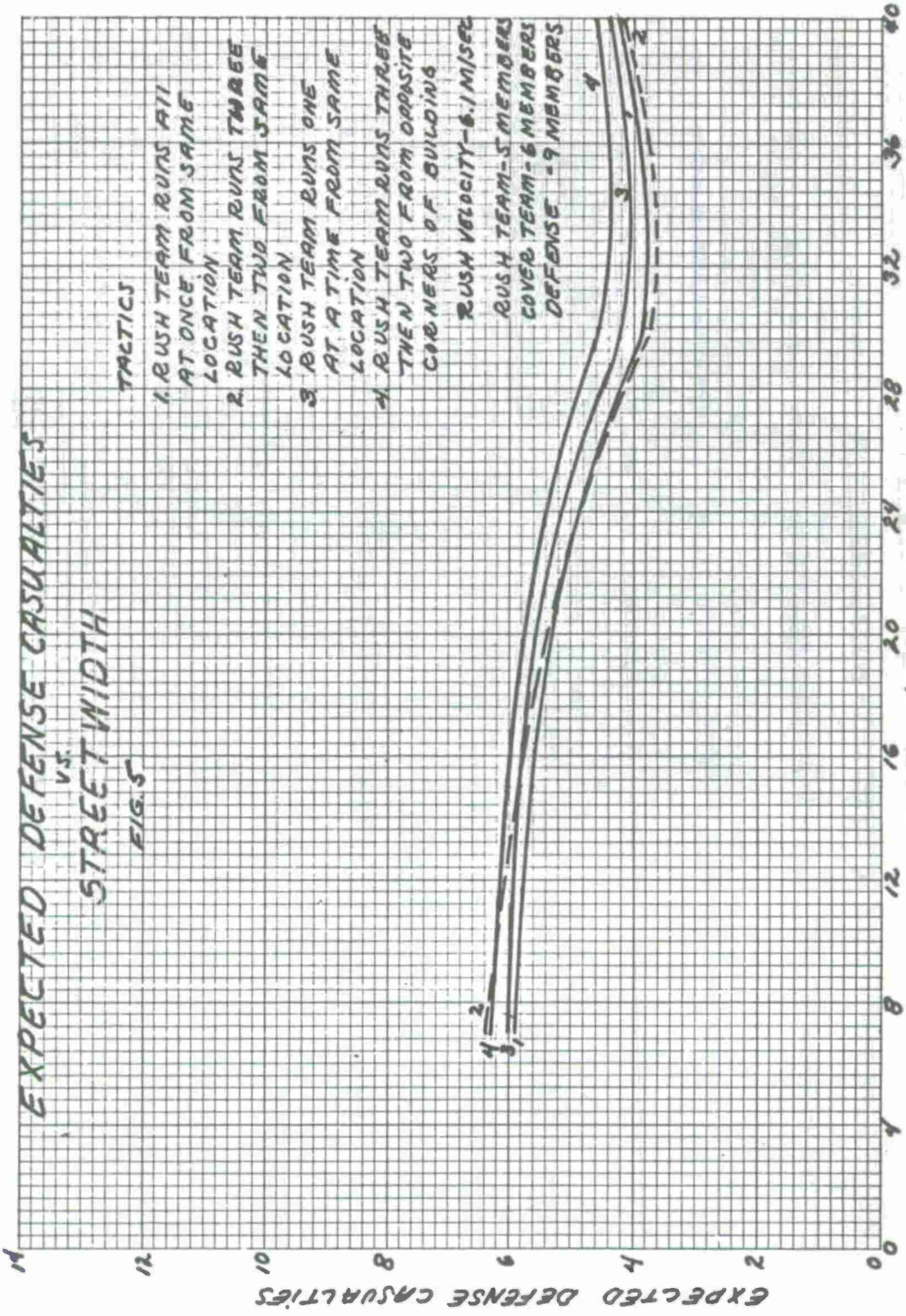

Figure 5 Expected Defense Casualties vs Street Width

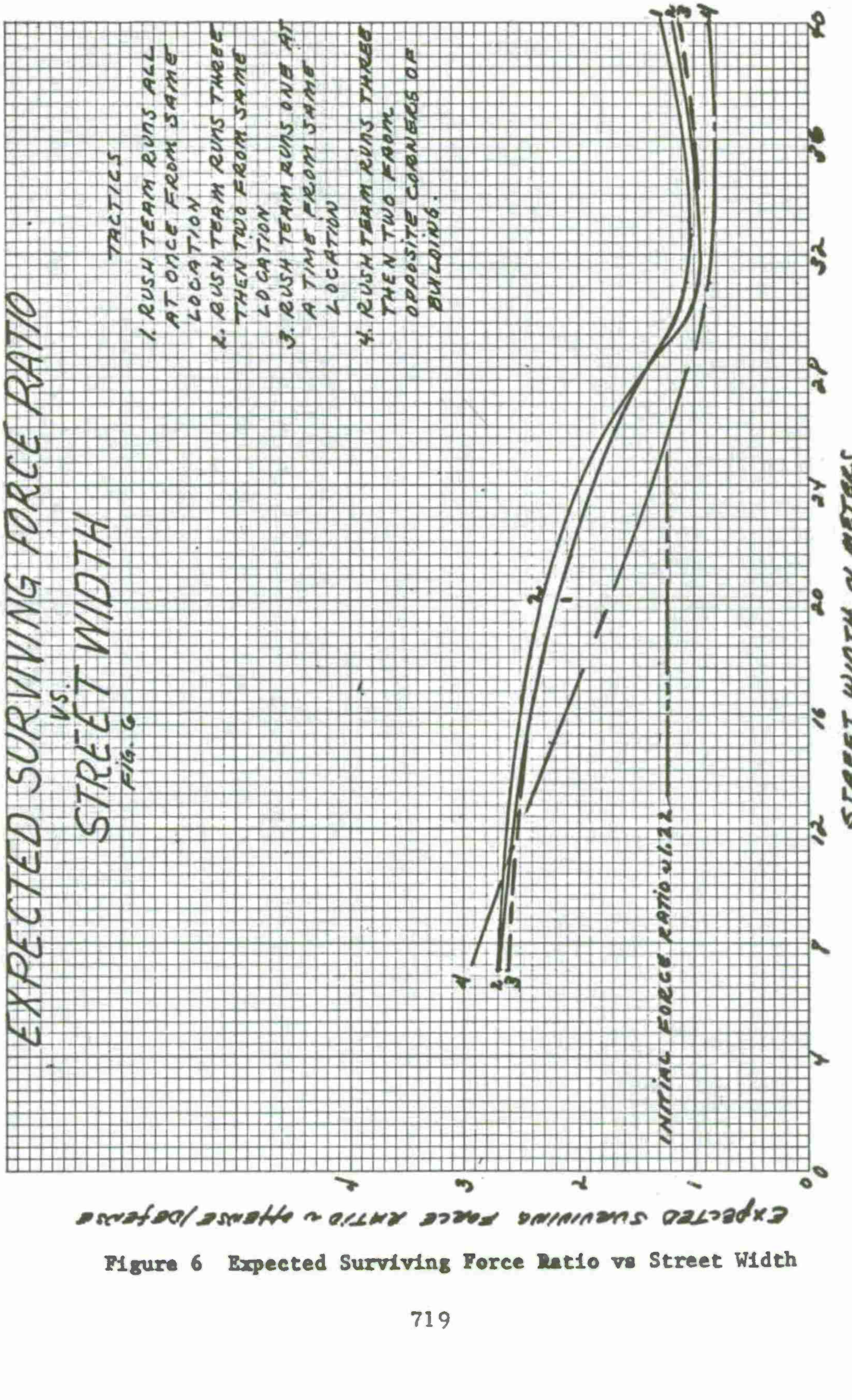

Figure 6 Expected Surviving Force Ratio vs Street Width

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MODELING TACTICAL NUCLEAR REQUIREMENTS: AN APPROACH

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ABSTRACT

The United States Army Concepts Analysis Agency has undertaken the development of a system, called the Nuclear Requirements Methodology (NUREM), which will result in improved analysis of tactical nuclear requirements. The philosophy behind NUREM and the system design of a major NUREM automated model, the Nuclear Fire Planning and Assessment Model (NUFAM), are discussed in this paper.

INTRODUCTION

In January 1974, the United States Army Concepts Analysis Agency began reviewing various ways to estimate the number of tactical nuclear warheads required within a theater. The purpose of this comparative review was to determine the feasibility of developing an improved approach for calculating tactical nuclear requirements. By April 1974, an approach had been outlined. The study sponsor, the Deputy Chief of Staff for Military Operations and Plans, then directed the development of this concept, called the Nuclear Requirements Methodology (NUREM).

COMPARATIVE REVIEW

In the comparative review portion of the study, two general observations were made:

First, existing tactical nuclear wargames and simulations are the best available tools for investigating a single "combat sample"*.

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*The following terms are used in this paper to describe the simulation of a limited portion of the battlefield:

Combat Sample: An engagement, over a variable period of time, by two opposing forces in a specified array.

Combat Sample Results: Both BLUE and RED casualties, equipment losses and nuclear expenditures which result from a specific combat sample.

Second, nuclear planners often discount the results of fully automated models due to the rigid decision rules these models employ. Therefore, it was felt that the credibility of a computerized tactical nuclear model could be improved if nuclear planners were more actively involved in ascertaining alternatives to commit major forces to escalate or to terminate the war.

These observations became fundamental to the design of the Nuclear Requirements Methodology.

NUCLEAR REQUIREMENTS METHODOLOGY (NUREM)

The NUREM process can be described in terms of combat sample analysis, combat sample results, scenarios, theater extrapolation and a possible requirement. A schematic of this process is at Figure 1.

Combat Sample Analysis. - Combat Sample Analysis concerns the detailed gaming/simulation of a discrete portion of the tactical nuclear battlefield. For example, a BLUE corps defending against a RED army for a 24-hour period could be the basic elements used to define a specific combat sample. The basic elements could be enlarged by considering factors such as force nationalities, force postures, terrain, nuclear delivery means and nuclear options open to both sides.

Combat Sample Results. - These results are the end products of a combat sample analysis. Specifically, the combat sample result is a summary of nuclear expenditures, personnel casualties and equipment losses. NOTE: The design of this portion of the methodology is based on building a large number of combat sample results. Enough combat sample results must be available to reasonably approximate a spectrum of possible nuclear exchanges.

Scenario. - A scenario traces the course of a nuclear war through hypothesis of the type of nuclear action which would take place throughout the theater on each day. Stated in terms of combat samples, the scenario defines the day-by-day ordering of combat samples along the front.

Theater Extrapolation. - A theater extrapolation sums the casualties, losses and nuclear expenditures over the duration of the war as specified in the scenario.

A Possible Requirement. - The primary output from a theater extrapolation: the total numbers, by type, of nuclear rounds expended at the conclusion of the war. Analagous to the concept of developing a number of combat sample results, the NUREM design provides for the generation of many possible requirements. Through

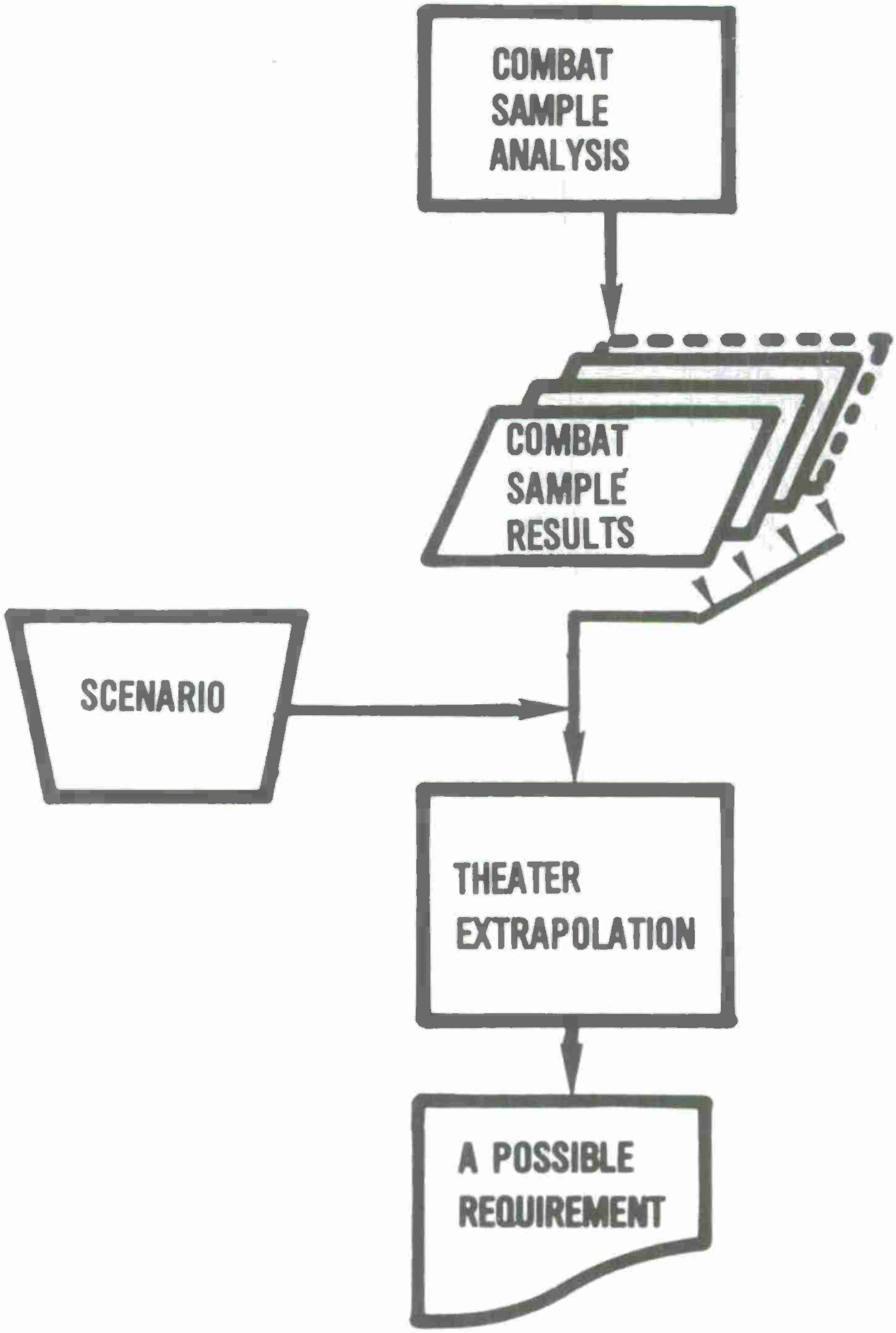

FIGURE 1, The NUREM Process

variation of scenarios and combat samples the decision maker will ultimately be provided with a range of stockpile requirements scaled to varying combat situations.

NUREM MODELS*

Figure 2 depicts the logical relationships among the five computerized models which perform the NUREM process. The models in this figure are classified by function: combat sample analysis and theater extrapolation.

Combat Sample Analysis. - Combat Sample Analysis models include the Subunit Status File (SUSF), Target Acquisition Routine (TAR), Nuclear Fire Planning and Assessment Model (NUFAM) and the FORECAST II Model.

Based on wargamer input, at present primarily a series of stylized unit arrays, the Subunit Status File is used to create a data base which defines each company-sized unit on the battlefield. The SUSF data base is processed by the Target Acquisition Routine resulting in specific units being detected and becoming potential targets for the opposite side's nuclear weapons.

The Nuclear Fire Planning and Assessment Model simulates the results of a nuclear exchange for a specified combat sample.

The last model in the system, FORECAST II, assesses collateral damage to fixed targets and civilian population centers.

Theater Extrapolation. - The theater extrapolation model is the Nuclear Requirements Extrapolator (NUREX). The NUREX will determine a possible nuclear requirement by summing the appropriate combat sample information, adding reinforcements and committing reserve forces as specified in a scenario.

The bulk of the NUREM modeling effort has been concentrated on development of the Nuclear Fire Planning and Assessment Model (NUFAM). The remainder of this paper is focused on the NUFAM design.

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*The proposed NUREM is a hybrid which draws on the strong points of three existing nuclear and conventional models: Tactical Nuclear Analysis System, USACAA; Theater Rates Model, Nonnuclear Ammunition Rates Methodology, USACAA; and Simulation for the Assessment of Tactical Nuclear Weapons (SATAN), Studies Analysis and Gaming Agency, Office of the Joint Chiefs of Staff.

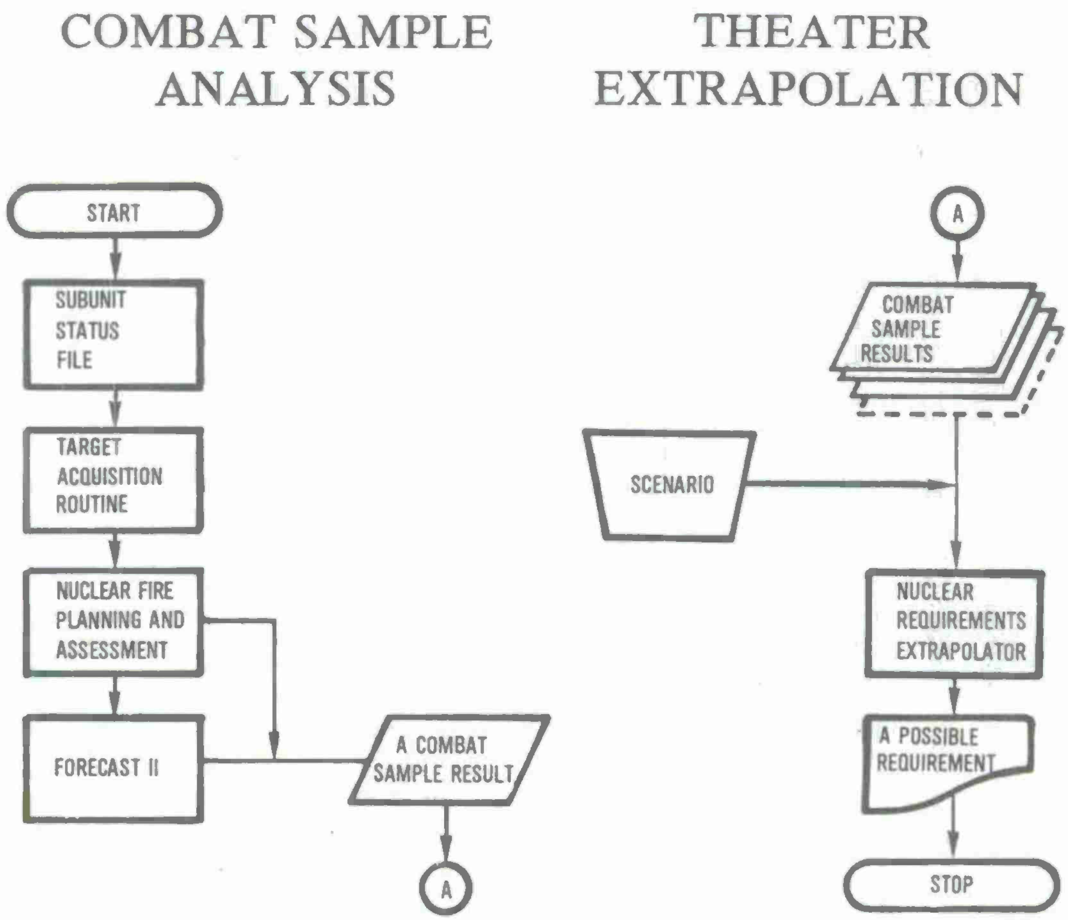

FIGURE 2, The NUREM Models

NUCLEAR FIRE PLANNING AND ASSESSMENT MODEL (NUFAM)

Functions. - The NUFAM simulates the nuclear exchange for a given combat sample by performing three broad functions: fire planning, dynamic human interaction and damage assessment. The relationships among these functions are shown in Figure 3.

a. Fire Planning Function. - The fire planning function controls the scope of the tactical nuclear exchange and the allocation of nuclear resources to battlefield targets.

b. Human Interaction Function. - The human interaction function was designed into the model to accomplish the following three goals: First, to subordinate the "automated" fire planning process to human judgment. Second, to introduce a high degree of flexibility to the testing of nuclear options. Finally, to dispel some of the "black box" aura that surrounds battlefield simulations by placing a man "in the loop."

c. Damage Assessment Function. - The damage assessment function simulates warhead delivery and calculates the damage which results from the simulated detonation of each nuclear round.

Event Sequencing. - The flow of information through the three functions--fire planning, human interaction and damage assessment is controlled by an "event stepping" technique. Through this technique the model represents the tactical nuclear battlefield as a series of discrete events. The sequencing and processing of events is accomplished automatically within the model by an application of the GASP (General Activity Simulation Program) IV Simulation Language.* During model design it was felt that the GASP IV was especially well suited for NUFAM for the following reasons:

- The GASP IV package provided fully programmed event filing and timing structures.

- The GASP IV, a series of FORTRAN subroutines, could be readily integrated with an existing FORTRAN nuclear assessment program to form the NUFAM nucleus.

- A FORTRAN based model could have greater "convertibility" to other computer systems than a model which required a specific simulation language compiler.

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*The GASP IV Simulation Language, Pritsker, A. Alan B., John Wiley & Sons, Inc., 1974.

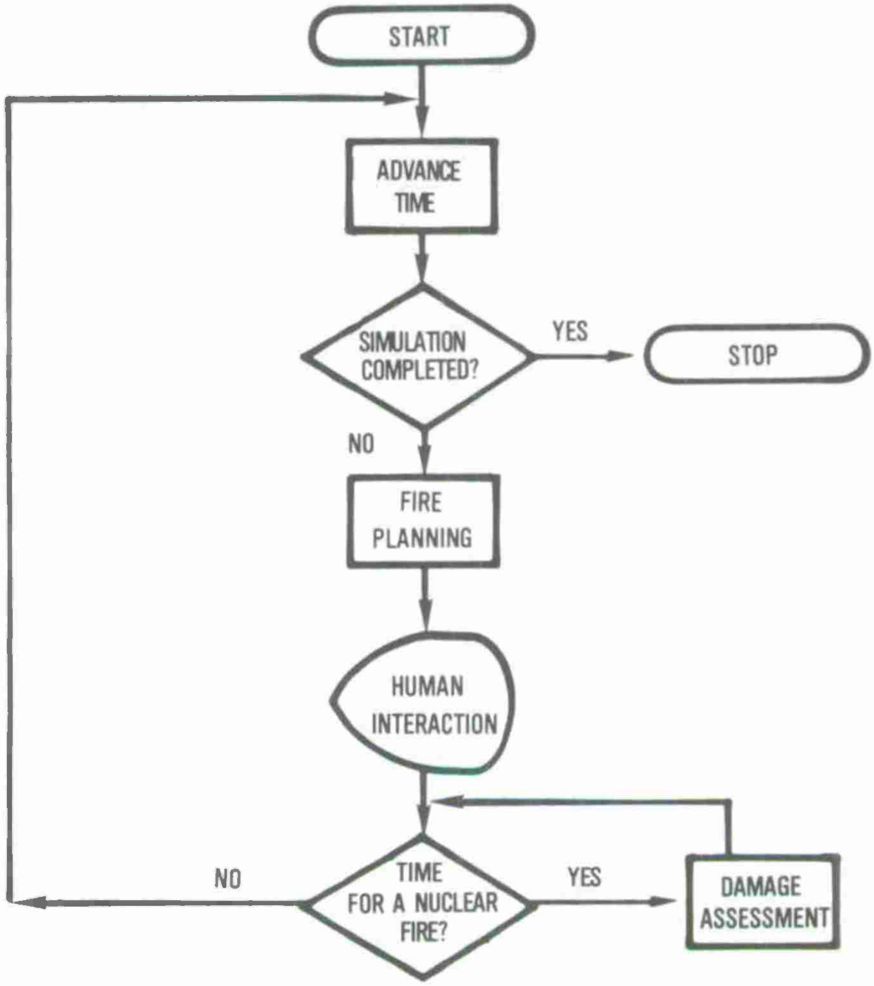

FIGURE 3, NUFAM Functional Flow

THE NUFAM SIMULATION

In this section the discussion is concentrated on the simulation of the three NUFAM functions (fire planning, human interaction and damage assessment).

Fire Planning. - Simulation of the model's fire planning function is accomplished in two operations: control of battle scope and intensity, and nuclear fire order generation.

a. Control of Battlefield Scope and Intensity. - The primary means of controlling the scope and intensity of the nuclear exchange is by automated selection of targets. At the beginning of the simulation, each unit "detected" by the opposite side is considered as a potential nuclear target.* Selection of a specific detected unit as a nuclear target is based on input parameters such as unit priority, unit-to-FEBA distance and timelinesss of intelligence. For example, consider a situation where a possible nuclear option is a limited "show of force." The intensity and scope of the exchange could be scaled down by designating, as nuclear targets, only a limited number of high priority units in close proximity to the FEBA. The opposite extreme would be a high intensity exchange. In this case, an unlimited number of units throughout the theater could be engaged--limited only by target detection capability and survival of nuclear delivery systems. By varying the selection parameters essentially any intensity of exchange can be simulated. A secondary means of controlling the scope and intensity of the exchange is by user introduction of any number of preplanned targets. Since preplanned targets are represented as the location of a desired ground zero (DGZ) this gives the model the flexibility to integrate strikes against both fixed and land mobile targets.

b. Nuclear Fire Order Generation. - After the entire list of detected units has been processed--in order to select those nuclear targets which are acceptable in terms of the battle scope and intensity constraints--two operations occur. First, each nuclear acceptable target is introduced into the simulation at the time it is "detected." Second, at "detection" time the model attempts to generate a fire order for an opposing nuclear delivery

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*At this point, it is emphasized that NUFAM is part of a system of models. Prior to the NUFAM simulation the Subunit Status File and Target Acquisition Routine, respectively, have been used to produce a detailed data base of all battlefield units and a list of all units "detected" by the opposing sides.

system. The following approximates the major steps NUFAM uses to generate a fire order:

- o The NUFAM obtains the five priority delivery system/warhead combinations which the user has specified as desirable for the target type under consideration.

- o The model then considers every firing unit, on the firing side, which possesses the highest priority delivery system/warhead combination. The specific firing unit which will be selected to fire is the one that

  - has not been destroyed by a previous nuclear shot.

  - meets all range and safety constraints.

  - is perceived by the firing side as being able to deliver its nuclear round on the target sooner than any other firer. (Ties are broken by selecting the system which can achieve the smallest minimum safe distance.)

- o If the model cannot locate a suitable firer which possesses the highest priority delivery system/warhead combination, lower priority combinations are exhaustively considered. Since the combinations are arranged by order of priority as soon as a "best" firer is found, within a combination, it becomes the model's candidate firer to allocate against the target.

- o Before generating a fire order for the candidate firing unit, the model is designed to allow dynamic human interaction. (The human interaction function is discussed below.)

- o After human interaction, if any, NUFAM creates either a flee or a fire event.

  - A flee event occurs when the nuclear target is lost from the firing side's observation. (Any nuclear delivery system allocated to a "fleeing" target is unavailable for use against other targets until the flee event occurs.)

- A fire event is scheduled when simulated launch time occurs before simulated flee time. (The processing of a fire event will be discussed in the damage assessment function.)

Human Interaction. - The implementation of the "man in the loop" concept has been facilitated by a software package of FORTRAN-callable display generator routines known as UNIGRASP (UNIVAC Interactive GRAphics Support Package). Through integration of UNIGRASP, GASP IV and FORTRAN techniques the analyst/planner is presented with a graphic display* representing the current status of the NUFAM simulation. This cathode ray tube (CRT) display is the input/output medium through which the user may influence the simulation. The CRT display provides two operational modes: zoom-in and zoom-out.

a. Zoom-In Mode. - In this mode the user can zoom-in on a very small portion of the battlefield (for example, a battalion sector) for fire planning a specific nuclear target. While observing the CRT the planner may dynamically accept, reject, or modify a fire order generated during NUFAM fire planning. Modification can be made by shifting the computed point of impact to offset the DGZ from population centers; or to damage multiple targets with a single shot; or to select a different firing system. The following elements of the graphic display aid the user in making the above decisions:

- o Location and shape of the target under consideration.
- o Locations and shapes of other nuclear acceptable targets in the vicinity.
- o All targets in the vicinity broken by previous nuclear shots.
- o Nearby population centers.

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*Graphics applications are shaped by the characteristics of hardware to a greater degree than more conventional computer applications. The USACAA configuration consists of a UNIVAC 1108 mainframe (196K of 36 bit words in central memory), a drum, ten disk drives, and the usual peripheral devices for system I/O. Three of the nine CRT terminals in the systems are UNIVAC 1557/1558 interactive graphic terminals.

- o Previously fired nuclear rounds.

- o The desired ground zero (DGZ).

- o Two representative "effects circles," centered at the DGZ, of the firing system/warhead combination currently under consideration.

b. Zoom-Out Mode. - The second mode available to the planner furnishes a zoom-out capability. Here the user can zoom-out from the battalion level of resolution to study the situation at brigade, division or corps level. In this mode the user may

- o Determine areas in which future nuclear shots should be rejected or modified.

- o Determine times at which potential escalation boundaries are reached.

- o Determine when to halt the exchange.

Damage Assessment. - The NUFAM damage assessment function is initiated when simulation time advances to a fire event. Damage assessment will be described as two operations: warhead delivery and battlefield assessment.

a. Warhead Delivery. - Warhead delivery concerns the success or failure of nuclear warhead launch and detonation. First, the model checks to ascertain if the firer still survives. Second, the firing system's ability to deliver a successfully detonating nuclear round is simulated. If the firer has been destroyed or if the system fails the reliability simulation, an immediately available target event is created. Upon creation of an immediately available target event, information on the target is provided to the fire planning process for generation of a new fire order. Alternatively, if the firer is still viable and passes the reliability simulation the battlefield assessment operation is initiated.

b. Battlefield Assessment. - Battlefield assessment of any unit in the proximity of the simulated detonation is accomplished through circle/rectangle overlap calculations. The damage inflicted on both "primary" and "collocated" units is described in terms of

- o Prompt and delayed personnel casualties.

- o Equipment destroyed.

- o Units broken.

Conclusion of the NUFAM Simulation

a. Termination. - The NUFAM continues the simulation until

- o A predetermined simulation time is reached.
- o A specified number of casualties, broken units or nuclear detonation is exceeded.
- o The planner/analyst at the graphics CRT stops the exchange.

b. Model Output. - At the conclusion of the simulation extensive assessment data and simulation event histories are printed. Optionally, CALCOMP plots can be generated as can various statistical summaries. The most critical NUFAM outputs are the numbers of nuclear warheads expended, personnel casualties and equipment losses by side.

USES OF NUFAM OUTPUT

The NUFAM model output is subjected to qualitative analysis and is incorporated into a "combat sample result." Upon repeated use of the model a spectrum of simulations and associated combat sample results are produced. This information then forms the basis for extrapolation of a possible nuclear stockpile requirement.

A STUDY OF THE ARMY'S REQUIREMENTS FOR AIR FORCE CLOSE AIR SUPPORT (ARAFCAS)[1]

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Vector Research, Incorporated

1.0 Background and Military Problem

In 1963 a Joint Army and Air Force Board derived Army requirements for Air Force close air support (CAS) sorties in European and Southeast Asia environments. These quantitative requirements are still being used for planning, and were used in establishing the Army CAS sortie requirements in the Joint Strategic Objectives Plan for FY 1974-81 and FY 1975-82. Because of the many technological, doctrinal, and threat changes which have transpired since the 1963 study, the Combined Arms Combat Developments Activity (CACDA) of TRADOC recently conducted the ARAFCAS study to reevaluate the requirements of committed Army divisions and maneuver battalions for CAS during a mid-intensity conflict in Europe.

This paper describes the assistance that Vector Research, Incorporated (VRI) provided to CACDA via the generation and analysis of parametric information regarding the ability of a committed division to accomplish its mission as a function of the amount of CAS provided. As a means of generating this information, VRI developed the DIVOPS (DIVision OPerationS) combat model, whose structure is described in section 2.0 of this paper. The model was applied to scenarios developed for the study by the sponsor, as described in section 3.0. The insights and conclusions drawn from this application are discussed in section 4.0. The paper concludes in section 5.0 with a description of the military use of the study results, including a discussion of some problems which the study encountered and an indication of ways in which such problems might be avoided in future studies.

2.0 The DIVOPS Model

The model developed for use in the ARAFCAS study is a deterministic non-player, analytic representation of combined-arms activity, which considers interaction among maneuver forces, field artillery systems, air defense weapons, target acquisition sensors, and close air support aircraft in division-level combat. It produces a time history of results of combat (weapon and personnel losses, force locations, supply consumption, etc.) over a period ranging from several hours to a day or more. The DIVOPS model draws heavily from the VECTOR series of theater-level models developed by VRI (see VRI, 1973 and VRI, 1974-1), including incorporation of the differential models of maneuver unit combat and the concept of

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[1]This study was performed by Vector Research, Incorporated, (VRI), in conjunction with BDM Services Company as a part of VRI's subcontract to BDM at the Combined Arms Research and Analysis Facility, Fort Leavenworth, Kansas; the study was sponsored by the Combined Arms Combat Developments Activity of TRADOC.

tactical decision rules, which provide for the use of military judgment in the model's representation of command decisions and related tactical behavior.

In order to meet the schedule of the ARAFCAS study, the model was assembled quickly, and therefore has a number of restrictive assumptions which are described in section 2.1. The model consists of state variables, which describe the status of the combat at any instant in time, and process models which determine how the values of the state variables change. The most important state variables are described briefly in section 2.2, and the process models are discussed in section 2.3. The model's input requirements and output are described in section 2.4.

2.1 Limiting Assumptions of the DIVOPS Model

The ARAFCAS study was a tightly time-constrained effort in which model development and application to a European scenario were required to be completed in a period of four months. During that period a model was assembled which represents many of the important aspects of division-level ground combat with air support. It was necessary, however, to incorporate several limiting assumptions into the DIVOPS model, including the following:

(1) The model includes no representation of air-to-air combat. It was felt that such representation was not necessary to the determination of the requirement for close-air support in terms of number of sorties delivered on target, and that adequate treatment of air-to-air combat would involve consideration of interactions above the level of the division, and therefore outside the scope of the model.

(2) Maneuver force engagements at night are not represented in the model, i.e., no significant combat other than fire support is assumed to occur at night.[2] This assumption was necessitated by the unavailability of appropriate models and data within the study schedule.

(3) Maneuver force engagements at river lines or in urban areas are not represented because the required models and data would not have been available within the study schedule. The European scenario played did not contain river-line combat and contained only one small town for possible urban-area combat.

(4) All effects produced on or by maneuver units at the FEBA are computed in the model for an average unit in a Blue brigade or Red division. It was determined that models containing a more detailed representation of maneuver and firepower processes and also allowing the necessary sensitivity analyses of these processes could not be assembled and run during the period of the study.

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[2]Alternatively, the model can represent night combat as though it occurred in the daytime.

2.2 State Variables in the DIVOPS Model

The state variables of a model describe the relevant details of a "snapshot" of the battlefield at a given instant in time. The more important state variables in the DIVOPS model include the following:

(1) Time is kept track of with two model clocks. Overall time is updated in 15-minute increments.[3] During each increment, activities and fire support allocations can change, force locations are updated, and ammunition inventories and weapon and personnel levels are changed to account for expenditure or attrition. In addition, a more microscopic clock is used during periods of significant maneuver unit combat. This clock updates time in eight-second intervals within a single 15-minute increment,[4] allowing for a detailed representation of fire and maneuver during an engagement.

(2) Battlefield Geometry as represented in the model is shown in figure 1. The battlefield includes corridors, each of which consists of an area generally occupied by a Blue brigade and an area generally occupied by a Red division. The forward edge of the Blue force in each area is identified by the Blue FEBA, and the forward edge of the Red force is marked by the Red FEBA. These four FEBAs are straight lines which may move independently or in some coordinated fashion as combat progresses. Forces within an area are located with respect to their FEBA by range bands.

(3) Forces explicitly represented in the model include Red and Blue maneuver forces (including personnel and up to nine types of weapon systems in Blue company-size or Red battalion-size units), field artillery forces (up to four types of weapon systems on each side), air defense artillery weapons (up to six types of weapon systems on each side), attack helicopters, other Army forces (represented as targets only), and tactical air forces (represented as sorties with up to ten kinds of ordnance loads on each side).

(4) Ammunition Supply Levels are maintained for each type of weapon represented.

(5) Plans or intentions of the front-line units in each Blue brigade or Red division area are maintained independently of the intended activities of opposing units. The model resolves the plans of opposing forces into activities in which these forces engage.

(6) The model keeps track of the activities of all forces represented. Front-line units engage in various kinds of combat or movement activities which are established on the basis of the plans of pairs of opposing front-line units; air defense artillery can

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[3]The size of the increment can be adjusted with input data.

[4]The size of the interval can be adjusted with input data.

engage in air defense fire; and artillery, attack helicopters, and tactical aircraft engage in various kinds of fire support activities.

(7) The model continuously maintains a description of <u>targets</u> which have been acquired by up to seven kinds of sensors. Artillery fire and close air support is assigned to the targets on this list in accordance with user-specified rules.

(8) The <u>terrain</u> on which forces are operating is categorized with respect to its effect both on line of sight in maneuver unit engagements and on movement rates. The type of terrain on which a force is operating can change as the force moves.

2.3 Process Models in the DIVOPS Model

Values of the state variables in the DIVOPS model change as combat progresses. The ways in which they change are governed by the process models described below.

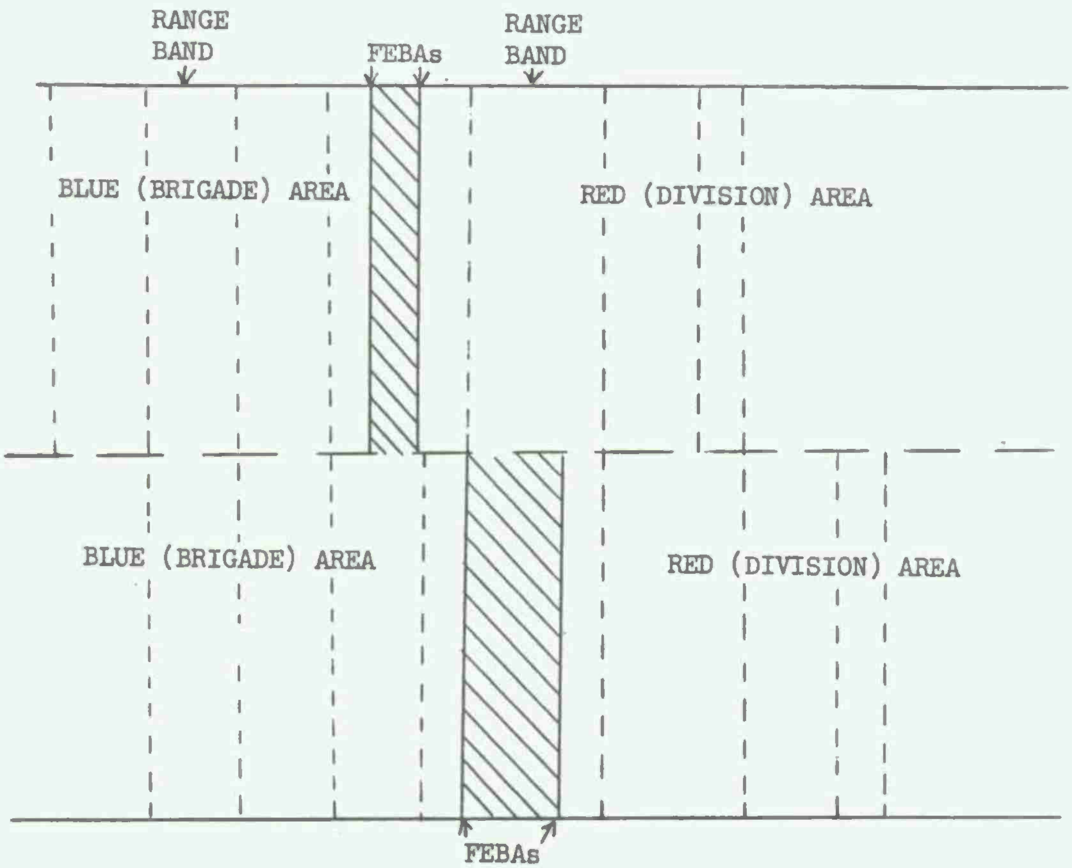

FIGURE 1: BATTLEFIELD GEOMETRY

(1) Tactical decision processes are represented by means of a very general facility of the DIVOPS model which allows the user to input, in a completely flexible way, rules to govern the model's representation of command decisions and related tactical behavior. The rules may express decisions as contingent upon any of the state variables in the model or any condition which can be described in terms of any set of these variables. In the DIVOPS model, these tactical rules govern force plans and activities, force movement and reorganization decisions, support fire calls and support fire allocation, supply allocation decisions, and the detailed tactical behavior of engaged units.

(2) Firepower processes represented in the model include air-to-ground firepower processes (close air support and fires by attack helicopters), ground-to-air firepower processes (air defense artillery fires on tactical aircraft and attack helicopters), and ground-to-ground firepower processes (artillery fire support and fires by engaged maneuver units). These processes are represented by various analytic models, including VRI's differential models of combat (see Bonder and Farrell, 1970).

(3) The process of target acquisition for fire support is represented in the DIVOPS model by an analytic model developed for this purpose. The model is based in part on the STARMAN-C model developed at CACDA by Bailey (1974), which in turn is based on a more detailed AMSAA model. The model developed for the ARAFCAS study uses sensor deployments and characteristics as well as target deployments to generate lists of targets detected each 15-minute time period.

(4) Movement and reorganization processes, including decisions to move front-line forces (i.e., advance or withdraw) or to "reorganize" rear-area forces (e.g., commit reserves), are governed by tactical rules. Given a decision to move, a separate computation determines the actual distance moved or the time required for the reorganization to take place.

(5) The process of ammunition consumption is represented in conjunction with the model of the associated firepower process, and the basis for the computation is the same as for the associated firepower model. (For example, if the firepower model gives attrition on a per-sortie basis, the model also keeps track of ammunition expenditure per sortie.)

2.4 DIVOPS Model Input and Output

Three general kinds of inputs required by the DIVOPS model include force and supply inventory and deployment data, weapon and other system performance data, and tactical decision rules.

The following general kinds of output are provided from a run of the model:

(1) a time history of weapon system and personnel losses; including an attribution of the losses to the system type causing them,

(2) surviving force strengths, positions, and statuses for each model time period,

(3) ammunition stocks for each time period, and

(4) target acquisitions, fire support allocations, and close air support sorties flown in each model time period.

3.0 Model Application

A general European scenario and threat description was provided for the ARAFCAS study by the sponsor. In order to use this material in the DIVOPS model, it had to be expanded and supplemented with inventory, performance, and tactical rule data. A brief description of the scenario appears in section 3.1, followed by a discussion in section 3.2 of the performance and inventory data used in the study. The procedures employed to develop tactical decision rules for use with the scenario are described in section 3.3. Section 3.4 describes the selection of runs of the DIVOPS model made to determine the effect of the amount of CAS provided on the Blue force's capability to accomplish its mission.

3.1 The European Scenario

The scenario used in the ARAFCAS study specified a mid-intensity European conflict in which a Blue mechanized division was facing two Red tank divisions followed by a motorized rifle division in second echelon. The study investigated two days of combat, or "snapshots", in this scenario. The first snapshot involved a Blue area defense against the Red advance, while the second snapshot included the counterattack phase of a Blue mobile defense. The force ratios and missions specified in the scenario resulted in very intense combat which, while represented appropriately in the DIVOPS model, created a problem in the acceptability of the study (see section 5.0).

3.2 Performance and Inventory Data

Blue force inventories were developed from H-Series TOEs adjusted for the study time frame (1980) with information supplied by the Army's Armor, Infantry, Field Artillery, and Air Defense Schools. The forces were deployed as specified in the scenario and based on details provided by representatives of CACDA and the Command and General Staff College (CGSC). Red force inventories were developed from the ARAFCAS study threat package supplemented with additional material. Data describing the performance capabilities of the weapon and sensor systems represented in the model was collected from a variety of sources, included approved Army studies, Tactical Air Command (TAC), and the Army's Intelligence Threat Analysis Detachment.

3.3 Tactical Rule Development

The tactical decision rules used in the study were developed from information provided by personnel in CACDA, CGSC, and TAC during a series of meetings held for that purpose. The meetings allowed these individuals, who were knowledgeable in the doctrinal and behavioral aspects of combat, to interact with members of the ARAFCAS project staff in order to specify verbally a set of rules in sufficient detail for them to be used in the DIVOPS model. The project staff then prepared a written summary of the rules, coded them for the computer, incorporated them into the model, and conducted preliminary runs of the model using these rules. An additional meeting was then held with the Army and Air Force personnel at which the summary of the rules was reviewed, and the effects of the rules on the simulated combat was analyzed. This meeting allowed the rule developers to revise any rules which were producing unreasonable results in the model. These revisions were then incorporated into the model.

The rules which were developed in these sessions represented planning and activity selection by ground maneuver units, controlled ammunition resupply, governed fire support activities, and determined the behavior of forces while engaged in maneuver unit combat. Details of the rules can be found in CACDA (1974) or in VRI (1974-2).

3.4 Model Run Design

Two major sets of study runs were performed with the DIVOPS model in the European scenario. The first set of runs was designed to analyze the sensitivity of the model to variations in tactical rules or data values, in order to determine the area in which to focus for the second set of runs. This first set of runs consisted of about 40 variations in data and rules which provided insights into the dynamics of combat as represented in the model. Following this sensitivity analysis, a set of runs was designed to determine the impact of the amount of air support provided on the outcome of combat under several sets of conditions believed to be of primary interest, based in part on the sensitivities discovered in the first set of runs. These runs consisted of a systematic variation in the level of response of air support under each of 14 sets of conditions, for a total of approximately 75 additional model runs. The purpose of this set of runs was to provide parametric information about the effect on mission accomplishment of the amount of CAS provided. The measure of mission accomplishment chosen by the sponsor was FEBA position at the end of 24 hours of combat. Results of these runs are discussed in the next section.

4.0 Results, Insights, and Conclusions

Figures 2 through 4 present illustrative results of runs designed to predict the position of the Blue FEBA at the end of a 24-hour snapshot as a function of the amount of CAS provided. Each point on the figures represents the result of a single model run; the points are connected by straight lines for clarity of presentation. Values on the abscissa of each graph - number of CAS sorties flown - have been suppressed to keep the presentation unclassified.

Figure 2 illustrates the final Blue FEBA position in the southern brigade area[5] at the end of the 24-hour defensive snapshot. In this case, mission success was defined in terms of Blue's ability to hold the original FEBA position, indicated by the dotted line at the top of the graph. The sharp jump in Blue's final FEBA position as CAS increases indicates a definite requirement for support. This sharp increase results from the missions and break points of both sides, which require both Red and Blue to conduct a decisive engagement such that if either side is successful, the other side is made completely ineffective. The anamolous behavior of the curve in the upper right corner (where an increase in CAS results in a slight decrease in ability to accomplish the mission) is caused by the model's sensitivity to the relative timing of critical events such as the arrival of reinforcements, the delivery of CAS, and decisions to initiate or stop an engagement. Ideally, of course, Blue

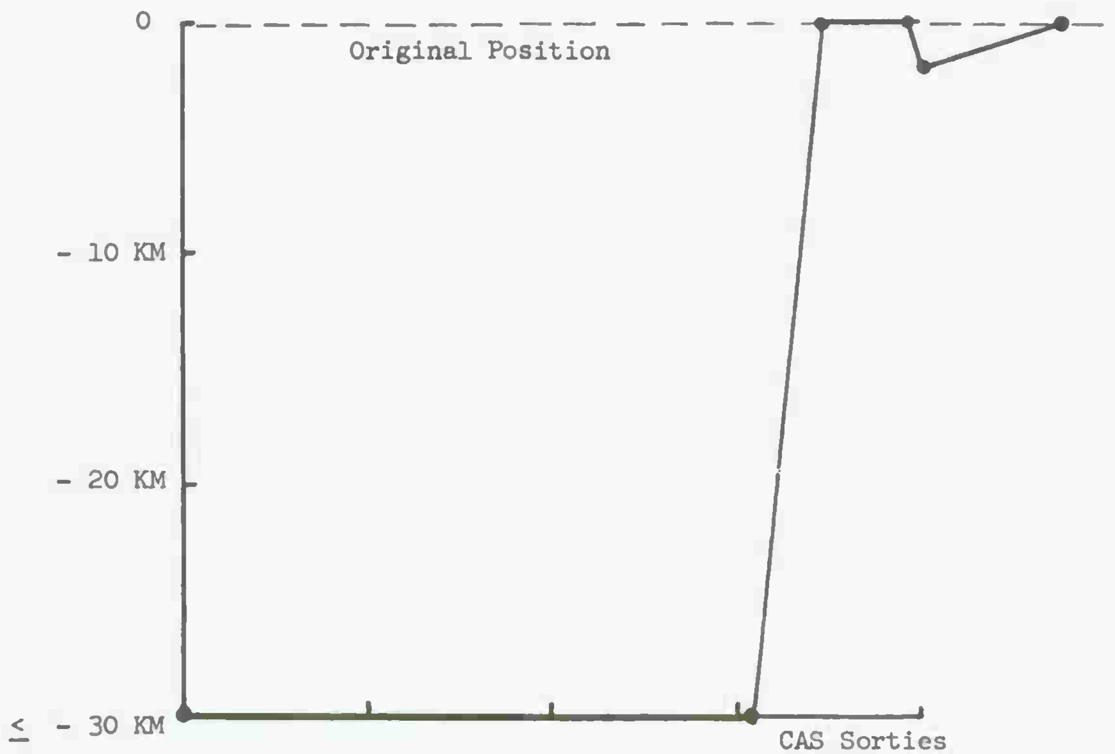

FIGURE 2: BLUE FEBA POSITION AT END OF DEFENSIVE SNAPSHOT AS A FUNCTION OF CAS PROVIDED

[5] In all model runs, regardless of the amount of CAS provided, Blue was successful in his mission in the northern brigade area, so the analysis concentrated on Blue's FEBA position in the southern area.

should never be less successful with an increase in air support, but increased CAS causes a change in the entire pattern of behavior within the model which results in non-optimal use of air support. Since the decision rules for the use of air were developed by Army and Air Force tacticians, this suboptimal employment under certain conditions is probably realistic - a commander is never able to predict with certainty the sequence of future events.

Figures 3 and 4 show the final Blue FEBA position in the southern area after 24 hours of the counteroffensive snapshot. In these runs, mission success in the southern area was defined in terms of Blue's ability to eliminate a six-kilometer Red penetration and hold the position indicated by the upper dotted line in the figures. The runs shown in figure 4 differ from those of figure 3 in that the latter assumed Blue's use of artillery-delivered scatterable mines while the former did not. It is interesting to note that scatterable mines not only decrease Blue's CAS requirements in order to conduct a successful counterattack, they also allow him to hold his original position (although not to counterattack successfully) when no CAS is provided.

It should be noted that the DIVOPS model produces extensive output concerning force levels, activities, attrition, ammunition expenditures, fire support allocations, etc., which were also examined in determining the impact of CAS on ground combat. Although FEBA position as presented above provided a useful single measure of mission success in evaluating CAS requirements, examination of the detailed output of the model allowed an analysis of the dynamics of combat with respect to both the impact of CAS on the ground situation and interactions among ground elements themselves. An important feature of a good model is its ability to predict results which were unforeseen and which may even seem counterintuitive until the underlying relationships are examined more closely. The DIVOPS model takes into account many complex interactions which make it impossible for one to predict beforehand what the outcome of a run will be. Thus, repeated runs of the model in the ARAFCAS study produced results which were not always foreseen and which have given rise to some interesting insights.

For example, in runs in which Blue did not break off combat before Red came within range of Blue's LAWs, the improved LAW seemed to be a very effective anti-armor weapon whose use sometimes reversed the course of the battle. This may suggest that Blue should attempt to hold a defensive position until after the advancing Red force comes within range of the LAW.

Insights were also gained regarding the employment of the mines, particularly artillery-delivered scatterable mines. Use of these mines against Red second-echelon forces attempting to exploit a penetration sometimes delayed the commitment of these reserves long enough for Blue to conduct a successful counterattack against a weaker Red force and to take up a defensive position (after having restored the integrity of the FEBA) before the Red second echelon force reached the FEBA. Blue was then never forced to attack against the entire Red force. This suggests that scatterable mines can be useful in support of a mobile defense.

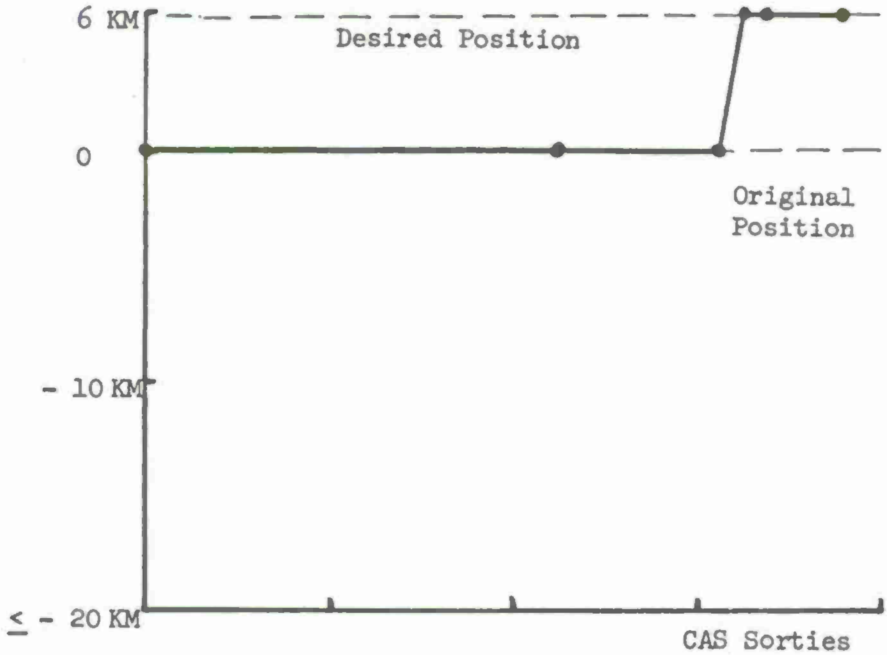

FIGURE 3: BLUE FEBA POSITION AT END OF COUNTEROFFENSIVE SNAPSHOT AS A FUNCTION OF CAS PROVIDED (WITH SCATTERABLE MINES)

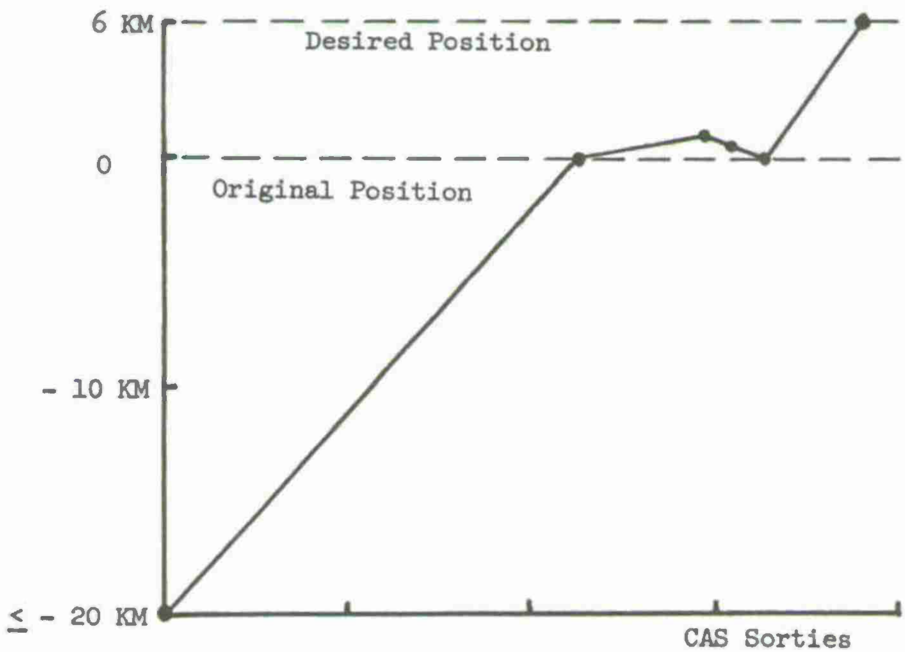

FIGURE 4: BLUE FEBA POSITION AT END OF COUNTEROFFENSIVE SNAPSHOT AS A FUNCTION OF CAS PROVIDED (WITHOUT SCATTERABLE MINES)

In model runs in which either scatterable or conventional mines were employed against an attacking Red force, the Red unit was often kep from closing on Blue until after CAS arrived and weakened Red to the point at which he was forced to break off the attack. It thus appears that mines and CAS can be used effectively in conjunction with each other.

5.0 Aftermath

Although the ARAFCAS study produced quantitative CAS requirements for a Blue division which were appropriate to the study scenario, it now appears unlikely that these numbers will be used by the Army for planning purposes. The basic reason for this is that the scenario used in the study produced very intense combat in which Blue required a large amount of support in order to accomplish his mission. This use of a "worst-case" situation has been deemed inappropriate for developing long-term planning factors for an entire European theater. In addition, because of the time constraints within which the project was forced to operate, no variation was possible in the availability of Army systems (such as artillery) to determine other ways in which Blue's deficiency in the scenario could be remedied.

Several steps could be taken to avoid such an outcome of studies of this kind. First, there appears to be a need for more interaction between the sponsor and the eventual user of study results. Additional communication between contractor and user analysts is also needed. Such contacts could help to assure that studies are designed so as to maximize the utility of their results to the user. This problem could also be attacked at the level of the Study Advisory Group (SAG). If SAG continuity were improved, members of such groups would have a better background to set and monitor the direction of studies of this kind. Finally, additional time should be provided for completion of studies such as this one. Such time could be used not only to improve the quality of the study team's work, but also to allow response time for SAG guidance, so that such guidance could be effective in setting and maintaining an appropriate direction for the study.

The ARAFCAS study effort was not completely wasted, however. The insights gained from the study should prove useful in planning for combined-arms activities such as those represented in the ARAFCAS scenario, and the DIVOPS model is currently being considered for use in several other studies.

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DEPOT MAINTENANCE CAPACITY PLANNING MODEL

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INTRODUCTION

The Depot Maintenance Capacity Planning Model was developed by the US Army Management Engineering Training Agency. It is designed to provide planning information relative to depot maintenance facilities in support of operational requirements for Army equipment maintenance.

Depot maintenance is concerned with performing the necessary planning, execution, and control activities associated with the overhaul, rebuild, conversion, and modification of major items of equipment. Depot maintenance is one of two methods that ensure the Army is provided with adequate quantities of equipment. The other is the procurement of new items of equipment. In order to maintain inventories at the required Authorized Acquisition Objective (AAO) level, the Army must select between repairing equipment in need of repair or purchasing new items. In choosing between maintenance or procurement as replacement methods, the Army managers must consider factors such as the lifetime of new items versus repaired items, procurement costs versus repair costs, leadtime for procurement versus repair time, the need for maintaining a "hot base" in product facilities, etc.

A continuing problem of Army maintenance management is maintenance depot manpower and facilities which are either over- or under-programmed, resulting in premature facility expansions and closures. Facilities required to repair and overhaul equipment represent a sizeable investment. Support Facilities in the Army are comprised of literally billions of dollars worth of construction, equipment, tools, and talent. Additional capabilities are acquired when it has been determined that existing facilities cannot reasonably accommodate increasing demands. This determination is not easily made and necessarily involves a high degree of uncertainty. Maximum capacity or ultimate capability is an elusive, if not indeterminate, quantity.

The capability of a shop or facility is the ability to produce a given product or unit of output. Capability is dependent, in part, upon the industrial engineering design of a shop and resultant shop layout, and also, in part, upon manpower skills and tools and equipment available. A capability to produce is necessary before there can be a capacity to produce. Capacity is a quantification of capability.

The capacity of a shop or facility is the number of units which can be produced in a specified time period. Thus, capacity is a <u>rate</u> of output--i.e., quantity of output in a given time interval--but the number of units of output will differ according to the mix of the products being turned out. Capacity is limited by the availability of physical resources. In order to measure capacity, it is necessary to know the number of men or machines of each type that each shop or work center possesses, and the number of hours that each shop will operate during each time period. Furthermore, it is necessary to know how much of each resource will be used (consumed) by each unit of each different product produced by a shop. The capacity measure, then, is a function of time product mix, and resource quantities.

In regard to depot maintenance activities, capability is the ability to perform a given level of maintenance on a specific item or group of items, and capacity is the rate at which a given level of maintenance can be performed on an item or group of items. Because depot maintenance is performed on a wide variety of items, the capacity of maintenance depots is a function of the mix of products to be produced as well as the quantities of resources available to produce units of output and the rate at which resources are consumed in producing output. Depot maintenance resources include (but are not limited to) manpower, special tools and test equipment, common tools, floorspace, material (e.g., repair parts, hardware), and dollars. Each resource will be consumed at a different rate by each of the various maintenance activities included in the depot maintenance workload. Changing quantities in the production mix, or changing resource quantities, or changing the rate at which resources are used will put the production capacity of the facility at different levels, given the plant and equipment.

A capability or capacity for overhauling one type of item cannot be examined in isolation at the existing facility level. It is possible to increase the output of a particular type of item by trade-offs between work stations, skills, tools, and equipment, and some parts.

If a quantitative model is to be used to determine the best combination (or mix) of items to be overhauled, an objective function must be defined. Several objective functions are available. The economic value of the items might be emphasized (minimize dollar value of repairable item inventory). The military value or priority might be the major concern. Total quantity of serviceable items produced could serve as the goal. The selection of one of these objectives, or others, should determine resource utilization.

The determination of depot maintenance capacity may be oriented in either one of two directions: to ascertain the potential output utilizing specified resources; or, to ascertain what resources are required to accomplish a specific output. A useful model would be one that could be used for either purpose.

ACTIVITIES

Maintenance has been defined as all actions necessary for retaining an item in, or restoring it to, a specified condition (MIL-STD-721B). The necessary actions identified as Army Depot Maintenance include the following:

(1) Overhaul/Rebuild necessitated by use, battle, or crash damage, or by aging
(2) Conversion/Modification
(3) Activation or Inactivation

(4) Renovation
(5) Analytical Rework
(6) Repair
(7) Inspection, Test, Calibration
(8) Fabrication/Manufacture
(9) Reclamation/Disassembly

These maintenance actions may be performed on a wide spectrum of equipment included in the Army inventory. Since different maintenance actions on different items of equipment will require different quantities and types of resources, it is necessary for the capacity model that the various maintenance actions be identified for each item of equipment.

RESOURCES

The resources available for performing the depot maintenance operations must be examined for the following factors:

(1) Capability--where the work can be performed
(2) Work Measurement--how rapidly the tasks can be performed
(3) Constraints--limiting factors which affect workload distributions

The AMC Depot Maintenance Data Bank (DMDB) is a repository for maintenance capability-capacity-engineering data that will support:

- Workloading to existing maintenance resources
- Military construction Army based upon projected workloads
- Shop equipment
- Modernization and standardization of depot maintenance operations
- Total resource management of maintenance funds
- Support of budgetary requirements for maintenance funds
- Cost effectiveness
- Maintenance support services
- Skill and manpower requirements

Data in the DMDB furnishes an up-to-date inventory and description of the real and personal property on hand at each Army depot identifiable to each work center of that depot. Data is also available to determine where depot maintenance operations can be performed for particular items of equipment.

The Work Center is the building block of Depot Maintenance Capacity Analysis. Work Centers are functional areas which contain tools and equipment associated with a particular trade or craft where maintenance operations peculiar to that trade or craft are performed. This data, along with the manpower skills of the organization, indicate the susceptibility of a facility to perform maintenance on particular weapons or equipment systems.

CONSTRAINTS

Typically, the operations involved in any maintenance job become the sum of the tasks performed in each work center of the facility. With fixed real and personal property, the only variable becomes the number of man-hours that are utilized in performing each task; and, for the sake of efficiency (performing the most work with the fewest resources), the man-hours should be minimized.

In developing a model for a computer solution to the capacity problem, it is first necessary to identify the "activities" which will utilize depot maintenance capacity. An activity is considered to be the type of maintenance action to be taken on a particular type of item in a particular work center or work area at a particular depot. The output of each activity is a maintenanced item. The depot engages in "activities" to transform resources such as man-hours, machine time, materials, or floor space into maintenanced items. The extent to which an activity is to be carried out is called the "activity level." The activity levels will be constrained by the availability of resources (money, material, labor, equipment, and/or facilities) which are required to carry out the activities. Certain activities, or combinations of activities, cannot exceed a specified maximum level but can be less than the maximum. The constraints are algebraic expressions which are formulated by summing, for each resource, the resource quantities used up by the various activities.

The depot capacity model is designed to answer the question: What should be the level of each activity variable so as to maximize the combined total "utility" for all activities? Utility is a quantitative measure of preferability.

The formulation of the job expression prevents the assignment of any workload to a depot facility which is unable (not capable) to perform the work. This, however, does not prevent the workload from being assigned to a non-preferred depot. The model is designed for capacity only and is not concerned with the policy.

OBJECTIVE

The objective of a depot maintenance capacity model might be: (1) given the depot maintenance resources, determine the optimum mix of items which should be workloaded to the depots to maximize production, optimize priorities, or maximize "military value"; or (2) given the mix of maintenance requirements, determine the resources which will be required to perform the necessary maintenance. Whether resources are specified or are to be determined, the main problem is one of allocating resources to perform maintenance. The principal question to be answered by a capacity determination is: How many depot overhaul facilities are needed to support operational requirements without jeopardizing operational readiness and mission effectiveness?

DEPOT MAINTENANCE CAPACITY MODEL

Two problems in analytically determining capacity requirements are supporting data and complexity. First, the nature of available data controls the form of the analytic functions used in modeling. Functions can only be used whose parameters and coefficients are available from existing data bases or which can be accurately estimated. Second, the maintenance systems are complex because they involve many interrelationships. Available resources may be used in different quantities and in different ways for different items of equipment. Trade-offs between different resources and/or different items of equipment can affect output quantities of the maintenance process and, hence, capacity.

A model which will accommodate the interrelationships inherent in depot capacity determination is linear programming. Supporting data for such a model is also available. The type of data required for a linear programming depot capacity model and sources for such data is given in Table 1. Basically, data is required for maintenance requirements (workload mix), quantities of each type of resource available in each work center, and quantity of each resource "consumed" by each "product" (maintenance activity) in each work center.

TABLE 1. DATA ELEMENTS FOR DEPOT CAPACITY MODEL

DATA ELEMENT
Resources
Brick and Mortar
Work area of each work center (square feet of floor space available for maintenance in each work center)
Tools and Equipment
Work center common equipment (quantity of each item available)
Work center special tools and test equipment (quantity/hours of STTE available)
Manpower
Personnel/Man-hours available in each work center by Skill/Skill Level
Requirements
Quantity of each kind of equipment programmed for depot maintenance by work accomplishment code (PRON)
Activities
Time (Man-hours) to complete one unit for a specified work accomplishment code (WAC) of an item programmed for maintenance (work center unit M/H standard)
Special tools and test equipment time to complete one unit for a specified WAC of an item programmed for maintenance
Dollars per unit for maintenance by PRON
Time-space rate for work area

Linear programming is a technique for handling the problem of how to utilize limited resources to the best advantage. In linear programming, the key is to optimize (maximize or minimize) an objective function (which expresses the nature of the objective) in such a way as to stay within or satisfy the constraints. The constraints can be expressed as an upper bound or lower bound or as a range within which the final solution must lie. The solution to a linear programming formulation of a problem will yield an optimal allocation of limited resources. In addition, the linear programming model permits one to ask certain "what if" questions and obtain the answers without solving a whole new problem. For example, in a depot capacity model, some "what if" questions might be: What if depot maintenance facilities were added (or deleted)? What if depot maintenance technology were to change? What if the objective function were changed? What if the requirements change?

A linear programming model for depot maintenance capacity might be constructed as shown in Figure 1. Resource quantities and resource consumption rates may be considered at the work center level or, if desired, any other level where data is available. Maintenance requirements may be broken out by work accomplishment code, by end item, or any other convenient category. It is only necessary that resource consumption rates, resource quantities, and requirements be related for model formulation.

Requirements are defined to be those items (units) which are earmarked for depot maintenance. Resources are those quantities of manpower, machines, material, and money which are consumed in depot maintenance activities. Resource consumption rates are the quantities of each resource consumed by one item (unit) undergoing depot maintenance.

The principal objective of a depot capacity model should be to determine resources required to maintain Army equipment in a combat-ready condition. It could further serve to provide justification for certain resource requests (e.g., dollars from Congress). A statement of the objective for an LP model might be made in any one of several different ways:

1. minimize cost of providing resources;
2. minimize value of resources consumed;
3. minimize quantity of resources consumed;
4. minimize penalty of not providing maintenance;
5. minimize value of repairable item inventory;
6. maximize military value of "maintenanced" items;
7. optimize some priority value; etc.

Several assumptions have been made in the development of the model:

1. Resources available for depot maintenance are known or can be determined. Resources include manpower skills, tools and test equipment, handling equipment, floor space, etc.

2. Work standards for each skill and resource consumption rate are available for the resources required for depot maintenance.

FIGURE 1. EXAMPLE OF A LINEAR PROGRAMMING MODEL
FOR DEPOT MAINTENANCE CAPACITY

	X_{1A}	X_{2A}	X_{3A}	X_{1B}	X_{2B}	X_{3B}	X_{2C}	X_{3C}	S_1	S_2	S_3	
Requirements												
Product 1	1			1					1			= 466
Product 2		1			1		1			1		= 1782
Product 3			1			1		1			1	= 282
Resources--Depot A												
A1	92											≤ 17600
A2	38		28									≤ 28100
A3		498										≤ 29900
A4		347	26									≤ 30200
Resources--Depot B												
B1				180	5							≤ 31600
B2					256	150						≤ 41250
B3					45	80						≤ 17600
Resources--Depot C												
C1							30	50				≤ 11250
C2							20	20				≤ 24600
C3							60					≤ 40500
Objective									3100	8400	5700	= Minimum

3. The total depot maintenance workload is known or can be determined. Information needed to determine depot maintenance workload seems to be available from several different sources. The type of information required is:

a. the types and densities of Army equipment authorized for TOE units;
b. the mean time between maintenance for each type of equipment; and
c. usage factors and/or maintenance generation factors for each item or type of equipment.

MODEL FORMULATION - AN EXAMPLE

There are three products--designated 1, 2, and 3--planned for maintenance at any one or more of three depots--designated A, B, and C. The products may be physically different items or they may be the same item requiring different kinds of maintenance which use resources at different rates and/or use different resources.

To perform a given type of maintenance on an item requires certain resources--floor space, manpower, tools, and equipment, for example. The resources may be in different work centers or in the same work center. The resources are limited in quantity and thus restrict the amount of work a depot can perform. Each activity uses different combinations of resources and uses resources at different rates. The activities and resources must be related in the model. In linear programming this is accomplished in the set of constraints.

In this example the objective will be to minimize the value of the repairable inventory. The slack variables--S_1, S_2, S_3--represent repairable inventory not accommodated by the depots due to limited depot maintenance capacity. The objective function coefficients represent the value of the respective products. The solution to this problem represents the quantity of each product which can be accommodated by existing depot capacity while minimizing the total value of the inventory of unrepaired items. The variable X_{ij} represents the quantity of product i which is to be programmed for maintenance at depot j.

The model is formulated as follows: Depot A can handle any of the products 1, 2, and/or 3. Resources available at Depot A are represented by A1, A2, A3, and A4. Each unit of product 1 repaired at Depot A requires 92 units of Resource A1 and 38 units of Resource A2. Each unit of Product 2 repaired at Depot A requires 498 units of Resource A3 and 347 units of Resource A4. Each unit of Product 3 repaired at Depot A requires 28 units of Resource A2 and 26 units of Resource A4. These can be summarized in a table as shown below.

Depot A Resources	Product 1	Product 2	Product 3
A1	92		
A2	38		28
A3		498	
A4		347	26

Similarly, the resource consumption rates for products repaired at Depots B and C are shown in the following tables. Note that only Products 2 and/or 3 can be handled by Depot C.

Depot B Resources	Product 1	Product 2	Product 3
B1	180	5	
B2		256	150
B3		45	80

Depot C Resources	Product 2	Product 3
C1	30	50
C2	20	20
C3	60	

In the repairable item inventory there are a total of 466 units of Product 1, 1782 units of Product 2, and 282 units of Product 3. Thus,

$$X_{1A} + X_{1B} + S_1 = 466$$

$$X_{2A} + X_{2B} + X_{2C} + S_2 = 1782$$

$$X_{3A} + X_{3B} + X_{3C} + S_3 = 282$$

These are the requirements constraints.

The quantities of each resource available at each of the depots are given in the following table.

Resource	Quantity Available (Units)
Depot A: A1	17,600
A2	28,100
A3	29,900
A4	30,200
Depot B: B1	31,600
B2	41,250
B3	17,600
Depot C: C1	11,250
C2	24,600
C3	40,500

The set of resource constraints are

Depot A

$$92X_{1A} \leq 17,600$$

$$38X_{1A} + 28X_{3A} \leq 28,100$$

$$498X_{2A} \leq 29,900$$

$$347X_{2A} + 26X_{3A} \leq 30,200$$

Depot B

$$180X_{1B} + 5X_{2B} \leq 31600$$

$$256X_{2B} + 150X_{3B} \leq 41250$$

$$45X_{2B} + 80X_{3B} \leq 17600$$

Depot C

$$30X_{2C} + 50X_{3C} \leq 11250$$

$$20X_{2C} + 20X_{3C} \leq 24600$$

$$60X_{2C} \leq 40500$$

The value of Product 1 has been determined (by management) to be 3100, 8400 for Product 2, and 5700 for Product 3. The objective is

$$3100\ S_1 + 8400\ S_2 + 5700\ S_3 = \text{Minimum}$$

The solution to this example is given in Figure 2.

ALTERNATIVE SOLUTIONS

In considering depot maintenance capacity requirements it may be desirable to give some attention to alternative allocations of depot maintenance resources. One alternative which might be of interest to the decision maker is the addition of certain resources at one or more maintenance depots. Quantities of existing resources may be increased by some amount, or entirely new resources may be added at one or more depots. The addition of new resources will require that new constraints be added to the problem. These new constraints will relate the consumption of the resources by depot maintenance activities to the quantities of resources available just as the other resource constraint functions. If quantities of existing resources are merely increased, then only the right-hand-side of the constraints affected need to be changed before solving the new problem.

A related alternative is that of decreasing resources available. Some resources might be eliminated completely; some resource quantities may simply be reduced. Eliminating resources will require that some constraints be deleted from the constraint set. Reducing quantities of resources will result in changes in the right-hand-side of the affected constraints.

In most cases, changes to the linear programming problem can be handled without solving a whole new problem. Appropriate changes are made in the final matrix of the previous solution and a new optimum solution to the modified problem is obtained. Analysts familiar with linear programming and the related computer software can provide assistance in making appropriate changes to consider the above alternatives.

FIGURE 2. SOLUTION TO EXAMPLE OF LINEAR PROGRAMMING DEPOT MAINTENANCE CAPACITY MODEL

X_{1A} = 191.3	Workload not assigned due to shortage of resources:
X_{1B} = 171.1	
X_{2A} = 60.1	Product 1 = 103.6
X_{2B} = 161.1	Product 2 = 1185.8
X_{2C} = 375.0	
X_{3A} = 282.0	Objective = 10,281,880.0
Unused Resources:	Evaluators:
A2 = 12,934.4	A1 = 33.7
A4 = 2,034.1	A3 = 16.9
B3 = 10,349.0	B1 = 17.2
C2 = 17,100.0	B2 = 32.5
C3 = 18,000.0	C1 = 280.0

Other alternative solutions that might be of interest could be in regard to adding or deleting depot maintenance facilities which might have an effect on maintenance capability. Whole depots might be added or deleted; an existing facility might be expanded to enable it to take on increased workload in terms of capacity or capability or both; or an existing facility may have some of its capacity and/or capability taken away. Adding or deleting facilities could involve the addition or deletion of variables in the problem as well as addition or deletion of constraints. These changes also are possible without solving a whole new problem.

Further alternative solutions may be obtained from changes in the objective function. Several objective functions are available. For example, the economic value of items of equipment might be emphasized. The priority or military value might be of major concern. The goal might be the total quantity of serviceable items produced. The selection of one of these objectives, or some other one, should determine resource utilization.

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VEHICLE USEFUL LIFE STUDY
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INTRODUCTION

An important consideration in the management of a fleet of vehicles, military or commercial, is knowledge of the useful life of the vehicles and whether or not it is economical to extend a vehicle's life by subjecting the vehicle to a costly major overhaul.

The Department of the Army in a move to reassess the useful life of its tactical wheeled vehicles requested the Army Materiel Command (AMC) to conduct a Vehicle Average Useful Life Study which would have the following primary objectives:

- Determine the age (mileage) at which it becomes economical to replace each of the four major payload tactical wheeled vehicles (1/4, 3/4-1 1/4, 2 1/2 and 5 ton vehicles);
- Determine the economics of overhauling each of these wheeled vehicles and the remaining life after overhaul.

This paper will concern itself with the vehicle average useful life study conducted for the 5 ton truck. The results of this study, as indicated in this paper, should not be considered at this time as the official U. S. Army position on this subject.

VEHICLE SAMPLE

The data used in this study was obtained from TAERS reporting on 5,704 M39A2 Series 5 ton trucks operated from 1965 thru 1969. The M39A2 trucks evaluated in the study consisted of three specific body types (1) M52A2 Tractor, (2) M51A2 Dump Truck and (3) M54A2 Cargo Truck. A summary of the trucks contained in the study by body type, theatre of operation and total mileage accumulated is shown below. It should be noted that the maximum mileage for an individual tractor or dump truck that was used in the study was 50,000 miles while the maximum mileage for an individual cargo truck was 65,000 miles.

NUMBER OF VEHICLES INCLUDED IN STUDY

M39A2 5 TON TRUCK

BODY TYPE AND LOCATION	NO. VEHICLES	TOTAL MILES (MILLIONS)
M52A2 TRACTOR		
EUROPE	259	1.9
CONUS	907	2.8
OTHER	1015	12.6
TOTAL	2181	17.3
M51A2 DUMP		
EUROPE	153	1.1
CONUS	460	1.6
OTHER	1369	13.0
TOTAL	1982	15.7
M54A2 CARGO		
EUROPE	211	1.3
CONUS	602	1.5
OTHER	728	6.7
TOTAL	1541	9.5
GRAND TOTAL	5704	42.5

USEFUL LIFE ASSESSMENT METHODOLOGY

The useful life of the M39A2 series 5 ton trucks (M54A2 Cargo, M52A2 Tractor and M51A2 Dump Truck) have been assessed by determining the mileage at which the average system cost per mile (costs associated with the acquisition, shipping and maintenance of the truck) is minimized (truck economic life). In addition, an evaluation of the vehicle's Reliability, Availability and Maintainability (RAM) performance characteristics over the economic life span has been made to establish if the vehicle's useful life should be considered less than the vehicle's economic life. This may occur, for example, if a truck at some mileage prior to the economic life mileage began having frequent breakdowns due to a relatively inexpensive component failure. This type of breakdown may not have much effect on the cost analysis but may result in a substantial reduction in the vehicle's reliability prior to the economic life mileage. If, however, the RAM parameters do not appreciably degrade throughout the economic life of the truck, then the useful life would be equal to the economic life of the truck.

TAERS DATA ANALYSIS

In exercising the above methodology, the procedure employed was to analyze the maintenance costs (scheduled and unscheduled) to determine how the costs were changing as the vehicle increased in mileage. This procedure was also carried out for the analysis of the RAM characteristics.

The TAERS data provided information on the maintenance actions (both scheduled and unscheduled) required for the vehicles as the vehicles increased in mileage. In particular, for each maintenance action, the following data were recorded: date action occurred, mileage at which action occurred, maintenance level (organization or support), man-hours required, failure detection code (i.e., whether the action was detected in normal operation of the vehicle, during an inspection or is just a regularly scheduled maintenance action), remedial action taken (repaired, replaced, adjusted or is simply the result of normal services), part name and Federal Stock Number, and quantity of parts replaced.

The analysis of the data from a cost standpoint utilized the parts cost contained in the Army Master Data File. The cost information is in 1974 dollars and was supplied to AMSAA by TACOM. The mean labor rate used in this study was $6.02 an hour. It is noted that there were approximately 190,000 maintenance actions for the 5,704 vehicle sample and about half of these were parts replacements.

The analysis of the TAERS data from a RAM standpoint presented a significant problem. Normally in the analysis of data for the determination of reliability and availability estimates, failure data is required. However, from the TAERS data it is extremely difficult, if not impossible, to determine for all unscheduled maintenance actions which actions are reliability failures. As a result of this fact, an analysis of all unscheduled maintenance actions was undertaken rather than the usual analysis of failures. Specifically, the analysis consisted of three phases, all with the objective of determining how the vehicle's performance was changing as the vehicle increased in mileage (1) Unscheduled Maintenance Action Analysis - the goal of this analysis was to determine the probability of completing a random 75 miles without an unscheduled maintenance action (UMA) for continually increasing mileages, (2) Inherent Readiness Analysis - the goal of this analysis was to determine as a function of mileage, the probability that the vehicle is not undergoing active repair due to an unscheduled maintenance action when required for use at a random point in time, and (3) Maintainability Analysis - this analysis consisted of determining, as a function of mileage, the maintenance support index (MSI), the average man-hours required per vehicle per 1000 miles of usage, and the average man-hours required per maintenance action.

COST ANALYSIS

As noted earlier, the object of the cost analysis was to determine how the maintenance costs were varying as the truck mileage was increasing in order that the average system cost could be minimized. Thus, all the maintenance actions occurring with these trucks (2181 tractor, 1541 cargo, and 1982 dump) were costed in constant FY74 dollars (parts and labor) as a function of mileage.

The methodology employed in the analysis of this data involved the determination of a continuous instantaneous maintenance cost curve (the instantaneous maintenance cost refers to the maintenance cost at a specific mileage). This curve was used to obtain the cumulative maintenance cost curve and an average system cost curve (the system cost refers to all those costs associated with the procurement, shipment, and maintenance of a vehicle including such costs as the vehicle's acquisition price, administrative expenses sustained, tooling costs, first and second destination charges, and maintenance costs). From the average system cost curve, the mileage at which the average system cost is at a minimum can be determined which represents the point where the overall average cost to the Army to procure, ship, and maintain the vehicle fleet is at a minimum.

In determining the continuous instantaneous maintenance cost curve, it was necessary to conduct two separate cost analyses. This was due to the high frequency of engine replacements which, because of their high cost ($3300 each) relative to the other maintenance action costs, had the effect of confounding the maintenance cost results. Consequently, a continuous instantaneous maintenance cost curve was determined for all maintenance actions excluding engine replacements and a similar cost curve for engine replacement actions only. From these two curves, a continuous instantaneous overall maintenance cost curve was determined.

In the analysis of the average maintenance cost data excluding engine replacement costs, weighted regression analysis techniques were applied. A second degree polynomial with a logarithmic transformation of the independent variable (mileage) was found to adequately represent the data beginning at 1000 miles. The average maintenance cost data for the 0-1000 mile interval was thus considered as the constant in determining the cumulative maintenance cost curve. Since no significant difference was found between the three cost curves representing the different body types, the data were combined and a combined cost curve was determined. Again, a second degree polynomial with a logarithmic transformation of the independent variable (mileage) was found to best fit the data. Tests of significance indicated the coefficients were highly significant (.01 level). The function determined was:

$$f_1(x) = .17 - .032 \ln x + .0037 \ln^2 x$$

where

$f_1(x)$ = instantaneous maintenance cost (dollars per mile) excluding engine replacement costs

x = truck mileage (1000's of miles) ≥ 1.

In the analysis of the engine replacement actions, a Mann Trend test was initially carried out on those vehicles with maintenance histories starting at essentially zero mileage and having more than one engine replacement throughout its history. The purpose of this test was to determine whether or not the mean mileage between engine replacements (mileage to first replacement, mileage between first and second replacement, mileage between second and third replacement, etc.) was constant. The results of this test were highly significant (.01 level) and indicated the mean mileage between engine replacements to be decreasing. Based on these results, a Weibull intensity function was fitted to the engine replacement data (mileages) and was found to adequately represent the data. However, it was found that the three different body types could not be represented by a single function as in the analysis of the average maintenance cost data excluding engine replacement costs. From the Weibull intensity function, the following continuous instantaneous cost curves for engine replacement actions were determined:

$$f_2(x) = .055x^{.4321} \qquad \text{(tractor)}$$

$$f_2(x) = .041x^{.3687} \qquad \text{(cargo)}$$

$$f_2(x) = .031x^{.4887} \qquad \text{(dump)}$$

where

$f_2(x)$ = instantaneous engine replacement cost (dollars per mile)

x = truck mileage (1000's of miles).

Utilizing the above functions $f_1(x)$ and $f_2(x)$, the following instantaneous overall maintenance cost curves were determined:

$$f(x) = .17 - .032 \ln x + .0037 \ln^2 x + .055x^{.4321} \quad \text{(tractor)}$$

$$f(x) = .17 - .032 \ln x + .0037 \ln^2 x + .041x^{.3687} \quad \text{(cargo)}$$

$$f(x) = .17 - .032 \ln x + .0037 \ln^2 x + .031x^{.4887} \quad \text{(dump)}$$

where

$f(x)$ = instantaneous overall maintenance cost (dollars per mile)

x = truck mileage (1000's of miles) ≥ 1.

From the continuous instantaneous overall maintenance cost curve, the cumulative maintenance cost curve was obtained. However, as previously noted, the average maintenance cost excluding engine replacement costs for the 0-1000 mile interval was considered as a constant in determining this function. The functions determined were:

$$F(x) = 129.14 + 207.69\,x + 38.155x^{1.4321} - 39.25\,x \ln x + 3.70\,x \ln^2 x \qquad \text{(tractor)}$$

$$F(x) = 28.15 + 207.69\,x + 29.940x^{1.3687} - 39.25\,x \ln x + 3.70\,x \ln^2 x \qquad \text{(cargo)}$$

$$F(x) = 73.79 + 207.69\,x + 20.685x^{1.4887} - 39.25\,x \ln x + 3.70\,x \ln^2 x \qquad \text{(dump)}$$

where

$F(x)$ = cumulative maintenance cost (FY74 dollars)

x = truck mileage (1000's of miles) ≥ 1.

The results of the analyses indicated above, thus revealed the following:

- The instantaneous maintenance cost (the maintenance cost at a specific mileage) when excluding engine costs for all body types (cargo, dump or tractor) was found to be decreasing from 15.6¢ per mile at 1000 miles until the vehicle reached 40,000 at which point the cost leveled off at 10.0¢ per mile and then remained at this figure through 65,000 miles of usage;

- The instantaneous maintenance cost attributed to engine replacement costs was found to be increasing with increasing vehicle usage for all three body types and in addition, the rate of increase was found to be different for each body type. For example, the instantaneous maintenance cost derived from engine replacements for the tractor (the body type with the highest engine replacement costs) was noted to be increasing from 5¢ per mile at 1000 miles to near 30¢ per mile at 50,000 miles. For the dump truck, the engine associated instantaneous maintenance cost was noted to be increasing from 3¢ per mile at 1000 miles to slightly more than 20¢ per mile at 50,000 miles while the cargo truck (the body type with the least engine replacement costs) was determined to be increasing from 4¢ per mile at 1000 miles to about 17¢ per mile at 50,000 miles. It should be noted that the engine costs presented are based on replacing the engine with a new engine whereas it is known that part of the time the engine is replaced with a rebuilt engine which may be less costly than a new engine. However, in order to provide a conservative or worst case cost picture all engine replacements were costed at the new engine price;

- The overall instantaneous maintenance costs associated with all parts including the engine was also found to be increasing with increasing vehicle usage for all three body types and the rate of increase was determined to be different for each body type. For example, the tractor was determined to be increasing from approximately 22¢ per mile at 1000 miles to near 40¢ per mile at 50,000 miles while the dump and cargo trucks were determined to be increasing from 19¢ and 20¢ per mile at 1000 miles to 31¢ and 27¢ per mile at 50,000 miles, respectively;

- The cumulative overall maintenance cost curves indicate that the tractor is noted to have the highest cumulative maintenance cost over the 50,000 miles of usage ($16,000). This compares with $12,600 for dump truck and $12,000 for the cargo truck over this same mileage interval.

As stated earlier, the primary objective of this cost analysis was to determine the mileage at which the overall system cost to the Army is at a minimum; i.e., the costs associated with procuring, shipping, and maintaining the truck is minimized. Utilizing the overall instantaneous maintenance costs developed and the truck rollaway cost (includes acquisition costs, engineering and tooling costs, administrative costs, first destination charges and applicable second destination charge) of $24,700, an average system cost as a function of mileage is determined. A plot of the average system cost as a function of mileage is shown on Figure 1. As noted on this figure, the average system cost for all three vehicles (tractor, dump and cargo truck) is indicated to be beyond 60,000 miles although at 60,000 miles the average system cost is found to be near its minimum. For example, at 60,000 miles the average system cost is noted to be decreasing only by a value of .5¢ or less for each additional 1000 miles of usage (through an extrapolated 70,000 miles of usage). Based on these figures, the economic life of these trucks was considered to be 60,000 miles.

PERFORMANCE ANALYSIS

Unscheduled Maintenance Action Analysis

As indicated earlier, in place of a reliability failure analysis, an analysis of all unscheduled maintenance actions was carried out due to the difficulty in determining if an unscheduled maintenance action was in fact a reliability failure. In analyzing the unscheduled maintenance actions, a system Weibull failure rate function was applied, i.e.,

$$r(t) = \lambda\beta t^{\beta-1} \quad t > 0,\ \lambda > 0,\ \beta > 0$$

where

t = mileage on vehicle

λ = scale parameter

β = shape parameter

This function assumes that the probability that a vehicle will have an unscheduled maintenance action at mileage t is proportional to r(t) and independent of the unscheduled maintenance action history of the system prior to t. This definition differs from the usual definition which states that the probability of an unscheduled maintenance action at mileage t is also proportional to r(t) but conditioned on no unscheduled maintenance actions prior to t. The former definition applies to repairable systems whereas the latter definition does not.

From this function, the probability that a vehicle with mileage t will complete an additional s miles without undergoing an unscheduled maintenance action (as determined by a non-homogeneous Poisson process) is

$$P(s/t) = e^{-\lambda(t+s)^{\beta} + \lambda t^{\beta}}$$

where $\lambda(t+s)^{\beta} - \lambda t^{\beta}$ is the expected number of unscheduled maintenance actions for a vehicle during the mileage interval (t, t+s).

Noted below are the maximum likelihood estimates (MLE) for the system Weibull failure rate function determined for each body type.

Body Type	$\hat{\lambda}$	$\hat{\beta}$
M52A2 Tractor	.0339	.6442
M51A2 Dump	.0119	.7682
M54A2 Cargo	.0239	.6969

The results of the analysis are shown on Figure 2. Indicated on this figure is the expected number of UMA's for the next 1000 miles of usage and the probability of completing 75 miles without a UMA for each 5000 mile interval from 0 to 50,000 for tractor and dump truck and from 0 to 65,000 miles for the cargo truck. A goodness-of-fit criteria indicated that the data shown is based on a model that is noted to provide a good fit of the field data. As can be readily observed on this table, there is essentially no change in the noted parameters as a vehicle is increasing in mileage through the indicated mileages. The average probability of completing 75 miles without requiring an unscheduled maintenance action over the 0-50,000 mile interval is .91 for the tractor and dump truck while the average probability of completing 75 miles without requiring an unscheduled maintenance action for the cargo truck over the 0-65,000 mile interval is .92.

Inherent Readiness Analysis

As with a reliability failure analysis, the determination of availability is normally based on failure data. For example, Inherent Availability (A_i) is normally defined as:

$$A_i = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair.

As noted in previous sections of this report, unscheduled maintenance actions rather than failure data were available. Further, the TAERS data provided information on the mean man-hours to repair rather than the mean time to repair. The mean time to repair for a particular maintenance action could be less than the man-hours involved if two or more mechanics worked on a particular maintenance action. To utilize this data, however, to obtain an estimate of an availability statistic, one can determine the probability of a truck not undergoing active repair due to any unscheduled maintenance action when called upon to operate at a random point in time (Inherent Readiness) and this is given by the following expression:

$$R_i = \frac{\text{MTBUMA}}{\text{MTBUMA} + \text{MMHTR}}$$

where MTBUMA is the mean time between unscheduled maintenance actions (assuming an average speed of 20 mph) and MMHTR is the mean man-hours to repair. It should be noted that the Inherent Readiness parameter is a lower bound on an Inherent Availability value, i.e., if all unscheduled maintenance actions were reliability failures and if no more than one mechanic ever worked on a maintenance action then the mean man-hours to repair would be equivalent to the mean time to repair and $R_i = A_i$.

The results of this analysis are shown on Figure 3. Indicated on this figure is the mean miles between unscheduled maintenance actions (MMBUMA) and Inherent Readiness (R_i) values for 1000 mile intervals through 50,000 miles for the M52A2 Tractor and M51A2 Dump Truck and through 65,000 miles for the M54A2 Cargo Truck. As can be readily observed, no degradation in the Inherent Readiness has occurred with any of the body types as the vehicles increased in mileage. One interesting sidelight noted in this table is that the lowest MMBUMA and R_i values occurs during the initial 1000 miles of usage. This, however, is probably due to quality control problems that may occur with a new vehicle. In summary, it is noted that over the mileages studied (50,000 miles for the tractor and dump truck and 65,000 miles for the cargo truck) the MMBUMA and R_i values are 1388 miles and .92, respectively, for the M52A2 Tractor, 1034 miles and .93, respectively, for the M51A2 Dump Truck, and 1206 miles and .92, respectively, for the M54A2 Cargo Truck.

The Inherent Readiness parameter discussed above is noted to be the probability that the truck is not undergoing active repair due to an unscheduled maintenance action when called upon to operate at any point in time. This parameter, thus, does not include vehicle logistic downtime, i.e., downtime associated with obtaining and waiting for parts. This was not included in the study as it was not readily available in the TAERS data. In comparing the Inherent Readiness estimates with similar estimates obtained from a recent AMC Materiel Readiness Report, the Inherent Readiness values compare favorably with the AMC Readiness Report values. For example, the Inherent Readiness value of .92 for the M54A2 Cargo Truck as obtained in this study converts to a .96 value when transforming the man-hour indications to clock-hour indications (a conversion factor of 1.8 man-hours = 1 clock hour is used). This .96 readiness value is thus determined to be the same as the AMC Readiness Report value of .96. The AMC report further notes that when logistic downtime is considered in the availability parameter, the availability of this vehicle is indicated to be .85.

Maintainability Analysis

The object of this analysis was to determine if the man-hours required for maintenance were changing as the truck increased in mileage. In addition, a parts replacement analysis was conducted. This latter analysis consisted of the following: (1) major component replacements as a function of mileage (engine, axles, differential and transfer case), (2) high cost parts (in excess of $100.00) replacements, (3) ten most frequently replaced parts and (4) determination of the frequency of replacements for all vehicle parts. These analyses were carried out separately for each of the three 5 ton vehicles studied (M52A2 Tractor, M51A2 Dump Truck and M54A2 Cargo Truck).

Shown on Figure 4 are summaries of the man-hour data obtained for the tractor (similar data for the dump and cargo trucks is available but is not presented because of the length of the paper). Of particular interest in this figure are the average man-hours required per truck per 1000 miles, the average man-hours required per maintenance action and the maintenance support index (number of maintenance man-hours required per hour of truck operation); all reported by 1000 mile intervals.

As can be readily observed on Figure 4, the average maintenance man-hours required per truck per 1000 miles (and subsequently the maintenance support index) was noted to be at its highest during the initial 1000 miles of usage (37.7, 26.8 and 33.7 man-hours for the tractor, dump and cargo trucks, respectively). This is believed due to two primary reasons: (1) the relatively large number of man-hours associated with the processing in of a new vehicle and (2) initial quality control problems that occur with a new vehicle. However, the maintenance man-hours required is noted to decrease from the levels required during the initial 1000 miles of usage to about 10.0 man-hours at 5,000 miles with the number of man-hours required for maintenance remaining relatively stable at or near 10.0 man-hours through at least 50,000 miles. Thus, over the initial 50,000 miles, the average man-hours required for maintenance per truck per 1000 miles was 9.2 and 7.7 man-hours for the tractor and dump trucks, respectively, while for the cargo truck over the initial 65,000 miles, the average man-hours required for maintenance per truck per 1000 miles was 9.5 man-hours. The average maintenance support index for these mileages was noted to be .18, .15 and .19 for the tractor, dump and cargo trucks, respectively.

In analyzing the average man-hours required per maintenance action, it was noted that the average tractor, dump and cargo truck required maintenance on an unscheduled basis an average of 36.0, 48.3 and 53.9 times, respectively, over the mileage accumulation periods noted above, and during each of these maintenance stops the tractor, dump and cargo trucks had on the average 2.3, 1.8 and 1.9 components, respectively, repaired, replaced or adjusted. The number of man-hours utilized for each of these component actions averaged 2.6 man-hours for the tractor and cargo truck and 2.5 man-hours for the dump truck. Shown on Figure 4 are the maintenance man-hours required for each maintenance action by 1000 mile intervals.

As noted above, an analysis of major component replacements (engine, transfer case, differential and axle) for all three vehicles was made. This analysis consisted of determining for these components, the number and percent replaced by increasing 1000 mile intervals. The object of this analysis was to determine if any of these major components exhibited wearout characteristics at a particular mileage or mileage interval. The results of this analysis indicated that the engine was the only major component to exhibit wearout characteristics with increasing mileage of the vehicle. This was noted with all three vehicle body types. It was indicated that the average M52A2 tractor will have its first engine replacement at 22,000 miles, the second engine replacement at 36,000 miles and the third engine replacement at 48,000 miles. The average M51A2 dump truck was noted to have its first engine replacement at 30,000 miles and the second engine replacement at 48,000 miles. The average M54A2 cargo truck exhibited its first engine replacement at 31,000 miles and its second engine replacement at 52,000 miles. As can be seen, the engine wore out quicker in the tractor than in the dump or cargo truck. This is evidenced by the fact that during the initial 50,000 miles of operation, the tractor required approximately three engine replacements while the dump and cargo trucks required approximately two engine replacements. A summary of the performance of these major components indicated that during the initial 50,000 miles of operation of the tractor, 100% of the trucks would have an engine replacement, 23.5% of the trucks would have a transfer case replacement, .9% of the trucks would have a differential replacement and 2.0% of the trucks would have an axle replacement. A summary of the performance of the major components for the dump truck during the initial 50,000 miles of operation revealed that 100% of the trucks would have an engine replacement, 21.4% of the trucks would have a transfer case replacement, none of the trucks would have a differential replacement and 4.8% of the trucks would have an axle replacement. With the cargo truck, the performance summary indicated that over the initial 65,000 miles, 100% of the trucks would have an engine replacement, 16.2% of the trucks would have a transfer case replacement, .2% of the trucks would have a differential replacement and 10.0% of the trucks would have an axle replacement.

In further analysis of parts replacements, a study of the high cost parts (in excess of $100.00) replacements was made. This analysis consisted of determining the frequency of replacement for all high cost components contained in the truck on an overall basis as well as by increasing 10,000 mile intervals. The object of this analysis was to determine which high cost components were being replaced most frequently and at what mileage intervals did these replacements occur. The results of this analysis indicated that the engine, starter, fuel pump and regulator were the most frequently replaced high cost components for all three body types. The results further indicated that the replacement of these components occurred at a relatively high rate throughout the mileage life of these vehicles. For example, on an overall basis, 18% of the tractors had starter replacements. Dividing these replacements into mileage intervals shows that 19% of the tractors had starter replacements in the 0-10,000 and 10,000-20,000 mile intervals, 16% of the tractors had starter replacements in the 20,000-30,000 mile interval and 11% of the tractors had starter replacements in the 30,000-40,000 mile interval. In the 40,000-50,000 mile interval no starter replacements occurred, however, only 19 vehicles were contained in this interval.

As indicated above, the parts analysis also included a determination of the ten most frequently replaced components in these trucks. These 10 most frequently replaced components were computed by 10,000 mile intervals as well as on an overall basis. This is done in order to determine if the components being replaced in the initial 10,000 mile interval are also being replaced in subsequent 10,000 mile intervals. For example, with the M52A2 Tractor, the battery is noted to be first or second most frequently replaced component in all mileage intervals as well as on an overall basis.

USEFUL LIFE ASSESSMENT

Although the average system cost is indicated to reach a minimum beyond 60,000 miles, the average system cost was found to be very near its minimum at this mileage. Further, since none of the RAM parameters were determined to be degrading as the vehicle mileage was increasing, the economic life noted (60,000 miles) is considered the truck's useful life. By converting the mileage indication to years, the M39A2 5 ton truck is considered to have a 20 year useful life (based on 3000 miles a year usage).

FIGURE 1

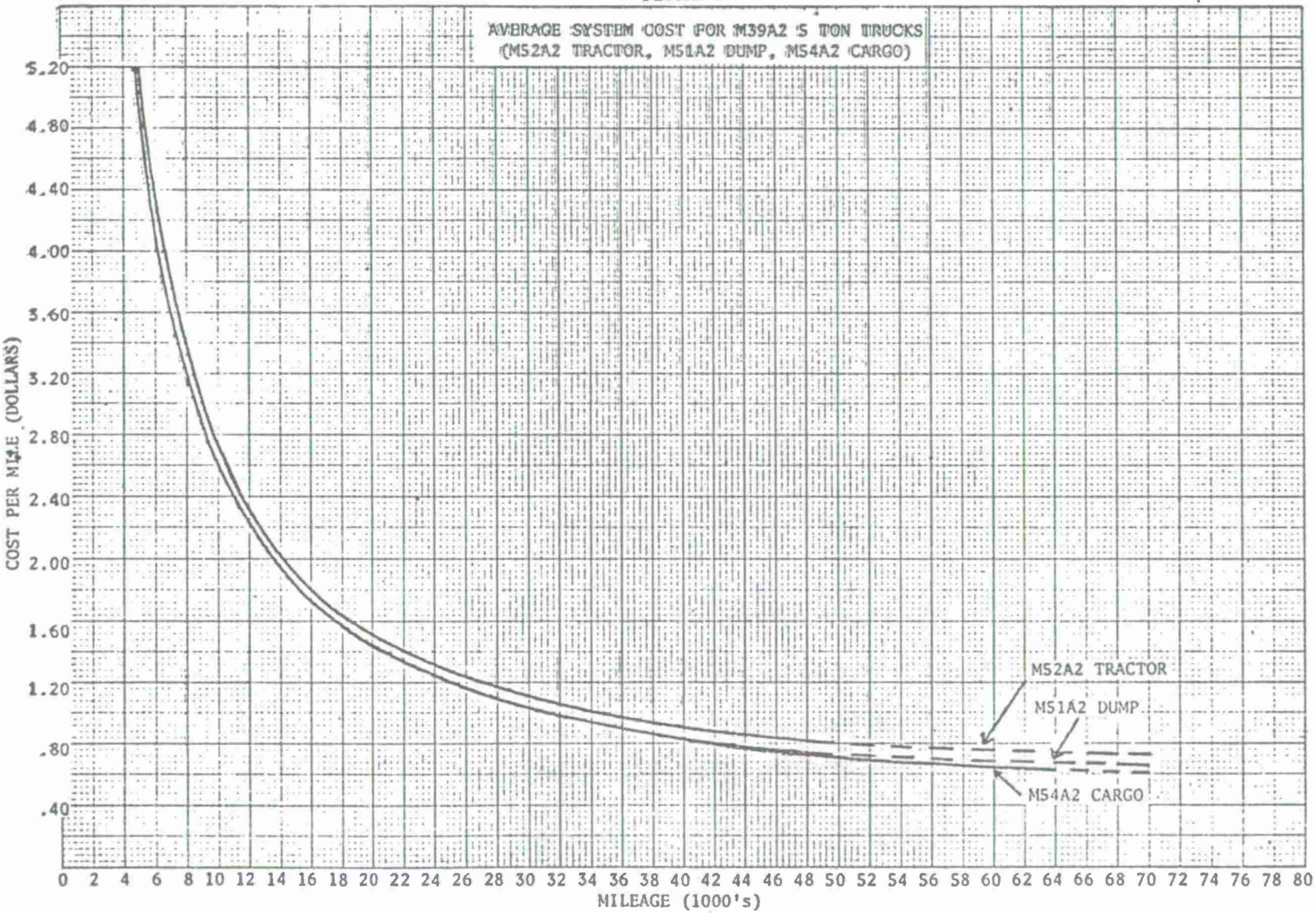
AVERAGE SYSTEM COST FOR M39A2 5 TON TRUCKS
(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)
COST PER MILE (DOLLARS)
5.20
4.80
4.40
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
.80
.40
M52A2 TRACTOR
M51A2 DUMP
M54A2 CARGO
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80
MILEAGE (1000's)

FIGURE 2

PROBABILITY OF COMPLETING 75 MILES
WITHOUT AN UNSCHEDULED MAINTENANCE ACTION
FOR M39A2 5 TON TRUCKS

(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)

	EXPECTED NUMBER OF UNSCHEDULED MAINTENANCE ACTIONS FOR THE NEXT 1000 MILES			PROBABILITY OF COMPLETING 75 MILES WITHOUT AN UNSCHEDULED MAINTENANCE ACTION		
MILEAGE	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO
0	2.9	2.4	2.9	.58	.58	.62
1000	1.6	1.7	1.8	.87	.87	.86
5000	1.0	1.2	1.2	.92	.91	.91
10000	0.8	1.1	1.0	.94	.92	.93
15000	0.7	1.0	0.9	.95	.93	.93
20000	0.6	0.9	0.8	.95	.93	.94
25000	0.6	0.9	0.8	.96	.94	.94
30000	0.6	0.8	0.7	.96	.94	.95
35000	0.6	0.8	0.7	.96	.94	.95
40000	0.6	0.8	0.7	.96	.94	.95
45000	0.6	0.8	0.7	.96	.94	.95
50000	0.6	0.8	0.7	.96	.94	.95
55000	-	-	0.7	-	-	.95
60000	-	-	0.7	-	-	.95
65000	-	-	0.7	-	-	.95
AVERAGE	-	-	-	.91	.91	.92

FIGURE 3

PROBABILITY OF TRUCK NOT UNDERGOING ACTIVE REPAIR
DUE TO AN UNSCHEDULED MAINTENANCE ACTION AT ANY
POINT IN TIME (INHERENT READINESS) FOR M39A2 5 TON TRUCKS

(M52A2 TRACTOR, M51A2 DUMP, M54A2 CARGO)

	MEAN MILES BETWEEN UNSCHEDULED MAINT. ACTIONS* (MMBUMA)			INHERENT READINESS (R_i)		
MILEAGE INTERVAL (1000's)	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO	M52A2 TRACTOR	M51A2 DUMP	M54A2 CARGO
0-1	345	418	340	.75	.84	.77
4-5	914	770	769	.89	.91	.88
9-10	1193	916	966	.91	.92	.90
14-15	1387	1010	1098	.92	.93	.91
19-20	1541	1082	1201	.93	.93	.92
24-25	1671	1141	1287	.93	.94	.93
29-30	1667	1191	1362	.94	.94	.93
34-35	1667	1235	1428	.94	.94	.93
39-40	1667	1275	1429	.94	.94	.94
44-45	1667	1282	1429	.94	.94	.94
49-50	1667	1282	1429	.94	.94	.94
54-55	-	-	1429	-	-	.94
59-60	-	-	1429	-	-	.94
64-65	-	-	1429	-	-	.94
OVERALL	1314	1025	1161	.92	.93	.92

*THE MMBUMA IS DEFINED TO BE THE LENGTH OF THE MILEAGE INTERVAL (1000 MILES) DIVIDED BY THE MEAN NUMBER OF UNSCHEDULED MAINTENANCE ACTIONS FOR A VEHICLE DURING THE MILEAGE INTERVAL.

FIGURE 4

MAINTAINABILITY DATA FOR THE M52A2 5 TON TRACTOR

MILEAGE INTERVAL (1000's)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. & UNSCH.)	NO. OF MAN-HOURS	AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES	AVERAGE MAN-HOURS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	1034	17455	38976	37.7	2.2	.75
1- 2	1212	8625	23192	19.4	2.7	.38
2- 3	1103	4762	15159	13.7	3.2	.27
3- 4	1016	4292	12473	12.3	2.9	.25
4- 5	948	3378	10280	10.8	3.0	.22
5- 6	875	2339	6250	7.1	2.7	.14
6- 7	815	2768	8274	10.1	3.0	.20
7- 8	776	2350	6324	8.2	2.7	.16
8- 9	738	2275	6595	8.9	2.9	.18
9-10	692	2396	7413	10.7	3.1	.21
10-11	667	2110	5706	8.6	2.7	.17
11-12	628	1759	4838	7.7	2.8	.15
12-13	592	2068	5775	9.8	2.8	.20
13-14	547	1749	5068	9.3	2.9	.19
14-15	519	1575	4165	8.0	2.6	.16
15-16	482	1584	4488	9.3	2.8	.19
16-17	447	1510	4637	10.4	3.1	.21
17-18	422	1333	3709	8.8	2.8	.18
18-19	387	1262	3514	9.1	2.8	.18
19-20	363	1184	3415	9.4	2.9	.19
20-21	330	1149	2771	8.4	2.4	.17
21-22	296	909	2395	8.1	2.6	.16
22-23	262	684	1856	7.1	2.7	.14
23-24	234	792	1849	7.9	2.3	.16
24-25	222	678	1987	9.0	2.9	.18
25-26	210	713	1905	9.1	2.7	.18
26-27	195	574	1469	7.5	2.6	.15
27-28	166	418	1162	7.0	2.8	.14
28-29	147	445	1055	7.2	2.4	.14
29-30	133	483	1044	7.9	2.2	.16
30-31	122	514	1410	11.6	2.7	.23
31-32	102	381	1012	9.9	2.7	.20
32-33	92	332	649	7.1	2.0	.14
33-34	83	265	631	7.6	2.4	.15
34-35	75	202	459	6.1	2.3	.12
35-36	70	239	597	8.5	2.5	.17
36-37	64	217	501	7.8	2.3	.16
37-38	56	236	554	9.9	2.4	.20
38-39	45	101	179	4.0	1.8	.08
39-40	40	74	188	4.7	2.5	.09
40-41	35	68	177	5.0	2.6	.10
41-42	30	93	193	6.4	2.1	.13
42-43	26	93	246	9.5	2.7	.19
43-44	21	63	195	9.3	3.1	.19
44-45	18	47	103	5.7	2.2	.11
45-46	15	71	86	5.7	1.2	.11
46-47	13	68	179	13.7	2.6	.27
47-48	13	42	87	6.7	2.1	.13
48-49	13	30	79	6.1	2.6	.12
49-50	9	24	39	4.3	1.6	.09

*INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH)

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES: 9.2

2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION: 2.6

3. AVERAGE MAINTENANCE SUPPORT INDEX: .18

TITLE: APPLICATION OF ORSA TECHNIQUES TO THE OPERATIONS OF A MISSILE RANGE

AUTHORS: Dr. John C. Davies and Mr. James C. Hoge, P.E., US Army White Sands Missile Range, New Mexico

I INTRODUCTION:

White Sands Missile Range (WSMR), as one of eight National Ranges so designated by the Secretary of Defense, is assigned three major mission areas:

- National Range Mission - WSMR operates the National Range in support of research, development, test and evaluation of weapon and space systems for all military departments, other government agencies, and authorized non-government agencies including foreign governments. As a part of this mission a major function of the Range is to conduct research and development pertaining to range instrumentation.

- Army Test and Evaluation - WSMR plans and conducts development tests of rocket and guided missile systems, air defense fire distribution systems and associated equipment and other materiel. To support this element, the Army maintains a large test equipment inventory, including special facilities for nuclear effects and environmental testing.

- Installation Operations - Facilities Engineering, Logistics, Procurement, and Army Air Operations provide support for the major mission elements, seventeen tenant organizations, and eight major support contractors dispersed over 4,000 square miles with launch and support facilities located as far as 400 miles away at Green River, Utah. Figure 1, showing WSMR overlaid on a map of the eastern United States indicates the expanse of WSMR's physical plant. The Range employs approximately 8,000 personnel in support of the three mission element, and has an annual operating budget exceeding $100,000,000.

The diverse nature of the missions of WSMR make it somewhat unique among Army installations in that its operations embrace both R&D and production functions. Although both the Army Test and Evaluation and the Installation Operations Missions continue to be prime contributors of OR studies at WSMR, this paper will concentrate primarily upon the National Range Mission.

During the past ten years, a large number of major OR studies have been conducted both by in-house personnel and outside consultants to WSMR. For the most part, these studies have originated within operating elements of the organization, many times without the usual consultant-client relationship so necessary for the successful implementation of OR study recommendations. This has accrued to the fact that many of these studies were conducted by the R&D element without benefit of sponsorship of or at


LAKE MICHIGAN
MICHIGAN
LAKE ONTARIO
NEW YORK
VT.
NH
MASS.
CONN
RI
LAKE ERIE
CLEVELAND
(GREEN RIVER)
PENN.
NJ
INDIANA
OHIO
PITTSBURGH
PHILADELPHIA
(BLANDING)
COLUMBUS
BALTIMORE
MARYLAND
WASHINGTON DC
DEL.
VIRGINIA
ATLANTIC OCEAN
(FT WINGATE)
KENTUCKY
NORFOLK
(ALBUQUERQUE)
RALEIGH
TENN
NORTH CAROLINA
(WSMR)
WILMINGTON
GA.
S.C.

FIGURE 1

least blessing by the operational element. Consequently, very few of the recommendations resulting from these studies were implemented.

Recognizing that he needed to improve his ability to reach command positions more expeditiously, the Commanding General directed his Plans Office to prepare a proposal for realignment thereof to include OR/SA functions. Concept approval was received from Headquarters, Army Materiel Command in late May 1973. Staffing the seven-man Analysis Group (five civilian and two military) began in September 1973.

The major thrust of the Analysis Group's efforts has been to investigate problems of management impact. It was never intended to perform all the installation's analyses involving OR/SA techniques. Rather, through staff review and critique of organizational studies and establishment of an OR/SA training program to encourage and improve the quality of OR/SA studies performed by operating elements.

It is the purpose of this paper to critically examine the progress made to date by WSMR's OR activities and perhaps make some contribution to the theme of this symposium.

II <u>CLASSICAL PROBLEMS IN THE IMPLEMENTATION OF OR</u>:

The decision by management in either the public or private sector to implement an OR program is based upon the premise that some tangible benefit will accrue to its implementation. Whether or not the expected benefit is ever realized depends to a large degree on "social" rather than technological considerations.

Ackoff and Rivett [1][1] pose the question, "Do OR projects ever fail?" Their observation is that only rarely does a solution just fail to work. The most common type of failure occurs because a proposed solution is simply not implemented. This type of failure is attributed to four principal reasons:

(1) "The company is reorganized during the study so that the managers responsible for the study are replaced."

(2) "Lack of involvement of a high enough level of management ..."

(3) "Attempts by individuals to use the research to further some personal, rather than organization's, objective."

(4) "Economic pressures that lead to a reduction of expenses including those for research."

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[1] Numbers in brackets refer to publications cited in the Bibliography found at the end of this paper.

A recurring problem for any OR group whether newly established or of long standing is the necessity of "selling" line management on the recommendations based on an OR study. Operating managers who have been successful by virtue of their ability to marshall resources and through the exercise of power feel threatened by the establishment of an OR group. Traditionally, the line manager has been able to reduce the probability of being convicted of incompetence if his decision was not successful by s selecting that course of action having "optimal ambiguity and fluidity." [2] He had good reason to feel essential and powerful when he was able to point to where his influence was important. On the other hand, the use of sophisticated quantitative models could tend to reduce this protection and the feelings of essentiality on the part of the line manager, and he would tend to feel that he was engaged in a "zero-sum game." If the OR group wins, he automatically must lose. The basic premise that managers invariably accept logical and rational solutions to managerial problems has been seriously questioned in recent years by sophisticated behavioral scientists and seasoned operations researchers such as Chris Argyris, C. West Churchman, and John D. C. Little. This may be demonstrated by the following scenario described by Stanfel [9]. An analysis group approaches a manager to obtain information regarding some area to adopt some rational, new method of managing. The manager, feeling a possible loss of power in the offing, loss of freedom in suppressing what he wishes to suppress, and an increased emphasis on his abilities, about which he may feel inferior, feels frustrated, and refuses to cooperate. The analysts, discouraged by their consequent inability to obtain information or get their ideas accepted, feel frustrated themselves, and withdraw. The resulting state is anything but a benefit to the organization.

Huysmans [4] suggests that the possible behavioral reaction of the manager to the research recommendations as a function of managerial understanding can be classified in one of four categories, to wit:

(1) Rational Rejection - The manager understands the research recommendations, but rejects them on rational grounds.

(2) Resistance - The manager rejects the recommendations and his way of thinking about the research problem deviates considerably from that of the researcher. (This is, perhaps, a reaction to the researcher selecting the wrong set of constraints.)

(3) Acceptance - The manager adopts the proposal, but does not understand it.

(4) Implementation - The manager understands the recommendation and adopts it. He further defines two subcategories of implementation, i.e., Sustained Implementation in which the researcher continues to be involved and Autonomous Implementation in which managerial understanding of the research is explicit and complete and continued support by the analyst is not required.

Huysmans hypothesizes that successful implementation of a proposal depends upon the congruence of the manager's way of reasoning vis a vis that of the researcher. "If the researcher attempts to create explicit and complete understanding of his research on the part of the manager, autonomous implementation will follow if the manager's way of reasoning is analytical, but strong resistance will follow if the manager's way of reasoning is heuristic. If the researcher attempts to create integral or general understanding of his research on the part of the manager, sustained implementation will follow, regardless of the manager's reasoning style. If the manager's way of reasoning is heuristic, the researcher's explicit-understanding approach will lead to suppression by the manager of analytic arguments. The researcher's integral-understanding approach, on the other hand, will encourage the manager to include analytic arguments in the preparation of his decision."

From the foregoing discussion, it appears that the probability of success of an OR group in gaining acceptance by line management lies somewhat closer to zero than unity. However, we in the Defense Community are perhaps more fortunate than our colleagues in the private sector. Military managers are generally ahead of their industrial counterparts with respect to their knowledge of and reliance on quantitative decision-making techniques. This enlightened management and command emphasis by the OR oriented managers simplifies, to some degree at least, the implementation problem described in the literature. However, even under ideal conditions, some implementation problems will always exist simply because it is not possible to quantify organizational objectives. In actual organizational practice, no one attempts to find an optimal solution to the "aggregate production, item allocation, and scheduling decisions" described by Simon [8]. Instead, various particular decisions within the whole complex are made by specialists within the organization. Their task becomes one of finding a satisfactory solution for one or more subproblems. This process of viewing decisions as being concerned with discovering courses of action that satisfy a whole set of constraints rather than achieving an organizational goal is what Simon [8] calls "satisficing." Failure by the analyst to select the proper set of constraints when defining the framework of a problem will certainly result in failure of management to adopt his recommendations.

Assessing the value of OR/SA in an environment where none of the study recommendations are implemented becomes a rather simple task since the payoff is zero and a cost savings can be incurred by abolishing the OR/SA function. Although not very elegant, one measure of the value of OR/SA may be a simple enumeration of the research recommendations implemented by line management. To be effective at all, the analyst must devote as much care to an implementation plan as he does to the more satisfying task of model building.

III APPLICABILITY OF OR/SA TO WSMR:

White Sands Missile Range is best characterized as a large, complex job shop. A customer comes to the Range with a set of specifications for a test program he wishes to run. The scenario which follows is not unlike that which takes place in the private sector every day. The customer works with a WSMR sales (project) engineer to refine the test specifications and to negotiate, to some extent at least costs as well as technical and logistical support requirements. After agreement upon the contractual terms, the customer, working with his sponsor (Army, Navy, Air Force, NASA, etc.) and the WSMR sales engineer, approaches the production scheduling and control department to establish a tentative test schedule.

In any job shop, production scheduling is, at best, a problem of nightmarish proportions, involving the assignment of men and machines to a particular sequence of tasks and to insure that the materials required for each stage of the processing are available at the machine centers when they are required. At WSMR, the production scheduling task is compounded by the fact that the "shop floor" covers an area of some 4,000 square miles and part of the raw materials required for a test are moving at supersonic velocities.

One end product of the White Sands job shop is a data "report" which may be produced in "real-time", immediately after the test is completed for "quick-look" assessment of test results, or some time after the test is completed for "post-test" data reduction. Nearly all tests require one or more of the data reports listed above. In addition to the test conductor or Range user, there are usually other "customers" involved with any particular test. For example, the Missile Flight Safety Officer requires certain real-time data reports so that he can make the necessary hold/fire or continue/terminate decisions required to insure the safety of personnel and property within the total test envelope. Certain items of production machinery (data collection, handling, transmission, and processing systems and equipment) are, themselves, Range customers, in that they require timing and pointing information as the test proceeds so that they can perform their required functions.

The acquisition and replacement of production machinery at WSMR is not significantly different than in any other production facility. The investment in White Sands is in excess of $1 Billion, of which only 30% represents facilities (buildings, power distribution, etc.). This factor, coupled with the long acquisition lead time, high unit cost for instrumentation systems, and ever increasing demands on accuracy and precision, provides a challenge to our "manufacturing engineering" department (i.e., range instrumentation R&D) in planning for and acquiring new instrumentation systems and equipment.

Whereas it is sometimes beneficial to think of WSMR in terms such as these, some problems arise simply because there is no real marketplace measure of performance. For example, there is no readily apparent vehicle for measuring the improvement in performance wrought by acquisition of a new instrumentation system. This is especially true of general purpose systems. In some cases, it may be possible to demonstrate that acquisition of a new system with greater accuracy and more versatility can reduce the number of tests required for a particular program. However, the "savings" may be more than offset by increased O&M costs for support of many more programs where the full capability of the new system is not required. In the past, it has been axiomatic that greater accuracy and/or precision is "better". Under the new Uniform Funding Policy promulgated by DoD whereby Range users are required to pay for the direct costs of testing, it will be necessary to consider much more carefully the question of what is "better."

IV SPECIFIC APPLICATIONS OF OPERATIONS RESEARCH TO MISSILE RANGE OPERATIONS:

Recognizing that the nature of the WSMR activity was amenable to OR/SA techniques, several applications have been completed or are currently ongoing. For example, the "optimal" location of data collection instruments in support of missile flight tests has been recognized as a legitimate problem since the first rocket firing at WSMR in September 1945. Typically, the objective of most of these location studies has been to optimize performance (e.g., minimum expected error) for a single mission or even a single trajectory point, costs not considered. Needless to say, the optimum deployment of instruments based upon a single test accuracy criterion will bear little resemblance to a configuration based upon a minimum cost criterion. L. E. Stanfel of the University of Texas at Arlington, under contract with WSMR, began work on the location problem based upon a cost minimization objective function with the constraints guaranteeing acceptable performance. Such elements as the location of fixed and mobile sites and the types of available instruments, along with estimable future workload requirements, are considered in the model. To date, the theoretical aspects of the problem have, for the most part, been worked out, using an integer programming approach to the optimization. Preliminary results seem promising and further development is continuing.

Equipment replacement problems have been addressed at WSMR at least annually since the Range began operations. In 1970, B. D. Sivazlian, The University of Florida, developed several models for computing the most economical replacement age for two classes of equipment, intermittently and continuously operating. Although the technical content is sound and the potential benefit from application of the models to WSMR's equipment replacement decision making process is significant, the work has not been utilized.

Selection from among several instrumentation modernization projects competing for limited R&D funds is yet another recurring problem at White Sands. A solution should describe how much to spend on each project each year; this is, of course, an amalgamation of the familiar R&D Project Selection Problem and the Capital Budgeting Problem. Because projects are not, in general, independent, and the fact that most require work beyond a single budget year, it is reasonable to treat the problem as a sequential decision process. An attractive technique, and one applied by Robert E. Green of WSMR, to the Range Modernization Program, is dynamic programming. This model employed a payoff function which included, among other things, subjective probabilities of improved system effectiveness. Major problems with application of the dynamic programming model included estimating these probabilities and assessing progress of developmental tasks.

The Range scheduling problem alluded to in the preceeding section has been the subject of a number of investigations and a significant amount of work. For example, RCA Service Company, under contract to WSMR, developed a fairly sophisticated simulation model to describe the interaction of various resources required to support a daily schedule of missions. Airspace, groundspace, measurement capabilities of various instrumentation systems, requirements for roadblocks, and launcher availability were among the resource variables considered in the construction of the model. Based upon a given mix of test programs competing for test resources, a two-week "maximum feasible schedule" was generated, and a Monte Carlo simulation of daily operations, including holds, aborts, and cancellations, was run to provide an analysis of daily workload, support limitations, and cost. Completion of this effort preceded the phase-in of WSMR's third-generation computer system by less than one year. Since much of the programming was in machine language, the simulator was not used for purposes other than demonstration of its potential usefulness.

More recently, P. H. Randolph, New Mexico State University, and R. E. Green, WSMR, have devoted considerable effort to the development of an algorithm for constructing an approximation to an optimal daily schedule employing an enumeration technique and invocation of a stopping rule. Because of the general difficulty of scheduling problems, the authors were forced to treat a simplified version with respect to the true problem at WSMR. This simplification, coupled with the fact that Range Scheduling is a virtual real-time process and lack of a suitable data base has resulted in resistance to implementation of an automated scheduling procedure.

Stephen J. Lawrence, whose paper entitled "ORSA Techniques Applied to a Missile Flight Test Data Report Production Control System," abstracted in these proceedings, describes an interesting approach to the study of multi-resource constrained scheduling processes. In this study, a stochastic network of queues describing a data reduction process and report preparation is simulated by a GERT model. Preliminary results indicate that the technique may prove beneficial to line management to determine capacity constraints and assist in establishing near optimal personnel-equipment mix and assignments to minimize data report preparation time.

V EXPECTED VALUES OF WSMR's OR/SA ACTIVITIES:

It is interesting to note that many of the successful implementations of OR/SA activities have taken place in the Defense community. By and large, the greatest successes have been in the area of weapon systems acquisition. These observations lend some support to the factors affecting implementation suggested by Ackoff and Rivett [1] and by Rubenstein, et. al. [7]. In most of these cases, the OR/SA group reports directly to the Project Manager who is, in general, well acquainted with the "black art" practiced by the OR Analyst. Ackoff and Rivett indicate that successful implementation requires that,

> "The OR team should never report to anyone lower than the authority capable of controlling all the functions involved in the study ... The cost of the research should be borne by those for whom it is conducted."

Rubenstein, et. al. [7] failed to define "effectiveness" as a concept and suggest that it is one of the most difficult concepts with which they have had to deal. Their model of the implementation phase depends upon "Management's perception of OR client relationships, perceived significance of solutions, and perceived relevance of solutions."

Our own observations of many OR/SA tasks undertaken at various times throughout WSMR lend support to the foregoing observations. The principal reason for rejection of an OR/SA solution by line management seems to be a general failure to develop a consultant-client relationship between the analyst (or analysis group) and management of the organization for which (or whom?) the study was conducted. In those cases where the affected line manager was instrumental in causing the study to be conducted or where he was intimately involved with the definition and structuring of the problem, the recommendations were, almost without exception, adopted.

OR/SA activity at White Sands is, by Rubenstein's definition, in the Transitional Phase. Management has indicated its intention to use OR in the decision-making process of the organization. To enhance the probability of successful implementation of OR/SA studies, we are engaged in developing an on-post masters' degree program in OR in cooperation with New Mexico State University. Initial response has been overwhelming. Nearly 200 employees have expressed an interest in the proposed program.

To establish the client-consultant relationship between WSMR's Analysis Group and Operating Management, a radical change in our method of operation has been proposed and will be implemented in the near future. The proposal consists of assignment of OR analysts from the Plans Office on detail to operating elements as project leaders and/or consultants to study teams tasked by line management to perform well-defined OR studies. This involvement by line managers and organizational OR analysts is expected to accrue to a significant improvement in our OR/SA implementation score card.

There is a plethora of challenging opportunities for OR/SA activities at this National Range for the simple reason that its operations are so technically and geographically diversified. The White Sands Missile Range Command Group is very much aware of its OR/SA staff element and consequently, we expect to have ample opportunity to assess the progress and implementation success of the OR/SA function in our group.

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Determination of 2.75 Inch Rocket System Potential Through Testing and Analysis

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For 2.75 Inch Rocket System

INTRODUCTION

The 2.75 Inch Rocket System is not a product of system analysis. The 2.75 Inch Rocket was adopted for Army use as an air-to-ground weapon primarily on the basis that it was available, adaptable for use with helicopters and was relatively low in cost. This paper will discuss the value of operations research to the rocket system from the viewpoint of management involved with system analysts through a series of studies, tests and analysis.

BACKGROUND

The 2.75 Inch Rocket was originally developed by the Navy as an air-to-air weapon prior to the Korean war. In this era, before guided air-to-air missiles, this free rocket was designed to be fired in shotgun-like salvos to detonate a small high explosive warhead within the target aircraft. As a primary air defense weapon in the mid 1950's the Navy stockpiled large quantities of the rocket with MK4 rocket motors.

In the late 1950's, the Weapons System Lab of the Army Ballistic Research Lab became the center for evaluating candidate rocket systems in order to select one as the air-to-ground weapon for the growing fleet of Army helicopters. A number of candidate rockets from 1.7 to 4.5 inches were considered and experiments were conducted. It soon became apparent that the only aerial rocket with sufficient stockpiles to support a continued program was the Navy 2.75 Inch Rocket. The existing stockpiles of Navy MK4 motors were disassembled in order to modify them by taking an angular section from each of the four nozzles. This modification imparted a low spin characteristic to the rocket, so important for stability when launched from a low speed helicopter. The modified MK4 motors were redesignated as MK40 Low Spin Folding Fin Aerial Rockets (LSFFAR). The Army Missile Command became involved in the early 1960's in the outfitting of the UH-1 Iroquois as the Army's first operational helicopter gunship. Similarly in the early 1960's, Picatinny Arsenal, then under the Munitions Command, accepted the technical responsibility for development of new warheads and fuzes for the helicopter air-to-ground role.

The Office of the Project Manager for the 2.75 Inch Rocket System was established at Picatinny Arsenal in 1965 to manage the system's high rate of production on a Tri-Service basis. At that time, the Navy retained the technical responsibility for the MK4 and MK40 rocket motors.

In 1967 the Navy relinquished technical responsibility for the rocket motors to Picatinny Arsenal, while the Missile Command retained responsibility for Army rocket launchers. During the peak usage rates in Southeast Asia when hundreds of thousands of rockets per month were both produced for and expended by the Tri-Services, the rocket system proved itself. It was reliable and carried warheads comparable to 105MM artillery shells.

INITIAL SYSTEM ANALYSIS

In the interim and with the 2.75 Inch Rocket System in being, system analysts started to evaluate how well the system performed. The initial assessment of performance was that it was marginal due to rocket inaccuracy and efforts were begun to develop a replacement system. At that time, little was done to evaluate in detail just what the characteristics of the system were and determine what improvements were necessary. The rocket accuracy from ground launched tests obviously left something to be desired. The fin stablized rocket naturally weathervaned into the local airflow when fired from a helicopter and pilots both cursed and blessed its performance.

Some pilots in Vietnam fired tens of thousands of rockets and became good rocket gunners; other pilots preferred to use other weapons when available. Within this environment, the Project Manager, in 1969, directed the Munitions Command (MUCOM) Operations Research Group (ORG) to conduct an analysis of the characteristics of the system. MUCOM ORG reviewed the available test reports, using helicopter launched data where available. Their evaluation was that out of 13 air launched tests, only five approximated the ground impact locations. Of these five tests only one accurately scored the impacts and none had properly scored both the helicopter and impact positions. However, an evaluation of the system was conducted and MUCOM ORG advised that reduction of the system delivery errors was possible.

TESTING AND ANALYSIS

Subsequently, the Project Manager initiated a major air-to-ground system accuracy test which became known as the 2.75 Inch Rocket/AH-1G System Baseline Accuracy Test. The objectives included a determination of the system accuracy and an error budget as well as potential cost effective system improvements. The test was structured to include a basic instrumentation checkout without firing rockets, followed by a rocket firing test from various ranges and attack profiles, using the same highly instrumented procedures. This phase of the test was conducted at the Test and Evaluation Command's Yuma Proving Grounds, Arizona with aero-ballistics personnel from Picatinny Arsenal supporting the test and analyzing the data. Concurrent with the last portion of the tests at Yuma Proving Grounds, the final phase of the test was conducted at the Naval Weapons Center, China Lake, CA which was structured to represent tactical conditions. In the tactical phase, 14 Army attack helicopter pilots of varying experiences fired rockets from the same Cobra gunship with minimal on-board instrumentation; however, helicopter and impact positions were scored accurately.

Munitions Command Operations Research Group was again tasked by the Project Manager to analyze the Baseline Accuracy Test data to determine the system effectiveness. Through coordination between the test engineers and the system analysts, a representation of the system was developed from the data. In order to represent the dynamics of an aerial rocket system, it was decided to develop a Monte Carlo simulation program to sample from the cumulative error sources and thereby represent the variable conditions of multiple attacks and rocket launches. The error sources were defined in terms of the following distributions:

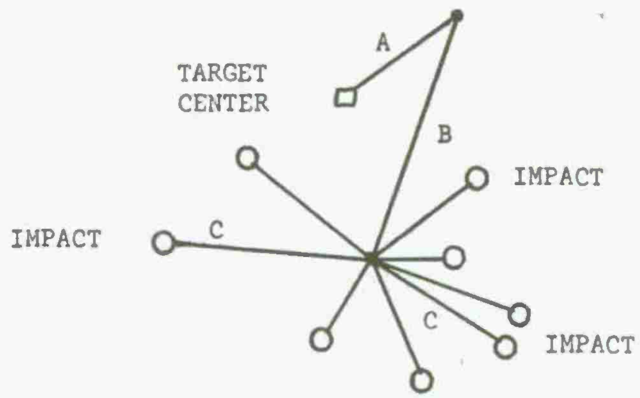
a. Pass to pass.

b. Ripple to ripple.

c. Round to round (see Figure 1).

The pass to pass and ripple to ripple distributions were developed from the tactical test data where successive passes were made at a fixed target, and successive firings were made during each pass. Since the tactical test only used ripple sizes of two rockets, data from larger ripples gathered during the previous instrumented test phase were substituted for the round to round or ballistic distributions. The distributions of accuracy in the range coordinate were evaluated as a function of range due to the test conditions and available effectiveness methodology. (See Figure 2). The effectiveness of the current 2.75 Inch Rocket/AH-1G system was calculated by using the Monte Carlo simulation program to sample from the error source distributions. With this technique, the variabilities in an aerial engagement of a target were represented, and the location and the effects of each warhead impact with respect to the target were evaluated. A matrix of 123 combinations of ranges, ripple sizes, targets and warheads were selected to include a spectrum of attack profiles and targets including personnel, materiel and armor. The level of target defeat was assessed after each ripple of rockets with respect to a fixed level of defeat or effectiveness. If the defeat level had been achieved, the attack was terminated. If the target had not been defeated, additional ripples or passes were simulated until defeat was achieved. Since time and funds were limited, the distributions were truncated and only 50 replications of the attack were conducted for each point in the matrix. The output of the program was evaluated in terms of the 10th and 90th percentiles as well as the average number of rounds to defeat the target.

FIGURE 1: GRAPHIC EXAMPLE OF AERIAL ROCKET ATTACK SIMULATION

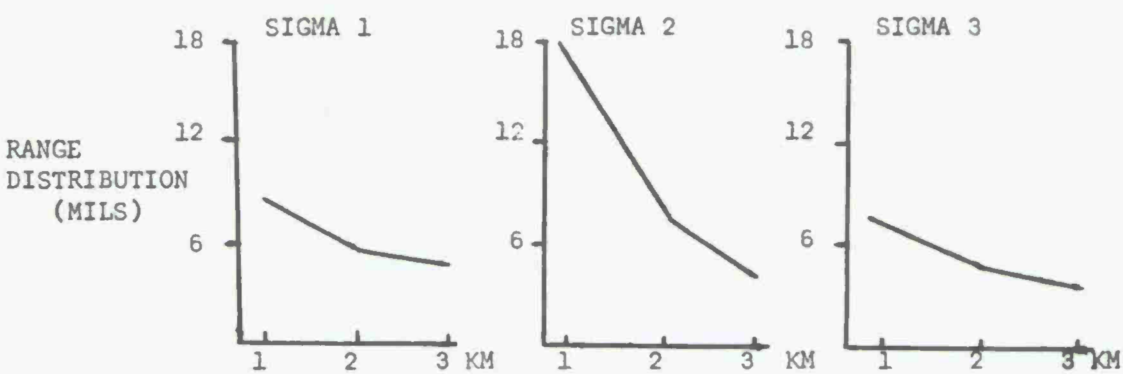


A = SIGMA 1 - PASS TO PASS DISTRIBUTION ABOUT THE TARGET

B = SIGMA 2 - RIPPLE TO RIPPLE DISTRIBUTION DURING A PASS

C = SIGMA 3 - ROUND TO ROUND DISTRIBUTION OF ROCKET IMPACTS

FIGURE 2: DISTRIBUTION VALUES FOR THE SYSTEM DESCRIPTION DERIVED FROM TEST DATA



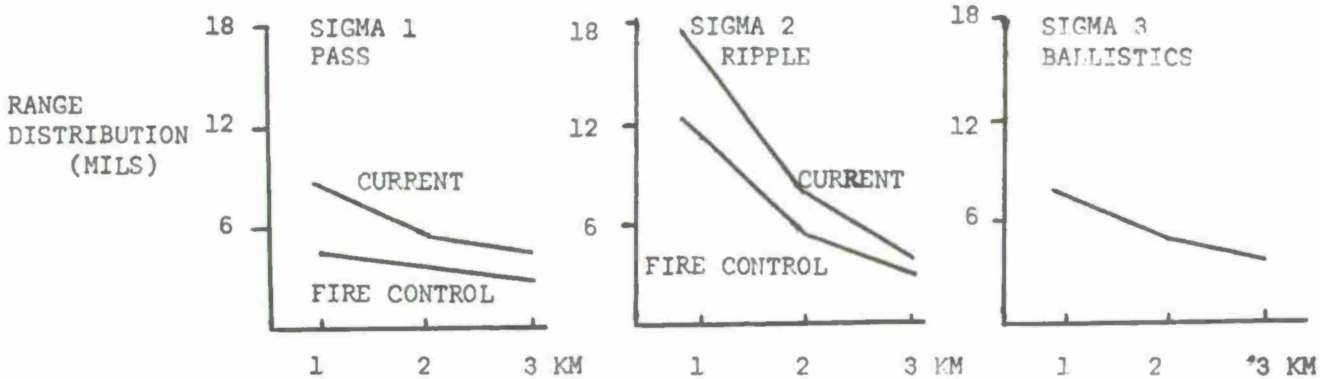
	SIGMA 1	SIGMA 2	SIGMA 3
AZIMUTH DISTRIBUTION (MILS)	9	10	11

Upon evaluation of the magnitude of the pass to pass and ripple to ripple distributions, it was apparent that simply a reduction in the round to round distribution would not make a significant change in the effectiveness of the system. Estimates were then made for the reduction of the pass and ripple distributions which could be provided by adding fire control to the helicopter. (See Figure 3). Once fire control was added, the round to round distribution was also reduced by application of test data gathered on a 2.75 Inch Rocket modified to improve ballistic accuracy. The effectiveness for the current system and for each of the three 2.75 Inch Rocket/AH-1G System Concepts were calculated with the same methodology. The improved systems reduced the average number of rockets needed to defeat each target as well as reducing the variability of the helicopter system as represented by the band of the 10th to 90th percentile levels. The study further confirmed that helicopter fire control was a cost effective method to increase system effectiveness.

ADVANCEMENT IN SYSTEM ANALYSIS TECHNIQUES

A few months after the Baseline Accuracy data became available, the 2.75 Inch Rocket Project Manager's Office initiated a fire control working group to detail a low cost fire control subsystem which could be retrofitted into the Army's AH-1G fleet. Subsequently, sponsorship of this study effort was accepted by the Cobra Product Manager's Office at AVSCOM with support from MUCOM ORG, the Army Materiel Systems Analysis Agency (AMSAA), Frankford Arsenal, the 2.75 Inch Rocket Project Manager's Office and other interested agencies. During this Fire Control Analysis, MUCOM ORG again provided the effectiveness data on the rocket subsystem, while AMSAA supplied turreted weapon effectiveness. Building upon the experience gained during the Baseline Accuracy Study, the system errors were identified in a different manner. One of the major goals of the Fire Control Analysis was to determine the impact of the accuracy of rangefinding on the effectiveness of the total system. Consequently, the system description was parameterized in terms of distributions for range error, subsystem error and ballistic dispersion. Range error was varied from a sigma of 25 percent down to 25 meters, representing range-finding capabilities from visual estimation to a fully stabilized laser rangefinder. The subsystem errors were based on the difference between the available data for the current subsystem and the residual errors which would remain within a fire control. The basic ballistic dispersion of the rockets fired in ripples was held constant. (See Figure 4). Whereas, the Baseline Accuracy Study used accuracy values which were a function of range (see Figure 2), MUCOM ORG had developed modifications to their methodology which allowed representation of the basic rocket trajectory characteristics independent of range. The trajectory methodology also allowed use of the same system description in a number of attack profiles. During the Fire Control Analysis, time and funds did not permit use of the Monte Carlo simulation technique against all

FIGURE 3: COMPARISON OF DESCRIPTIONS OF THE CURRENT SYSTEM AND ESTIMATED FIRE CONTROL IMPROVEMENTS



AZIMUTH	CURRENT	9	10	11
DISTRIBUTION;	FIRE CONTROL	5	3	11

FIGURE 4: SYSTEM DESCRIPTIONS FOR A ROCKET FIRE CONTROL ANALYSIS

SYSTEM	RANGE SIGMA	SUBSYSTEM SIGMA	BALLISTIC SIGMA
A	25% (Current)	13 Mils (Current)	9 Mils (Current)
B	20% (Improved)	13 Mils (Current)	9 Mils (Current)
C	10% (Improved)	13 Mils (Current)	9 Mils (Current)
D	25 Meters (Improved)	13 Mils (Current)	9 Mils (Current)
E	25% (Current)	8 Mils (Fire Control)	9 Mils (Current)
F	20% (Improved)	8 Mils (Fire Control)	9 Mils (Current)
G	10% (Improved)	8 Mils (Fire Control)	9 Mils (Current)
H	25 Meters (Improved)	8 Mils (Fire Control)	9 Mils (Current)

the targets. Instead, a Matrix Program was used which produced an expected effectiveness value as an average output for the distribution of impacts around the target. The Monte Carlo simulation was only used in select cases to crosscheck the Matrix Program output. During this study, the effectiveness of a helicopter load of ordnance was to be evaluated, so that the number of rockets was held fixed and the level of effectiveness was allowed to vary. The helicopter was assumed to be rippling the complete load as rapidly as possible. Personnel, materiel and armor targets were again chosen as representative to evaluate the improved subsystems.

The results of the Fire Control Analysis was unexpected in some aspects, for it determined that range accuracy was not as important as reducing the subsystem error at the range of 1,500 meters. At the range of 2,500 meters, range accuracy was more important, but overall significant system improvement was achieved by reducing both range and subsystem error. The Fire Control Analysis was successful in providing further definitive information on the improvement in system effectiveness which could be provided by helicopter fire control. A further recommendation on the method for rangefinding in support of this analysis has recently been forwarded to the Army Materiel Command, and it is expected that an engineering development effort will be initiated.

EVALUATION OF SYSTEM POTENTIAL

The experience of the 2.75 Inch Rocket Project Manager's Office with the system analysis performed during the Baseline Accuracy Study and the Fire Control Analysis developed an awareness of the value of Operations Research. The application of these techniques to determine in advance how changes in the system would impact on performance became a necessity.

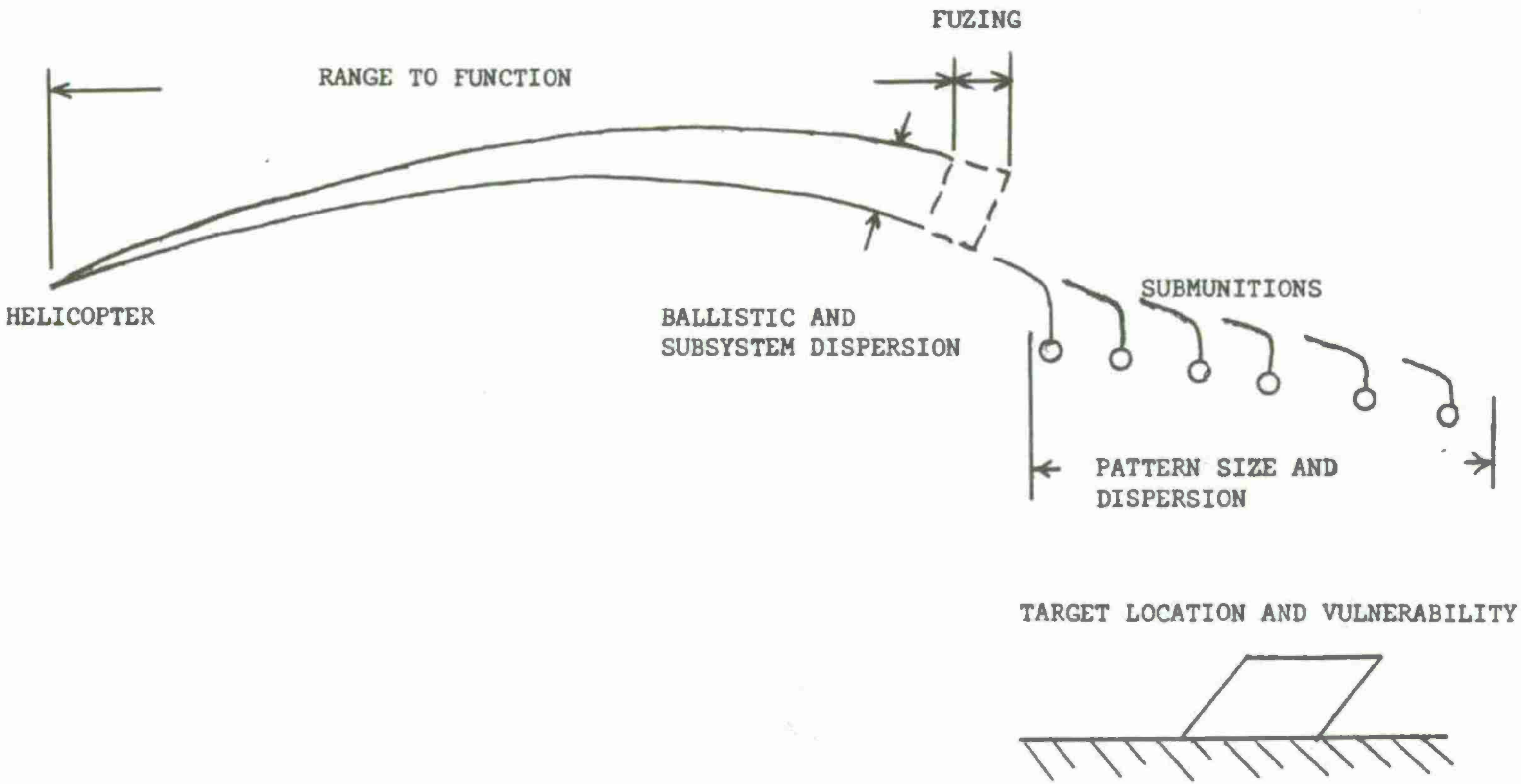
The desireability of simulating a proposed improvement as realistically as possible is most clearly demonstrated in the development work now being done on a new warhead concept. Through coordination between design engineers and system analysts at AMSAA, assumptions were developed for the deployment of a cargo warhead which would eject multiple submunitions. The submunition was assumed to be multi-purpose in nature with a fragmenting body for anti-personnel and light materiel effects plus a shaped charge for heavy materiel and anti-armor effects. The concept included multiple rocket ripples to deliver a large number of submunitions into an area, thereby increasing the probability of hit on point targets, while providing good effectiveness against the area target. The concept included a high drag device on each submunition which, upon expulsion, would rapidly decay the high horizontal velocity imparted by the rocket, thereby slowing the submunition into a near vertical fall. By firing ripples of these rockets, a high density of submunitions could be achieved.

The vertical descent, and orientation of the shaped charge, is expected to provide good effectiveness against armor targets since the tops of armored vehicles provide the least protection. The submunition warhead concept has supplied a new challenge for the system analysts. In addition to range error, subsystem error and ballistic dispersion, they now had the problem of representing air burst fuzing error, distribution of the multiple unit payload, and the effects of many submunition units saturating an area. (See Figure 5). The initial effectiveness calculations performed by AMSAA included submunition payloads of 10 or 36 units per warhead with 76 warheads per helicopter. The larger number of submunitions were defined as being subcaliber in size with a lower lethality per unit. Patterns achieved from each warhead were also parameterized with the assumption of four sizes.

The results of the effectiveness calculations with the submunition warhead indicated that a significant increase in effectiveness could be attained. The increase was much greater than could be achieved by high explosive unitary or flechette warheads, even with the best fire control from the previous studies. The submunition warhead's requirement for an airburst warhead to function at the proper range is partially solved by such a fuzing subsystem under development by the 2.75 Inch Rocket Project Manager. The need for complementary fire control rangefinder was also obvious and it is expected that development of a fire control subsystem for the AH-1G will be available in the same time frame as the new warhead.

Although the larger number of submunitions per warhead appeared to have the best anti-personnel effects, pragmatism and the desire to keep development and hardware costs as low as possible have directed the major efforts towards the full caliber submunition with 10 per warhead. Prototype hardware penetration tests have confirmed that the estimated probability of armored target defeat, given a hit, had been a good approximation. Hardware fragmentation tests are expected to provide confirmation of the lethal area estimates. The assembly of hardware mockups by Picatinny Arsenal and subsequent live firings at the 2.75 Inch Rocket Test Site at the Hawthorne, NV Naval Ammunition Depot have confirmed the estimates of pattern size and evaluated techniques for dispersal of the submunitions. The process of developing assumptions of hardware performance, calculating effectiveness, designing hardware to perform in the prescribed manner and confirming the design by actual tests has been demonstrated to be an efficient method for system development. Significant portions of the development work remain to be done; however, in reviewing previous developments by the Tri-Services in similar submunitions, the development of a high drag, multi-purpose submunition warhead appears to be only dependent upon the Army's desire for a new capability in aerial rockets. Under direction of the Project Manager, the technical agency, system analysts and the test site have successfully cooperated in bringing an improved warhead through to a successful prototype design.

FIGURE 5: SIMULATION OF A HIGH DRAG, MULTIPURPOSE SUBMUNITION, ROCKET WARHEAD CONCEPT



SUMMARY

The series of studies, tests and analysis in which the 2.75 Inch Rocket Project Manager's Office has been involved, has reaffirmed the need to conduct Operations Research improvement to the system which can be quantified. From a system manager's point of view, Operations Research is needed in order to save time and money in the development of effective hardware. Without the assessment by system analysts, the enthusiasm of management and users would not be as evident as it is today in support of concepts such as fire control or a new warhead. In this manner, management has come to be familiar with the necessity for Operations Research and System Analysis.

SYSTEMS ANALYSIS: A PURELY INTELLECTUAL ACTIVITY[1]

Seth Bonder
Vector Research, Incorporated

This paper was originally prepared and presented as the keynote address at the 25th Military Operations Research Symposium in June, 1970. The working group chairman has requested that it be presented at this Symposium, essentially intact, since he (and I) believes that the main ideas are still both relevant and important.

I am honored to have been invited to present the keynote address at this the 25th Military Operations Research Symposium.

A keynote speaker at MORS should stimulate, perhaps provoke, attendees to think about the essential issues regarding the application of operations research and systems analysis to defense planning. Yet it is difficult to develop new provocative thoughts about our field, which has received a great deal of introspection and appraisal in the last couple of years -- most of it critical. This criticism, levied by both those high on the Hill and from within our own community (e.g., Frosch, 1969; Kent, 1969; Flax, 1969; Bonder and Pollock, 1969), blames poor quality analyses and analysts for the fact that systems analysis has not become the panacea for defense planning. Apparently the new administration has listened to this criticism, as evidenced by the fundamental change to the "participatory management" concept, which purports to give increased power to the military Chiefs of Staff with an associated decreasing role (and stature) for the OSD-Systems Analysis Office (Hamilton, 1970). Extrapolating General Kent's comment from the last keynote address (Kent, 1969) that we are "...in the limelight with an edict to produce or perish," the 1970's could possibly see a repeat of the Hoxie committee (Davidson, 1952), which in 1910 legislated against the use of efficiency experts on government contracts.

Thus, I could fulfill my keynoter's role, and surely provoke you, by following the favorite pastime of expanding on the failures of the analyst. Instead, I have organized a number of thoughts, some of which I have said before but bear repeating, to show that the loss in credibility of systems analysis is due not only to poor quality analysis, but also to the failure of our client and ourselves to recognize that systems analysis is a purely intellectual activity and, as such, is inappropriately performed and used in the management of defense resources.

World War II operations research activities were primarily directed to analysis of existing military systems to improve their operating efficiency. The availability of systems and the ongoing military operations

[1]Keynote address presented at the 25th Military Operations Research Symposium, New London, Connecticut, 16 June 1970.

facilitated the gathering of data on the systems capabilities and effectiveness, enemy characteristics and tactics, and environmental factors for use in the studies. The operations research activities might well have been called "operational inference" for much of the effort was devoted to estimation of system effectiveness and inferences regarding future operations. The efficacy of this kind of study is recorded in history.

Operations research was then a scientific activity, justified by the general success of the scientific method. Much of systems analysis today is not scientific but, to use a classical term, "natural philosophy." It is an intellectual art used in making necessary and useful predictions in problem areas where experiment and verification are difficult and at times impossible. Failure to recognize this change has resulted in gross misuse of systems analysis by the defense community. This morning I will attempt to establish this thesis and reflect on a number of problems it has created.

The shift in the fifties and sixties to problems of broader scope and complexity, such as the development of weapon systems, force composition, and in general planning for future programs, placed greater emphasis on prediction rather than inference. The move toward more centralized defense decision making in 1961 required the military services to learn and use systems analysis as a means of quantitatively justifying their share of the defense budget. Because of this emphasis on prediction and the requirement to quantitatively justify requests for resources, the concept of a model or representation of the real world has become central to the use of systems analysis, military or otherwise. If you will allow me the luxury of a simplified taxonomy, we rely heavily on systems engineering models to predict a system's engineering performance capabilities (such as an advanced bomber's speed and range and a proposed tank's accuracy and firing rate), operational models to predict its effectiveness, and cost models to predict a system's life-cycle costs.

Models, of course, are not a new concept, their development and use being integral to the physical sciences dating back conservatively 500 years to Copernicus and liberally 2400 years to the Greek philosophers. Fundamental to the procedure for developing models, and to my thesis, is the scientific method shown schematically in figure 1. At the risk of sounding tutorial, let us take a moment to examine the basic activities of the method.

The procedure begins by abstracting the real-world process in terms of those factors that reflect its relevant aspects. The scientist decides (a) which factors to consider initially as important and how to define them operationally, (b) what measures of performance to use, (c) what factors to consider as variable or constant, and (d) where to suppress randomness, thus creating a qualitative model of the process or system under study. Assuming the system he is modeling is an existing one, or structured somewhat like an existing one, his ties with the real world are retained via the measurement link. The data might first be used to

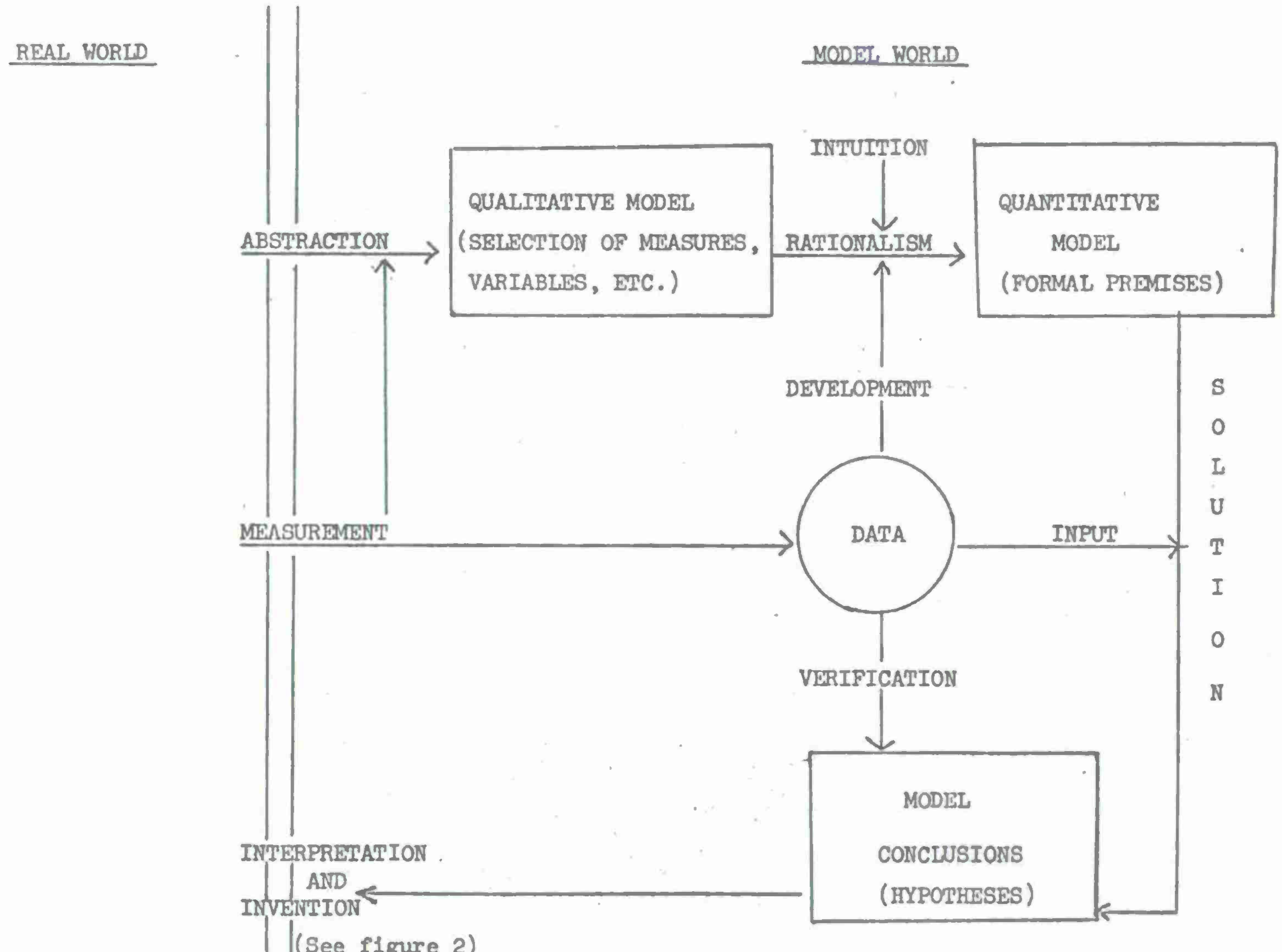


FIGURE 1: THE SCIENTIFIC METHOD OF MODEL DEVELOPMENT

provide some insights in performing the abstraction activity. Data, and a heavy dose of intuition, are then used in the rationalistic activity to develop, by both empirical and formal logic methods, relationships among the system factors. Essentially this is a process whereby the scientist creatively specifies model assumptions which hopefully represent the process behavior.

The relationships are formal premises which have to be solved in terms of the selected performance measures. The solution activity is usually, but not necessarily, a deductive one. Data from the real world are used as input to the solution activity in the form of values for the model coefficients, parameters, or distributions depending on the form of the model.

The solutions are hypotheses or predictions about the real-world behavior which have to be verified by comparison with empirical observations of the phenomenon. Verification of the model is the process of statistically testing derived hypotheses with experimental evidence. If the data compare with the model hypotheses, this lends confidence to the use of the model, and to its hypotheses as predictions of future events. Although not shown in the figure, the procedure is an iterative one to arrive at reasonable models. There exists continual feedback of hypothesis testing to the abstraction activity in a process learning and model improvement. Empirically verified solutions are then interpreted, hopefully leading to a better understanding, and some creative ideas for controlling or changing, the real-world process. Let us contrast this procedure to the activities performed in systems analysis, shown schematically in figure 2.

The systems analyst might first assist in focusing on the meaningful problem areas associated with the existing system. This perceptive identification activity is concerned with deciding <u>what</u> problem areas are to be alleviated by the future system rather than <u>how</u> to do it. If the analyst is creative, and the problems are relatively simple, he might then invent some alternative future systems to alleviate the problems, <u>prior</u> to performing any analysis per se. These alternative systems would have to be studied by developing, and appropriately manipulating, a model of each proposed new system.

If prior alternative systems are not readily evident, the analyst would resort to modeling the existing system directly, manipulate the model and interpret its conclusions, hopefully leading to some creative alternative systems <u>posterior</u> to the modeling and analysis. Regardless of the means of generating good alternative future systems, management would then examine these options for their effectiveness and costs and apply judgement regarding budget constraints, political effects, and other intangibles before selecting a particular proposed system, if any.

My thesis that systems analysis is not scientific rests on the modeling activities that we perform in contrast to those used in the physical sciences. This distinction is shown in figure 3.

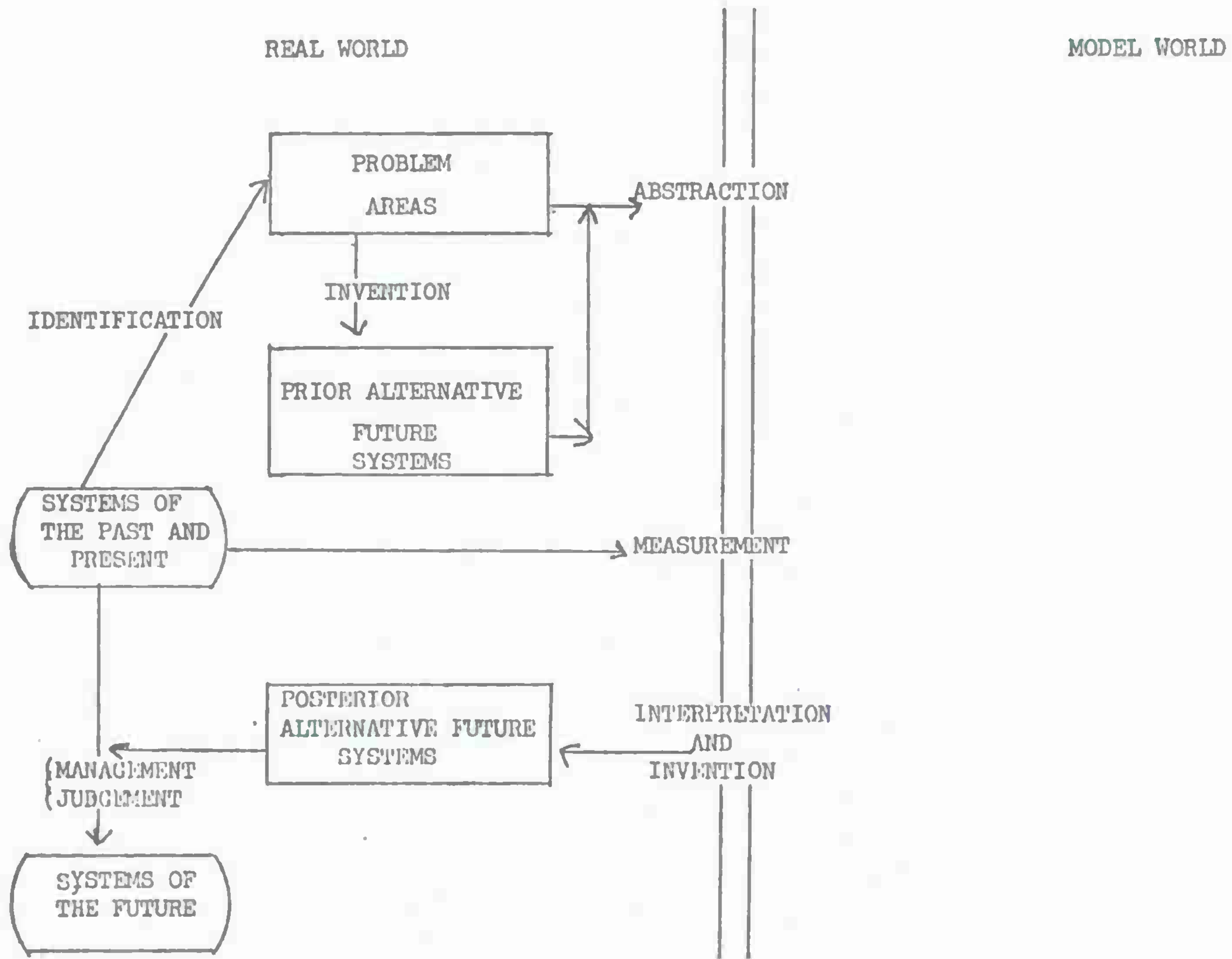


FIGURE 2: SYSTEMS ANALYSIS

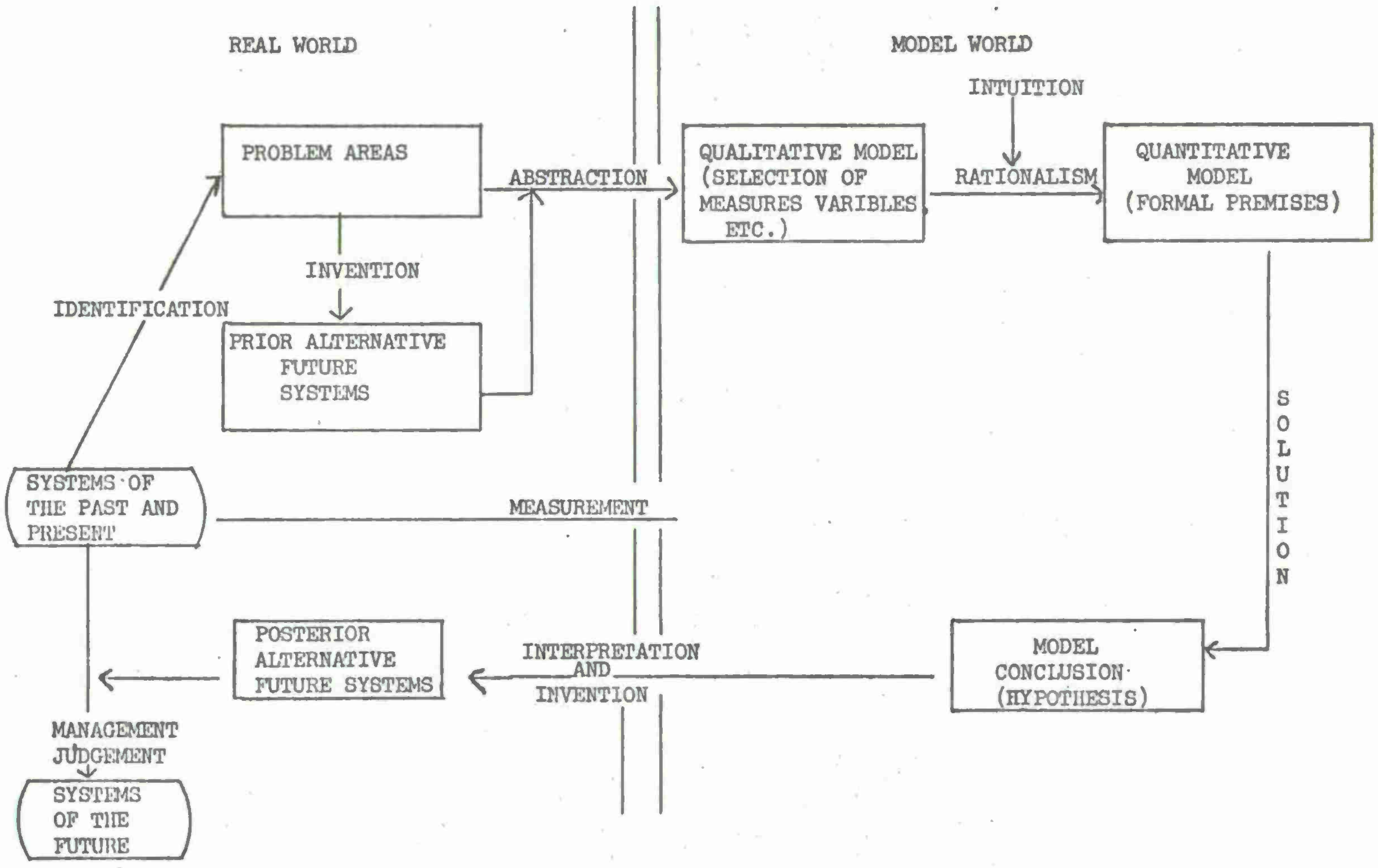


FIGURE 3: SYSTEMS ANALYSIS

Examination of the procedures employed in most planning studies would, I believe, indicate that military systems analysis does not employ the scientific method of model development, but rather, as Platonists, we think that predictive models can be developed by pure reasoning and logic alone. The systems anlayst uses models to predict the operational effectiveness of combat systems (air defense, ground combat, ICBM, AMSA, tactical fighters, etc.); yet, there clearly do not exist any verified operational models or theories of the processes, nor does it appear that data to test any existing or next generation models will become available in the near future.[2] Our experience suggests that combat is a process that does not readily lend itself to measurement. Although planning new systems requires prediction of their engineering performance capabilities, there are few, if any, verified systems engineering models that can reliably estimate performance of a system based on paper design alone.[3] The overweight problem of the F-111B, instability problems with the Cheyenne, wing failures with the C-5A, and the controversy over the technical feasibility of the ABM are apparent instances of the lack of verified predictive methods. Cost-effectiveness analyses require prediction of total system costs; yet, there are few, if any, verified cost estimating models, nor are reliable cost data being generated. Congressional investigations of the C-5A and MBT-70 evidence our inability to predict accurately procurement costs. Thus, when the measurement link between the real and model worlds is severed, systems analysis becomes a purely intellectual activity quite distinct from that of science. Failure to recognize this distinction has given rise to improper emphasis and use of systems analysis within the defense establishment and a resultant set of problems which have strongly contributed to its lack of credibility.

I have already remarked that models are central to defense systems analysis. The models can, however, be employed for different purposes within the defense planning process. The models can be used for quantitative <u>evaluation</u> purposes to provide essentially point estimate predictions of a proposed system's cost and effectiveness as information for decision-making. Alternatively, the models can be used for <u>analysis</u> purposes to provide management with

(a) insights into directional trends to increase his understanding of the system dynamics,

(b) guidelines for the development of data collection plans (i.e., what data are important, how accurate must they be, etc.), and

(c) guidelines for the development of technological and modeling research plans.

In essence, use of the models for analysis purposes, in contrast to that of evaluation, is a means of developing information that can be used to educate the analyst and decision-maker about the system.

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[2] I do not believe that any attempts have been made to use data from the Yom Kippur war to test any of our current generation combat models.

[3] Recent TETAM experiments and associated analyses suggest that even our digitized terrain LOS models, which we thought were good representations of reality, produce significantly erroneous LOS realizations.

The sort of models that are developed should, I believe, be related to their intended purpose, and the purposes for which a model is used should be consistent with its structure, verification, and ease of interpretation. My experience suggests that the DoD systems analysis activities err on both accounts.

Although a large amount of testing and verification is necessary before a model can reliably be used for quantitative evaluation of systems, the military services, whose operational, systems engineering, and cost models are rarely experimentally verified, paradoxically place primary emphasis on this purpose in the conduct of systems analysis studies. Reports of system planning studies are replete with numerical evaluations to substantiate and advocate positions that system A is preferred to system B because the exchange ratio, kills/dollar, sweep rate/dollar, or other measures of cost effectiveness are higher. Rarely are the uncertainties associated with these evaluations that might result from errors in input data and incorrect model structure or assumptions determined or included in the report. Less frequently do these uncertainties reach the ears and minds of service, JCS, and OSD decision-makers. Although the adversary system accepts, even encourages, the concealment of uncertainties, the service decision-maker must be made aware of them to make effective use of the model and its outputs.[4]

Because of the lack of adequately verified operational, systems engineering, and cost models, one would expect that the defense establishment would place heavier emphasis on use of the models in a study to develop the insights, trends, and guidelines necessary to educate management properly in the gut feelings about the system that we as analysts obtain when conducting the study. This kind of information is generated by parametric variation of the model variables and assumptions designed to answer "what would happen if ..." questions and to expose the full range of possible effects of a decision.

Paradoxically, the heavy reliance on detailed war game and Monte Carlo simulation models within the defense OR and systems analysis community makes this form of analysis extremely difficult. The difficulty stems from the excessive number of variables usually included in the model for "realism," which makes it (a) extremely costly to vary model parameters and assumptions and (b) virtually impossible to determine reliably the relationship between the many stochastic factors in the model and its output.

This improper emphasis in, and use of, systems analysis studies, and the absence of verified models have interacted with the concept of centralized management to create many of the publicly advertised failures of systems analysis. The Defense Department has had in the past, and will continue to have in the future, highly centralized control and decision-making in the allocation of defense resources. The centers of this control move around from time to time, but it is still highly

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[4]See Wilmotte (1970) for an interesting discussion of this point.

centralized. The OASD-Systems Analysis Office was the center in the MacNamara-Enthoven era, supposedly the Joint Chiefs and the services were the center under the concept of "participatory management" in the first Nixon administration, and I conjecture that OASD-PA&E is now becoming the central focal point. I do not foresee a time of decentralized control whereby investment decisions will be made at the grassroot agencies within each of the services where the studies are performed.

The classical pros and cons of decentralized versus centralized control have been argued by management enthusiasts for many years and I needn't repeat them here. For many reasons I believe that centralized control of defense resource investments is appropriate, be it at OASD-PA&E Office, the JCS, or any other center. However, failure to recognize that systems analysis is a purely intellectual activity, not a scientific one, has created a number of operating and conceptual problems in centralized management which have a direct effect on our field of endeavor.[5]

UNWARRANTED CREDENCE IN STUDIES

The idea of centralization in the Department of Defense implies a management information system capable of bringing to the decision-making office the relevant information about each proposal for use of defense resources. Under the false impression that he has a scientific study base, the decision-maker receives highly summarized, quantitatively supported investment proposals devoid of information regarding the many uncertainties and risks associated with the supporting data. Even in the rare instances when adequate parametric analyses are conducted to generate the appropriate insights, guidelines, and error effects of incorrect data and assumptions underlying the study recommendations, this information does not survive the many filters imposed between the study and decision-making levels.[6] Thus, if an investment proposal is accepted, there develops an unjustifiable certainty that the system will achieve the performance[7] and cost effectiveness estimated in the original study. These quantitative results are then presented to the legislature as undeniable evidence, based on the scientific method, that the systems are required for national security. The effect of this unfounded confidence is to focus the R&D program on one system instead of adhering to the recognized R&D strategy of parallel alternative efforts when high uncertainties are present. Controversies over the C-5A and the MBT-70,

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[5]These problems would still exist even with the unlikely return to the pre-1961 control of defense resources by individual services since centralized control exists <u>within each service</u>. That is, lower echelon organizations would still be competing for resources allocated by Department decision-makers.

[6]Theoretically at least, decentralization attempts to avoid this problem by having the decisions made at the level where the information is generated and uncertainties are clearly recognized.

[7]The interested reader is referred to memorandum "Promises Versus Achievements in the Materiel Acquisition Process" by the DUSA for some quantitative information regarding the Army's achievements.

cancellation of the F-111B, and termination of the Cheyenne (AFSS) production contract are, I believe, manifestations of this problem.

More importantly, this tyranny of numbers gives the impression that systems analysis as a tool for defense planning has failed when, in fact, there is little or no chance of success, if success is defined to be accurate, point estimate, prediction of engineering performance, system effectiveness, and system costs. It is an open question whether, if its proper analysis role were understood by the services, and if it were practiced by our community, that systems analysis would be used and would become a credible and valuable instrument for defense planning.

ADVOCACY VERSUS UNDERSTANDING

It is well recognized that, in the centralized control of defense investments in the Kennedy-Johnson administrations, the services bore the burden of proof to substantiate their requests for defense resources. As noted by Bill Niskanen (Niskanen, 1969), the Systems Analysis Office provided little or no guidance regarding assumptions, input data, threat levels, and other relevant information prior to or during the conduct of major studies by the services.[8] Accordingly, a completed study with its associated recommendations was readily rejected by simply generating different point estimates based on alternative inputs, assumptions, or models. Lacking data to support the assumptions or verify the system's predicted engineering performance, effectiveness, and costs, substantiation of service proposals, if different from those of the Systems Analysis Office, was virtually impossible. In the absence of data, proof is a meaningless concept regardless of who bears the burden.

The absence of effective communication and interaction between the services and the Systems Analysis Office created an apparent mistrust between them in the use of systems analysis studies. This resulted in an emphasis on conducting studies to <u>substantiate</u> requirements to the Systems Analysis Office, rather than studies to <u>determine</u> requirements. This distinction is an operational one which can have a marked effect on the quality of systems analysis studies. Studies to substantiate requirements, perhaps a priori management positions, stifle the analyst and destroy the creative elements necessary to developing a thorough understanding of the system.

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[8] In addition to the lack of study guidance, the OSD provided little or no guidance regarding political and budget constraints prior to performance of major systems studies. Thus, recommended forces and systems that may well have been substantiated by analyses might have exceeded budget or political constraints and therefore had to be disapproved. Rationale for disapproval, however, oftentimes focused on the study rather than the constraints. Procedures in the new "participatory management" purport to have eliminated this problem (see Hamilton, 1970).

Under the "participatory management" concept in the 1968-1972 time frame, the shoe supposedly was on the other foot in that the burden of proof for changes in the Joint Chiefs proposed military program lay with the Systems Analysis Office.[9] This meaningless "burden of proof" syndrome will, I conjecture, continue to serve only as a deterrence to cooperative analysis efforts to study and understand alternative system choices.

The development of a truly scientific study base to eliminate or reduce some of these problems is at best a long-range partial remedy, if at all possible. The following is a set of suggestions for ways to change the systems analysis activity, and embed it in an environment of cooperative efforts within defense management.

(1) In the absence of a scientific base of knowledge, an increased emphasis should be placed on parametric analyses in systems analysis studies to supplement the quantitative evaluations of engineering performance and cost-effectiveness of proposed systems. The activity should focus on developing trends, insights, and knowledge of the systems and the uncertainties surrounding the evaluations to provide the decision-maker with information that exposes the full range of possible effects of a decision. This information should be made available to higher echelons and stressed in final reports rather than suppressed. This emphasis in study activity may require the development of faster running, less detailed models rather than the existing trend toward more detailed descriptions that tend to be isomorphisms of the system with perfect fidelity rather than models.

(2) There should be an increased involvement by decision-makers at the service, Joint Chiefs, and OSD levels in major systems studies conducted at lower service echelons. This involvement should be through military-civilian analytic staffs who participate in lower level service studies but have direct verbal access to appropriate decision-makers. These staffs should serve as a management information system which can effectively communicate the system insights and the uncertainties associated with proposals for defense resources.[10] This information will enhance the judgment capabilities of military management by supplementing their real-world experience with insights obtained from the parametric analyses. Involvement by these analytic staffs will, I believe, produce some additional benefits:

(a) the existing antagonism between the military services and the Systems Analysis Office will be reduced, since their

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[9]One might conjecture that the focal point has shifted again.

[10]The Army's "Red team" concept in the ASRC process might be considered a move in this direction.

mutual participation will affect either prior agreement on assumptions, input data, and constraints of a study or, preferably, ensure that the study is run under different and many sets of assumptions, and

(b) the quality of studies will be improved due to the increased technical capability provided by the higher level service, JCS, and OSD staffs, thus making efficient use of scare technical talents which presently devote their energies to reviewing instead of doing studies.

Use of higher echelon analytic staffs in this manner will have the effect of placing the advocacy of the different centers where it belongs, at the beginning of the process in the form of alternative study assumptions, rather than using the study results to support a desired management position.

(3) Because systems analysis is a purely intellectual activity, the burden of proof should not be levied on any one center, but should be jointly on the services, the JCS, and the Systems Analysis Office. Effectively, the burden will rest with the conduct of quality service studies that have heavy involvement of JCS and OSD staffs. The emphasis should be on the use of systems analysis as a learning vehicle and not as an instrument for advocacy. Military judgment can and should be integrated into the process by (a) these staffs as guidelines for the study structure and assumptions and (b) the decision-makers after sufficient interchange with the analytic staffs to develop and highlight their intuition about the system and to learn of the uncertainties associated with the study.

(4) An inventory of standard models to estimate operational effectiveness, engineering performance capabilities, and costs should be maintained for use in major systems studies. These models should be capable of implementing alternative sets of assumptions jointly agreed upon by the service, JCS, and OSD staffs, and their predictive capability and sensitivities should be continually assessed. This will, at least, provide the best available models for major studies and will minimize the task of extracting all the biased assumptions from each study. Additionally, the availability of standard models will reduce the excessive redundancy in model developments and focus the scarce technical talents on model enrichments rather than continually "re-inventing the wheel" for each study.

I would like to conclude with a quasi-relevant baseball story. It involves three umpires who were arguing about the difficulty of calling balls and strikes. The youngest of the three claimed he had no problem, stating "If the pitcher throws a ball, I call it a ball and if he throws a strike, I call it a strike." The second, a middle-aged umpire, smiled and replied "It's not quite that simple. If he throws a ball, and if I see it as a ball, then I call it a ball. If he throws a strike, and if

I see it as a strike, I call it a strike." The third smiled sagely and said "Neither of you understand the job of umpiring — it's nothing until I call it."

The time has come for us to take stock and call systems analysis what it currently is — a purely intellectual activity. The thoughts I have presented this morning are not new to many of you; yet, we persist with the charade and operate as if systems analysis were a scientific activity. This facade is surely one of the main causes of our credibility gap, and if continued, will lead to our eventual demise. We have failed to teach the client and ourselves that our principal product is not quantitative evaluations, but rather, insights and trends developed from broad parametric analyses that shed light on the murky future. Our talent is not number generation, but perception and creativity that can identify problem areas, analyze complex situations, and invent reasonable solution alternatives. When data are available, we can perform and produce as scientists. In the meantime we must work at developing the proper intellectual environment needed to make the intellectual activity of systems analysis an effective planning vehicle.

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CRITIQUE OF OPERATIONS RESEARCH TECHNIQUES

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1. Analysis of specific events in the 1973 Mideast War has raised questions about the capabilities and utilization of the DA models, simulations and war games. Generalizing and broadening this analysis, major aspects of the ORSA study process are reviewed with the goal of overcoming the identified limitations and developing techniques that are tailored to credible, responsive and flexible support of decision-making. After listing problem areas under the headings of models, analysis and decision-making, we expand on some of these problems and, in the final section of the paper, suggest alternative approaches and potential solutions.

2. In this critique of operations research techniques we group the problems into three categories:

a. Model problems or shortcomings.

b. Limitations in the analysis process and in the interpretation of results.

c. Inadequacies of operations research in support of decision-making.

3. Some of the major model problems, applying to many of the current DA models, simulations and games are:

a. Models have not been validated.

b. Models require input data that are not available or cannot be measured.

c. Models do not have the ability to identify the deficiencies of a given force or to develop alternatives for overcoming these deficiencies.

d. The available models rarely fit a given problem.

e. Most models do not have the flexibility to investigate innovative tactics or to develop adaptive tactics.

f. Electronic warfare and chemical defense are neglected in modeling.

g. Human factors are not adequately represented.

h. Models do not realistically simulate combined arms including dismounted infantry.

i. Models are designed to include all interactions rather than just the relevant interactions.

4. Analysis and interpretation problems are:

a. Although scenario parameters and assumptions have more influence on the choices between alternatives than details within a model most studies fix the scenario and concentrate on these details rather than investigating the impact of major scenario assumptions on the choices.

b. Tactical innovations and adaptive tactics for the enemy force are rarely studied.

c. Any complex model includes a variety of input data and interaction assumptions of various degrees of credibility and validity. There is no way to assess the overall credibility of the model outputs.

d. There is no adequate theory to specify when differences between alternative forces generated by a complex model are large enough to be significant.

e. We do not have a satisfactory answer to the question: If a change (e.g., in weapon systems) at company level does not seem to have a significant impact on division mission accomplishment, is this change worthwhile?

f. Effective systematic and balanced methods of incorporating military judgment into studies have not been developed.

g. Input data for models and studies is not standardized and the dominant criterion for using particular data is that some source can be quoted.

h. There is a proliferation of measures of effectivenss (MOE), most study results are sensitive to the MOE used and there is no practical theory to guide the selection and interpretation of MOE.

i. Study results, such as the relative effectiveness of alternative systems or forces, are sensitive (sometimes in unexpected ways) to the time duration of combat simulated. One can easily prejudice the results by careful selection of the MOE and the time duration.

5. Operations research problems directly relating to the decision-making process are:

a. Most decision-oriented studies require answers as soon as possible. It is not always possible to predict a year or two ahead of time what types of decisions will become crucial; therefore, to produce useful analytic results that have not been overtaken by events, improved responsiveness is required.

b. The usual approach, of setting up presumably realistic conditions and comparing Alternative X with Alternative Y, does not have sufficient generality to support decisions. In contrast, general results could be developed by answering the following questions:

(1) Under what conditions is Alternative X significantly better than Alternative Y, and vice versa?

(2) How likely are these various conditions?

c. Models and the associated analysis processes are not always designed to support decisions.

d. Study results frequently lack credibility to the decision-maker, because there is not sufficient visibility into the model logic, the analysis process and the assumptions. The analyst cannot tell the decision-maker what really drove the results because he doesn't know.

e. Army studies frequently consider a limited set of alternatives (e.g., not including USAF reconnaissance satellites, USN attack aircraft or allied ground forces), leading to unrealistic conditions and requirements.

f. Statistical uncertainties and real uncertainties, if treated at all, are sometimes based on probability distributions that have no basis in fact. Probabilities are assumed to give the appearance of realism.

g. Various types of judgment, analytical and military, are employed at many points in the model development and analysis process without being clearly pinpointed as such.

6. Several of the problems listed earlier are illustrated in this section. These include Problems 3c, 4a, 4d and 4h.

a. The following type of problem is of major interest to TRADOC and to the Combined Arms Center: "Identify and rank the deficiencies of a specified force in a given scenario. Develop and rank recommendations for changes to overcome these identified deficiencies". In order for a model to support such an analysis adequately it needs at least the following characteristics:

(1) Measures of effectiveness appropriate to each type of potential deficiency, including specific types of systems, tactics, procedures, etc.

(2) Ability to discriminate between required performance (as specified in the mission) and actual performance (as simulated by the model).

(3) Capability for efficient sensitivity analysis.

(4) Cause-and-effect visibility.

(5) Complete record of what happened and why.

(6) Scope broad enough to include all potential deficiencies.

(7) Representation of each type of potential deficiency, including specific types of systems, tactics, procedures, etc. It is unlikely that a general-purpose division-level model will satisfy the seventh requirement, especially when we consider the selected types of systems, operations or functions in which a division could have deficiencies.

b. The next example relates to the usual procedure of fixing the scenario and concentrating on a detailed comparison of alternatives within that scenario. Table 1 shows a summary comparison of two alternative US forces (A and B). In the standard scenario the size of enemy attack is fixed (e.g., three divisions) and Force B is only slightly more effective than Force A (71% versus 67%). The MOE might be, for example, the percent of US tanks surviving after 10 hours of combat. When the scenario is changed to include a larger enemy attack (e.g., 4 divisions) the superiority of Force B over Force A is dramatically increased. In the lower half of the table another major scenario factor, the amount of US close air support available, is varied to two different levels from standard. In this case the larger value has no significant impact but the smaller value causes a reverse; i.e., Force A is significantly more effective than Force B. As indicated below the use of mathematical models, tailored to this application, can be used to investigate this sensitivity of force comparisons to variations in major scenario assumptions.

c. The significant difference problem and the MOE problem are illustrated in Table 2. Based on division-level computer-assisted war gaming the US alternative forces (A and B) are compared by using six different measures of effectiveness (selected from many other MOE that are produced by this war game). The differences between Force A and Force B are less than 10% with each of three of these measures (enemy personnel losses, time required for enemy mission and tank loss ratio). Can these differences be considered insignificant? Since this war game (DIVWAG) requires thousands of inputs and involves many interactions and uncertainties the answer to this question must be: "We don't know". These six measures of effectiveness (and others not shown such as remaining force ratio and enemy advance rate) do seem to be tactically significant but the first three make Force B look better and the last three make Force A appear more effective.

7. Having stated 25 problems in the area of operations research support of decision-making we now turn to possible solutions.

a. The first solution involves specific efforts to reduce complexity. The approach is to list the major reasons usually given by analysts to justify the need for complexity in models and, with the ultimate goal of supporting decisions in mind, develop methods for reducing complexity in each of these areas. Eight reasons for requiring complexity are summarized as follows:

(1) interactions

(2) many-on-many rather than one-on-one

(3) uncertainties and sensitivity to

(a) major situation parameters

(b) model details

(4) non-linearities

(5) discontinuities

(6) diminishing returns

(7) need for mission frequency estimates

(8) impact of low echelon change on higher echelon effectiveness

We can approach a given decision situation by estimating which of these reasons for complexity are directly relevant and attacking those aspects of the problem directly, with deliberate efforts to make the analysis (and model) as simple as possible while meeting the requirements of the specific decision-making situation. This simplicity-seeking effort can be supplemented by:

(1) setting up simple models tailored to the task of answering specific break-even questions.

(2) using criteria related to the type of decision to be made, estimate both the direction and the magnitude of errors made by a simple model. (For example, a particular model might overestimate enemy capabilities because the requirement for simplicity in the model keeps

the US force from being as flexibile as it would be in the real world.)

(3) employ two or more simple models that "surround" the real situation (e.g., one model favoring the enemy force and one model favoring the US force).

b. Tne second solution requires the capability for the rapid design of simple mathematical models tailored to new projects as that arise. An example of such a model is a set of eight differential equations that expresses some of the major interactions in air defense suppression. Four equations express the Blue loss rates of tanks, artillery, air defense weapons and aircraft (helicopters or high performance aircraft) and four equations express similar loss rates for the Red force. Tanks attack tanks, artillery attacks both artillery and air defense units, aircraft attack both tanks and air defense units and aircraft suffer losses due to air defense weapons. Both Red and Blue have allocation decisions (for artillery and for aircraft employment) and this set of eight equations can be analytically solved without the use of a computer to give survivors of all types as explicit functions of all the parameters.

c. The third solution involves a long-term joint effort by military analysts in all services and industry to improve our techniques for incorporating various types of systems, operations and contraints into models, simulations and games. As chairman of the 34th MORS Land Warfare Working Group this author has set up the following objective: "This group will explore alternative methods for incorporating in land warfare models and analysis processes various functions and operations that have been frequently neglected in the past, such as electronic warfare, adaptive tactics, deception, tactical air, chemical warfare, human factors, command and control, combat in built-up areas, surveillance and target acquisition".

d. The fourth solution involves supplementing a central model, simulation or game with various mathematical models or other sources. This approach is being developed for DIVWAG as the central model and these supplementary mathematical models are used for the following purposes:

(1) Post-game sensitivity analysis, especially with respect to factors that are basically uncertain.

(2) Sub-optimizing tactics and system employment procedures.

(3) Selecting likely enemy responses or initiatives.

(4) Achieving balance between the components of alternative forces to be compared.

(5) Narrowing down the number of alternatives and situations to be carried through in full-scale gaming.

(6) Evaluation of the stability and generality of the study conclusions.

(7) Selecting ranges of values for critical inputs that cannot be firmed up by the study sponsor.

e. The fifth solution requires structured judgmental analysis in the initial phase of a study, to accomplish the following:

(1) rule out certain combinations of alternatives and roles or missions

(2) identify the advantages and limitations of the alternatives

(3) focus on the key unresolved issues

f. The sixth solution is based on a systematic analysis of the decision situation for which the study is being done. The major elements of this decision analysis are:

(1) type of decision

(2) objectives or missions (of the systems or forces to be evaluated)

(3) scope of decision

(4) alternatives to be considered

(5) decision criteria

(6) motivation for decision (deficiency in force, deficiency in system, new threat, etc.)

g. The seventh solution is a combination of a fortiori analysis and break-even analysis, aimed at the following objectives:

(1) in one phase of the analysis bend over backwards to hurt your preferred system and to help the alternative systems

(2) determine what values the assumptions must take on to make two alternatives equally effective

(3) determine what values the assumptions must take on to make Alternative X at least P% more effective than Alternative Y.

h. The eighth solution is the SCORES process developed by TRADOC and operational at Fort Leavenworth. SCORES is a force-level integrating mechanism that was designed to incorporate a hierarchy of analytical and judgmental contributions from about 20 TRADOC schools and the three TRADOC coordinating centers. The goals of the SCORES Process are to evaluate a given force (division-level or corps-level) in a particular scenario, pinpoint the major deficiencies of the force in this context and develop and evaluate ideas for overcoming each of these deficiencies. The alternatives for improvement are to be restricted to those changes in organization, tactics or equipment that are feasible within the next few years and all force evaluations are to be within well-defined manpower and budgetary ceilings. The SCORES process was designed in such a way that all of the TRADOC schools and centers would contribute and would communicate with each other within a common framework in solving the same force structure problem. A key concept in the SCORES process is that of a gross manual war game that provides a broad framework which serves to identify critical situations, which could be examined in greater detail by the individual schools using higher resolution models or war games.

i. The ninth solution is based on sensitivity analysis, to answer the anticipated "what if" questions and to investigate the impact on study results of real uncertainties, without assuming artificial probabilities and carrying through the meaningless calculations based on such assumed probabilities. The following tools can be used for sensitivity analysis:

(1) hand simulations (incorporating one or more of the uncertain factors as random variables, if estimates of the probability distributions are available)

(2) past study results in related areas

(3) flexible computer models

(4) analytical mathematical models

(5) one-sided map exercises

(6) structured judgmental analysis

j. The tenth solution requires judgmental analysis to be applied in the final phases of a study. The rationale for each judgment should be recorded and the process would be greatly facilitated if the model and analysis process have sufficient visibility to show what happened when and why.

k. The eleventh solution is the development of a practical theory of measures of effectiveness. This would include (1) relating MOE to missions, to categories of study objectives, to duration of combat simulated and to alternative forces available (e.g., late-arriving reserves); (2) interdependence between MOE and (3) significance levels for MOE.

l. The twelfth solution requires the use of simple models to highlight (and investigate further) the major effects and relationships discovered by using more complex models. This would be especially useful in the presentation of the study results.

m. The thirteenth solution involves the use of more than one model or technique for the analysis of a given problem. Each model will have its own limitations and hopefully the advantages of the different models would lend credibility and insights concerning the results and trends uncovered.

n. The fourteenth solution requires that a study be designed in such a way that useful and valid results can be extracted along the way.

o. The fifteenth solution is aimed at reducing the complexity and the variety of alternatives that need to be considered by early collection of data on the real-world contraints, forces and systems for a given study.

8. We have posed twenty-five problems and fifteen potential solutions. Analysis of their content reveals that there is considerable overlap. Table 3 shows which solutions might be applicable to each problem and Table 4 identifies the particular problem for which each solution might be applied. Three general solutions that are not covered here also look promising:

a. a centralized Army facility for collection, storage and dissemination of all input data to be used in models, simulations and games.

b. increased involvement of the intelligence community in the study process, especially in developing adaptive and innovative tactics for the assumed enemy forces.

c. joint service participation in Army studies.

TABLE 1

STANDARD SCENARIO PROBLEM

Assumption	Effectiveness of US forces	
	Force A	Force B
Size of Enemy Attack		
1. Standard	67	71
2. Larger	45	65
Amount of US Close Air Support		
1. Standard	67	71
2. Larger	74	76
3. Smaller	56	40

TABLE 2

DIFFERENCES PROBLEM AND MOE PROBLEM

MOE		US Alternatives	
		Force A	Force B
Enemy losses	Tanks	580	650
	Personnel	9800	9950
Time required for enemy mission (hrs)		23	25
US losses	Tanks	250	300
	Personnel	4200	5800
Tank loss ratio	Enemy/US	2.32	2.17

TABLE 3

POTENTIAL SOLUTIONS FOR EACH PROBLEM

	POTENTIAL SOLUTIONS
Model Problem	
a	13
b	15
c	8
d	1, 10, 13
e	2, 3, 4, 8, 9
f	3
g	3, 10
h	10
i	1, 9
Analysis Problem	
a	1, 2, 4, 7, 9, 10
b	2, 3, 4, 7, 8, 9, 10
c	1, 12, 13
d	1, 7, 10, 12, 13
e	9, 10, 11, 13
f	5, 8, 10
g	
h	9, 11
i	9, 10, 11, 13
Decision Problem	
a	1, 5, 6, 14, 15
b	1, 2, 4, 6, 7, 9, 10
c	1, 5, 6, 7
d	1, 2, 4, 5, 9, 10, 12, 13
e	2, 4, 6, 9
f	1, 2, 4, 9
g	5, 10, 13

TABLE 4

PROBLEMS POTENTIALLY SOLVABLE BY EACH SOLUTION

POTENTIAL SOLUTIONS	APPLICABLE PROBLEMS		
	MODEL	ANALYSIS	DECISION
1	d i	a c d	a b c d f
2	e	a b	b d e f
3	e f g	b	
4	e	a b	b d e f
5		f	a c d g
6			a b c e
7		a b d	b c
8	c e	b f	
9	e i	a b e h i	b d e f

TABLE 4 (Continued)

POTENTIAL SOLUTIONS	APPLICABLE PROBLEMS (Continued)		
	MODEL	ANALYSIS	DECISION
10	d g h	a b d e f i	b d g
11		e h i	
12		c d	d
13	a d	c d e i	d g
14			a
15	b		a

Preliminary Operational Analysis of Cannon Launched Guided Projectiles

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INTRODUCTION

The purpose of this paper is to describe an investigation into the operations and effectiveness of Cannon Launched Guided Projectiles (CLGP) utilizing the DYNTACS-X model.

The employment of CLGP on the battlefield will drastically change the armored weapon system battle environment. Artillery weapons may now selectively attack moving armored weapons with a relatively high probability of kill. Prior to the development of CLGP, artillery was effective only as an area fire weapon. Now artillery has the capability of firing at hard point targets. This revolutionary capability requires that the old methods of employing artillery be reviewed and that new methods of employment be developed to insure maximum operational effectiveness in the field. Three methods of employment have been proposed for CLGP. These are targets of opportunity fires, assured coverage fires, and preplanned fires. As this paper describes, all three have been incorporated into the DYNTACS-X simulation model, and a preliminary analysis has been conducted. The use of the simulation allows the system analyst to determine which employment options and CLGP performance characteristics will be the most effective before the weapon system becomes operational in the field.

THE DYNTACS MODEL

Background

DYNTACS, the DYNamic TACtical Simulator, is a high resolution battalion level armored combat model. Its development began in 1965 under the guidance of the CDC Armor Agency with the main thrust of the effort directed toward tank weapon systems. The model was developed by the Systems Research Group of The Ohio State University to provide a stochastic simulation of armor in a midintensity battle.[1,2] The simulation was made operational at the Rodman Laboratory in 1970 and was applied to support the Project Manager's office for M60 tanks in an evaluation of M60A1 tank mobility improvements. The model has since been modified to include artillery support, crew served weapons, counterbattery fire, aerial platforms, air defense, and minefields. The complete model with all extensions is known as DYNTACS-X. This version of the model was modified by Rodman Laboratory personnel to simulate scatterable mines and mine counter measures to support the Family of Scatterable Mines (FASCAM) study. In over 600 production runs, parametric data variations were made to mine probabilities of kill against vechile track and belly, and to the number of mines for each artillery projectile. Thus the most effective design characteristics were determined. DYNTACS has been modified by Rodman Laboratory personnel to play CLGP, and will be used in the Cost Operational Effectiveness Analysis (COEA) for CLGP.

Model Discription

The most outstanding feature of DYNTACS is the detail to which the individual weapon systems are described.[3] Inputs describe the individual weapons firepower, mobility, protection, detection capabilities, and their interactions with the terrain. This detailed data is very extensive and falls into three main categories; environment, tactics, and performance characteristics. The environment consists of a continuous 5 by 10 kilometer area with overlays that are used to describe vegetation, trafficability, obstacles, cover and concealment. The tactical data is supplied to the model through the input scenario which includes force organizations, decision criteria for selecting attack routes, firing assignments, firing priorities, formations, withdrawal routes, and other military judgements. Since the original model development was initiated to provide a tool capable of evaluating alternative changes in the design of tank weapon systems, extensive engineering data is required as input. For each type of ground vehicle that is simulated in the model, the basic dimensions and detailed mobility characteristics are required as input. Also, for each weapon type, detailed firepower characteristics describing accuracy, rate of fire and terminal effects are required as input.

DYNTACS is an event sequenced model, that is, events are ordered in time based on the duration of each event. When an element such as a tank is selected for an event, communications are processed, line of sight (L-O-S) and detections are determined, routes and formations are identified, target and projectile are selected, movement is calculated for a fixed distance or time and then the effects of the shot are assessed on the target. The length of time of this event is added to the clock time of the element and becomes the start time of the elements next event. The next element to be processed is the element with the lowest clock time. Artillery is incorporated into the model by sequencing events for forward observers (FO), fire direction centers (FDC), and fire batteries (FB). For CLGP the FB notifies the FO when the FO must activate his laser (enablement time). Targets are dynamically selected by the forward observers and artillery fire is requested as required. Time delays for communication and to deliver artillery fire are represented and the lethal and suppressive effects are assessed for each impacting round.

CLGP LOGIC

Although the CLGP round is launched from a standard artillery tube, the round requires the FO to act as a target designator. The FO must illuminate the target with a laser beam for the terminal maneuver of the round. During this time, the round will home in on the energy centroid of the reflected beam. To describe CLGP the following data is needed:

- humidity code and cloud ceiling
- artillery organization
- mode of CLGP fire
- number of volleys and tubes per volley
- response times for each mode
- terminal effects data

- ballistic data for CLGP round
- performance data for seeker

The three modes of CLGP employment that will be discussed are target of opportunity fire, assured coverage fires, and preplanned fires.

CLGP Target Selection

It is the FO's responsibility to select targets for the FB. For CLGP a new procedure for selecting targets was developed. Basically this method forms a target complex which consists of a detected enemy element and all other detected enemy elements within a 100m radius. The FO selects the best target complex based on ranges from FO and number of elements within a complex. The greatest priority is given to those complexes between 2 and 4 km from the FO. Within this range the complex with the greatest number of elements is selected. If there is more than one complex with the greatest number of elements, the complex with the greatest range from FO will be selected. The second priority is given to those complexes beyond 4 km from the FO. Within this range the complex with the greatest number of elements is selected. If there is more than one complex with the greatest number of elements, the complex with the least range from FO will be selected. The last priority is given to those complexes between 0 and 2 km from the FO. Within this range the complex with the greatest number of elements is selected. If there is more than one complex with the greatest number of elements, the complex with the greatest range will be selected.

The number of volleys and number of tubes that fire per volley are also dependent on the number of elements within the complex, as shown below.

NUMBER OF ELEMENTS	NUMBER OF VOLLEYS	NUMBER OF TUBES FIRED PER VOLLEY
1	2	1
2	4	1
3	3	2
4	4	2
5	5	2
6 or more	6	2

Since the assured coverage mode of fire uses one volley and a fixed number of tubes firing per volley, the above table only applies to the target of opportunity and preplanned modes of fire.

Target of Opportunity Mode

The first of the three modes of fire for CLGP to be discussed will be the target of opportunity mode. Of the three modes of fire the target of opportunity mode is most like conventional artillery fire. After selecting the best target complex by the method described above, the FO sends to the FDC the coordinates, the speed and the direction of the center element of the complex. Since the FO tries to maintain L-O-S with the target element, the FO will know the location of target element at enablement. If the target element receives a kill before enablement occurs, the FO selects as a new target, the element that he has line of sight with and is closest to the position of the dead element. This assures that the FO will have a target to designate at enablement, however both FDC and FB continue to process the original mission. After receiving the FO's information about the target the FDC using only this information predicts target location at the FDC's estimation of when enablement will occur. The FDC sends the aimpoint, quadrant elevation, zone, number of volleys and tubes to fire per volley to the FB. The FB then fires the volleys at fifteen second intervals and notifies the FO when the first enablement time will occur. The FO checks L-O-S for each round at the enablement time of the round. If L-O-S is lost on the first volley the FO will attempt to find L-O-S with any nearby element. If no new target is found the rounds are considered as lost. If the FO loses L-O-S on subsequent volleys the rounds of that volley are considered as lost and the FO will check L-O-S for the same target on all remaining volleys as the enablement times occur. Using the actual target position, L-O-S is also checked at impact for each round. If L-O-S is lost there will be no kill and the round will be considered as lost. If the volley results in a kill to the target element the FO will attempt to switch targets before the next volley. The FO selects a target that he has L-O-S with and is closest to the position of the original target. The target of opportunity mode has the same response times as conventional artillery, since the functions of the FO, FDC, and FB are basically the same.

Assured Coverage Mode

The second mode of fire for CLGP is the assured coverage mode. For this mode of fire the 3 by 4 km area in front of the FO was divided in 4 (1.5 by 2 km) equal quadrants. In each quadrant the aim points for the FB are fixed. The zone and quadrant elevation necessary to reach these aim points are at the battery site and the FO needs only to call in the quadrant number. After selecting the best target complex by the method described earlier, the FO calculates the average speed, direction, and location of the elements in the complex. Using the FO's estimate of FB response time the FO predicts which quadrant the complex will be in at the FO's estimation of when enablement will occur. The FO then communicates the quadrant number to the FDC. The FDC has only to send the quadrant number to the FB. The FB then fires the volley and notifies the FO when enablement will occur. At enablement, the FO must select a target to designate. Since the FO knows the location of the center of the quadrant, the FO selects as a target an element that he has L-O-S with and is closest to the center of the quadrant. There are no subsequent volleys in the assured coverage mode of fire. Due to the large area covered and due to the fixed aim points within each quadrant, some of the rounds do not acquire the target in this mode. Since there are less calculations, more estimations and less communication, the response times for assured coverage are considerably less than conventional artillery.

Preplanned Mode

The last of the three modes of CLGP fire to be discussed is the preplanned mode. In this mode the area in front of the FO was covered by twenty preplanned areas of 500m radius each. The FB's aim points for each of the preplanned areas are located 250m from the center of the footprint to provide the maximum seeker field of view at enablement. The FB has the quadrant elevation and zone necessary to reach the aim point at the battery site. After selecting the best target complex by the method described above, the FO predicts which preplanned area the complex will be in, at the FO's estimate of enablement time. The FO then communicates the number of the preplanned area and number of volleys to the FDC. The FDC then communicates this information to the FB. The FB fires the volleys at 15 sec. intervals and notifies the FO when the first enablement time occurs. At enablement the FO selects as a target an element that the FO has L-O-S with and is closest to the center of the footprint. The precedure described in the target of opportunity section also applies to subsequent volleys of the preplanned mode. Since the functions of FO, FDC, and FB are nearly the same for the assured coverage mode, the preplanned mode of fire has the same response times as the assured coverage mode.

INPUT SCENARIO

The input scenario used for this preliminary CLGP analysis was a modified version of the scenario used to support the FASCAM study. The scenario was modified to exclude mines and CLGP was added with some reorganization of both the attackers and the defenders artillery support. The scenario has 15 blue defending elements including tanks, APC's, TOW, and DRAGON. The defending force has one fire battery available half time and one laser designator as a forward observer. The Red attacking force consists of 32 elements made up of tanks and APC's with missiles. The attacking force has 3 fire batteries available full time with 3 forward observers calling in a rolling barrage as well as a continuous barrage of fire on the defensive position.

For this preliminary investigation of CLGP effects there was no logic incorporated into the model to detect the designator when the FO lases on a target, hence the FO is not vulnerable to enemy direct fire weapons. However, the FO is vulnerable to enemy indirect fire and its suppressive effects. The FB is not vulnerable to either direct or indirect fire since counterbattery missions are not being employed. Logic has been completed to detect the FO when he lases on a target and will be incorporated into the model before the CLGP COEA production runs are made.

COMPARISON OF CLGP MODES

Using different random numbers, five replications were made for each of the following options for the defending force:

- no artillery
- only conventional artillery
- target of opportunity mode of CLGP

- assured coverage mode of CLGP
- preplanned mode of CLGP

The results of the twenty-five runs are summarized in the tables below:

ATTACKERS KILLED/DEFENDERS KILLED

RANDOM NUMBERS	1	2	3	4	5	AVE
No Artillery	9/11	12/11	8/10	11/9	10/7	1.07
Conventional Only	8/11	18/10	9/10	14/9	8/10	1.14
Targets of Opportunity	11/10	16/10	8/13	18/8	12/10	1.35
Assured Coverage	30/12	18/10	16/13	17/10	17/11	1.76
Preplanned	21/11	21/10	15/11	23/8	27/9	2.25

CLGP ROUNDS/CLGP KILLS

	1	2	3	4	5	AVE
Target of Opportunity	18/4	19/4	15/1	20/2	18/3	8.05
Assured Coverage	66/7	42/5	42/4	30/5	30/5	10.08
Preplanned	26/10	28/12	20/6	32/13	34/13	2.67

RANGE FROM FB FOR CLGP KILLS (TOTAL 5 REPLICATIONS)

Range in Km	6-6.5	6.5-7	7-7.5	7.5-8	8-8.5	8.5-9
Target of Opportunity	1	2	6	5		
Assured Coverage		18	3		5	
Preplanned			7	27	20	

The Mann-Whitney[4] test was applied to investigate the statistical significance of the data from the various options that were replicated. Using the no artillery as a base case and comparing it to the other four options, for the attacker/defender casualty ration, results in the chart below:

CONFIDENCE LEVEL

Conventional	NO
Target of Opportunity	NO
Assured Coverage	99.2%
Preplanned	99.6%

Note, NO means less than 80% confidence. Using the conventional artillery only option, as a base and comparing it to each of the CLGP options results in the chart below:

CONFIDENCE LEVEL

Target of Opportunity	NO
Assured Coverage	90.7
Preplanned	98.4

Comparing the CLGP options for the attacker/defender and CLGP rounds/CLGP kill, results in the chart below:

	ATTACK/ DEFENDER	CLGP RNDS/ KILL
Target of Opportunity to Assured Coverage	88.9	NO
Target of Opportunity to Preplanned	95.2	99.6
Assured Coverage to Preplanned	88.9	99.6

For five replications, no conclusions concerning an increase in effectiveness for the target of opportunity mode of CLGP over the other options can be drawn since the data may be from the same distribution. However, for both the assured coverage and preplanned modes of CLGP the data is statistical significant and conclusions may be drawn from the results. Hence, for five replications this preliminary investigation indicates that the preplanned mode is the most effective of the options investigated.

Since for subsequent volleys the FO will switch targets if the target element receives any type of kill, the FO is given the ability to distinguish between an enemy element that has stopped to fire and an enemy element with a mobility kill. The direct fire ground vehicles are not given this capability and can only distinguish mobility and firepower kills or total kills, not mobility or firepower kills. To make the FO's capabilities more compatible with direct fire capabilities, the logic was modified to allow the FO to select targets with mobility or firepower kills as targets for subsequent volleys of the same mission. Five replications were made with the new logic in the preplanned mode of fire. A comparison of new logic to the old logic is shown below:

ATTACK/DEFENDER KILL

Old Preplanned	21/11	21/10	15/11	23/8	27/9	2.25
New Preplanned	25/9	27/8	15/12	23/7	18/10	2.50

CLGP RNDS/CLGP KILL

	1	2	3	4	5	AVE
Old Preplanned	26/10	28/12	20/6	32/13	34/13	2.67
New Preplanned	32/11	30/12	17/7	23/13	26/9	2.49

Applying the Mann-Whitney test for the two populations there is no statistical significance (less than 80% confidence level) between the two sets of data for five replications.

COMPARISON OF CLGP WITH TOW

Since in this scenario the FO is positioned with the other defending elements, and since in this scenario the FO doesn't detect enemy elements until they are within range of TOW weapons, the TOW and CLGP weapon systems are competing for the same targets. To measure the relative effectiveness of the appearance of CLGP on the battlefield, five replications were made for each of the following options:

- No TOW and no CLGP
- TOW with no CLGP
- CLGP with no TOW
- Both CLGP and TOW

Only the preplanned mode of CLGP was employed for these replications. The results of the replications can be summarized in the table below:

ATTACKER/DEFENDER CASUALTIES

	1	2	3	4	5	AVE
No TOW and No CLGP	2/10	5/9	6/12	3/11	4/10	.39
TOW with No CLGP	8/11	18/10	9/11	14/9	8/10	1.14
CLGP with No TOW	16/10	23/7	23/12	15/10	12/10	1.90
Both TOW and CLGP	25/9	27/8	15/12	23/7	18/10	2.50

Comparing attacker casualties for the no TOW no CLGP to the TOW only and to the CLGP only cases and using the Mann-Whitney test, results in a 99.6% confidence level that both these distributions are different from the no TOW and no CLGP case. If the TOW only and CLGP only casualties are compared there is a 95.2% confidence level that the distributions are not the same. Since the attacker/defender kill ratio increased more when only CLGP was added then when only TOW was added, this preliminary investigation shows that the addition of CLGP increases the effectiveness of the defending force more than the addition of its nearest competing weapon system TOW.

SUMMARY

In summary, a tool was constructed in which alternative modes of fire for CLGP were evaluated before the system became operational in the field. The preplanned method of employment was shown for this preliminary investigation to produce more casualties to the enemy for less rounds at longer ranges and with less friendly casualties and should be the preferred method when the system becomes operational in the field. The model was used to show that the addition of CLGP on the battlefield increased the effectiveness more than the addition of TOW. A tool, the DYNTACS model, now exists to evaluate any future concepts of employment of CLGP such as the use of remotely piloted vehicles as designators. The final analysis of the CLGP performance characteristics and employment options will be evaluated with a new scenario. This scenario will include HELLFIRE, CLGP and will be larger in scope than the FASCAM scenario. The scenario will be used to support the CLGP COEA.

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ON THE USES OF ORSA STUDIES FOR POLICY DECISIONS

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Introduction:

The basic premise of this paper is that ORSA studies should be useful to a broad array of military decisionmakers. Unfortunately, this has not been the destiny of many ORSA studies. The question is how can a professional ORSA study---technical, scientific, analytical--be communicated effectively to decisionmakers with varying degrees of scientific, analytical capability?

Risk is ubiquitous. The precise definition is dependent upon the discipline under focus---economics, statistics, insurance, or in the common vernacular. Risk levels are particularly difficult to assess. What about "calculated risks?" Did anyone calculate the risk? Does it mean that risks are really calculated? Or are they "deliberate" or "understood" without any calculation per the big dictionaries. According to Webster's New International, a calculated risk is simply a deliberate risk--without a set of calculations to justify that risk! The manipulation of probabilities is the basic fact of life for decisionmakers. Uncertainty stems from two basic sources: first, the random character of (most) natural forces; and, second, most of the workings of our universe are too complex for our human information processing capability. Our vision into the fuzzy future has two distinct trajectories: the gross perception of structure and shape; and the subsequent more precise evaluation of detail. The calculus of these two methodologies have been tagged the Arithmetic of the Future and the Geometry of the Future, or Quantitative vis-a-vis Qualitative, Objective vis-a-vis Subjective. Somewhere in time a hierarchal ordering has been imputed by our culture: Objective is better than Subjective, Quantitative is better than Qualitative.

Kane suggests that Arithmetic models process information that is coefficient oriented and generally concerned with the optimization of a few select parameters. Such models tend to be oriented to the present and are insular in that they are elaborate descriptions of existing situations and become rather inflexible and exhaustive descriptions of reality in a narrow area. These Arithmetic models are utilized by groups and echelons concerned with implementation instead of policy.

Geometric models are primarily concerned with structure and form rather than precise numerical specification. They are implicit in that they tend to be utilized heuristically. These models are both future-oriented and policy-oriented. These models are utilized for policy decisions, and are usually aimed at answering questions having to do with major structural change, rather than examinations of slight redirections in a Status-Quo. Geometric models are large in scope and often constitute an encompassing, overall point of view.

The world of the future is a fuzzy world. To plan for the future decisionmakers must have some idea of the future. Whether we use Hudson Institute's Standard World No. 1 (Basic Surprise-Free, Largely Business-as-Usual Projection) or Standard World No.2 (Deep World Depression Scenario in the 70's) we must have our own concept of what will happen to the GNP, Rate of WorldEconomic Growth, Cultural and Political Disunity & Diversity, Post-WWII Politics, Global Technological Economy, Changes in Behavior & Attitudes, etc. The future divides naturally into a Geometric and Arithmetic region. This dichotomy is more than a semantic split, as this polarity is more useful than stereotyped splits of Quantitative/Qualitative, Subjective/Objective. Kane adds:

> "What is subjective is not so much that which is felt, but much more that which is perceived as shape or relationship. Furthermore there is nothing qualitative about a triangle; it either is or isn't. The property of having three sides in no way depends upon the particular value of the angles between them, or the numerical length of the sides. It is the essence of the geometric concept in that it can be precise and well-defined even if details are ambiguous or unknown."

To arrive at credible, surprise-free decisions in which he has confidence, the modern military decisionmaker must understand the emerging trends that are suddenly here, having enhanced the dimensions of ORSA into the policy level. For the first time a total assessment can be made of current and proposed weapon systems, including social impact and public sentiment. It is the emphasis on widening the evaluation criteria, and looking for indirect or second-and-higher-order effects that is new. The basic difference is in the scope of the analysis, and the explicit consideration of societal costs in the cost-benefit equation. This is a difference of nature, and not simply of degree as noted by the following trends and changes noted in a recent AMCA report:

- o Increased Military R&D spending (Inflation)
- o Economic Impact of Large-Scale Production
- o Potential Civilian applications of Military Technology
- o Costly Mistakes (Irreversibility of Actions)
- o Dwindling Public Support
- o Growing Complexity of Society
- o Secondary & Derivative-Order consequences
  Evaluated from Social, Economic, Political, Biological viewpoint to minimize "tunnel vision"
- o Shift in Societal Values
- o Army Re-Programming & Budget Hearings

Although modern military decisionmakers have been taught and believe, cerebrally, that through the use of normative analysis (as opposed to precedent, appeal to authority, bargaining, or trial and error) that one is more likely to obtain (though not necessarily) better answers to questions and solutions to problems(if solutions exist); thus providing better advice. It does not follow that the creation of an operational model makes efficient use of judgment and intuition of the decisionmaker. Nor does it mean that more quantitative analysis is always preferred to less. ORSA costs are high in terms of time and dollars; solutions may be far more difficult to accept and implement than those arising from more subjective and political processes. Decisionmakers have had to become skeptical, and difficult to convince for their own preservation and sanity. The decisionmaker must keep his sense of historical perspective. Kransberg tells a story to clarify "perspective"; he cites a letter written by a college girl to her parents in Spring of '70.

> "Dear Mom and Dad: I am sorry to be so long in writing again, but all my writing paper was lost and I was blinded the night the dormitory was burned down by the demonstrators. I am out of the hospital now, and the doctor says that my eyes should be back to normal sooner or later. That wonderful boy, Bill, who rescued me from the fire, kindly offered to share his little apartment with me until the new dorm is built. He comes from a good family, so you won't be too surprised when I tell you that we are going to be married. In fact, you have always wanted a grandchild, so you will be grandparents next month..."

The letter continued:

> "Now please disregard the above practice in English composition. There was no fire, and I haven't been in the hospital. I am not pregnant and I don't even have a boyfriend. But I did get a "D" in French and an "F" in Chemistry, and I wanted to be sure you received this news in proper perspective."

In addition to perspective, the ORSA community has been soul-searching on the question of ethics, or what should be the role of the professional both in the Adversary as well as the Advocate. The September 1971 ORSA Journal attempted to clarify this knotty problem. The Military Operations Research Society, several years ago, set up a group to determine why ORSA studies were not being implemented by decisionmakers. What conclusions there were can be summarized as follows: The studies were somewhat parochial and limited, and great and unsurmountable difficulties had been encountered in communicating the virtues and values of ORSA techniques to management problems.

Of the three groups of professional decisionmakers---business executives, politicians, and military managers—only the military have a formal doctrine of decision, known as "the estimate of the situation". Its five formal steps are:

- Determination of the Mission
- Description of Situation and Courses of Action
- Analysis of Opposing Courses of Action
- Comparison of Own Course of Action
- The Decision

However, military decisions are made with that intangible something known as "military judgment", just as business decisions are made with "business judgment". Are decisions to be made in a rational way--rational defined in some economic, consistent sense? Referring to the process of decisionmaking in government operations, the Greek historian Herodotus tells of the decisionmaking procedure followed by the Persians of the Fifth Century, B.C., in making policy decisions:

> If an important decision had to be made, they would discuss the question when they were drunk, and the following day the masters submitted their decision when they were sober. If they still approved, it was adopted, if not, it was abandoned. Conversely, any decision made when they were sober was reconsidered when they were drunk.

Operations Research/Systems Analysis Studies:

Using Churchman's definition of OR as "the securing of improvement in social systems by means of scientific method" where social means a three-dimensional relationship between people: viz., (1) the decisionmakers, (2) those who are supposed to benefit from the system, i.e., the clients or beneficiaries, and (3) the operations researcher/systems analyst---the following questions arise:

Why is it that so few decisionmakers use ORSA studies in their decision process? It cannot mean that the ORSA practitioners are outnumbered. Is it that the ORSA community does not have the status it needs? Is it fair to say that because many decisionmakers do not use the results of ORSA studies they do not manage as they should, and the country (society) suffers? The only valid reason for any decisionmaker to be concerned with ORSA inputs (or any other) to his decision process is because he feels it will help him get better results (outcomes) or make better decisions (process) in the long run. How many unclassified ORSA studies have resulted in major program changes? One which stands out by its implementation is the Army Health Care Program which will be discussed in detail at the next Military Operations Research Symposium at Ft. Eustis in December. Do any others come to mind?

The more important the ORSA problem, the more complex it tends to be, and the longer it takes to generate, identify, formulate and solve. However, many of the problems change during solution, yielding answers to problems that no longer pertain. Ackoff give the following truism:

> "In the long run it is better to start with poor initial solutions that improve over time than with good ones that deteriorate over time. We can no longer ignore this tautology because the accelerating rates of technological and social change, the long run is becoming shorter, and the time required to solve the important problems that face us is getting shorter."

This telescoping of time, the feeling of exponential decay, the increasing concern about the deterioration of certain aspects of the quality of human life, have culminated into the Technology Assessment (TA) Movement. Due to unforeseen, deleterious side-effects, certain innovations like DDT, which have done a great amount of good in some ways, have degraded or endangered lives. ORSA approaches which worked so well in the 1950s and 1960s for developing complex missile systems and putting men on the moon cannot be used as before because of two important reasons, according to Strasser:

(1) The objectives are much more diffuse, relating less to tangible "hard" science and engineering than to the more elusive, subjective aspects of the social sciences.
(2) The disciplines involved are much more heterogeneous, and decisionmakers have not learned how to orchestrate them for coordinated assaults on large-scale problems.

It is important to note, however, that weapons effects, however destructive, do not fall into the domain of TA as it is perceived today. Weapons are built to deter; or, if they must be used, to destroy. Destruction is the primary objective or effect.

The framework for the development of a TA Methodology should be of interest to ORSA practitioners. A listing of the methodology used in the experiment of the U.S. National Academy of Engineering follows:

(1) Identify and Refine the Subject to be Assessed
(2) Delineate the Scope of the Assessment and Develop a Data Base
(3) Identify Alternate Strategies to Solve the Selected Problems with the Technology under Assessment
(4) Identify Parties Affected by the Selected Problems and Technology
(5) Identify the Impacts on the Affected Parties
(6) Evaluate or Measure the Impacts
(7) Compare the Pros and Cons of Alternate Strategies

It can be argued that the selection of an optimum or preferred course of action is not a lawful task for a TA group, and that this function should remain the prerogative of the decisionmaker. However, as cited before, the decisionmaker expects his analysts to provide him with bases for the application of his personal judgment.

The MITRE Corp/Office of Science & Technology used a modified approach in their pilot TAs of automotive emission, computers-communication networks, industrial enzymes, mariculture (sea farming), and water pollution (domestic wastes). Actually, their methodology is a combination of two approaches: the first, a Case History approach which lends relevance, practicability and reliability to the analyst's efforts, suffers from the lack of transfer of findings to other situations; the second approach concerns the extension of the state-of-art of existing methodologies to encompass TA in a generic sense, which makes results transferable even if abstract or academic. By combining the two approaches in an iterative manner, practicality and relevance come from the first, and generality and transferability from the second. This combined approach calls for patience, understanding and much compromise by all participants. The seven major steps of this TA Methodology are:

(1) Define the Assessment Task
(2) Describe Relevant Technologies
(3) Develop State-of-Society Assumptions
(4) Identify Impact Areas
(5) Make Preliminary Impact Analysis
(6) Identify Possible Action Options
(7) Complete Impact Analysis

Checklists were prepared for each area; e.g. State-of-Society Characteristics include the following categories: values, environment, demography, economic, social, and institution. These categories are broken into types and can be carried into sub-types, etc. MITRE's approach identifies two kinds of prior research that provide a basis for developing TA methodology. The first is a look at disciplinary research in many fields. The second area includes the interdisciplinary, decision-aiding methodologies developed currently to aid management decision-making. Here is ORSA, cost-benefit analysis, cost-effectiveness analysis, management science, computer simulation, PERT, PPBS, the "policy sciences". This approach puts stress on the feasibility of implementation of TA studies. Implied is the notion that TA analysis should incorporate into the formal study political, legal, administrative and institutional as well as economic, engineering and related considerations. As Hetman summarizes: "Effectiveness alone does not seem to be a sufficient criterion. Consideration should also be given to the chances of winning the support of governing bodies and citizen groups in adopting and carrying out proposed action options to influence anticipated impacts."

A major controversial point exists here as to whether TA is to be limited to the analysis proper, or to take into account action options, feasibility of alternate solutions and political supports for implementation. The contrary view is that TA should include the whole array of considerations and effects which lead to a policy decision and a policy implementation.

Inserting TA studies into a still broader context was explored by Chauncey Starr for the "Utilization of Scientific and Technical Resources in Overcoming Problems," Hearings on Technology Assessment, Part II, 1970, Washington, D.C. Social problems have arisen from previous action programs and future problem-solving actions will modify and alter these problems. This dynamic process of change requires continuous observation and analysis, and for this reason TA must be periodically up-dated as part of this dynamic sequence. The steps are listed indicating how the feedback process completes the problem solving loop:

(1) Recognition and Definition of a Social Problem
(2) Assessment of Technological Developments Involved
(3) Communication of Assessment Results to the Public and the Decisionmakers.
(4) Decisions on Legislative and Administrative Actions
(5) Implementation Process Involving Programs and Suitable Institutions
(6) Performance Observation and Measurement of the Progress in the Action Programs

This implies that technology control and management is only as important as it is integrated with other components into the final decision, or considered in the framework of society's objectives.

A Framework:

In the Cost-Benefit jargon, we talk about a Resource or a Program Cost (A) being committed to the achievement of Program Objectives (B)as in Figure 1. These may be called Direct Costs (F) and Direct Benefits (E), in that they represent an intended set of Cause-and-Effect relationships. In the process, two kinds of side effects are possible: Desirable (C) and Undesirable (D). Since these two unintentional effects are possible, they may be termed Indirect (G) and (H). The Desirable Side Effects (C) together with Program Objectives (B) add up to the Total Benefits (I); whereas Program Cost (A) and Undesirable Side Effects (D) add up to the Total Costs (J). What is called here "Indirect", and economist might call "external costs and benefits". Total Benefits (I) and Total Costs (J) really consist of a combination (K) of Social Effects, Physical Environmental Effects, Dollar and Other Economic Values, Political Effects, Institutional Effects, and various Others (K). These terms are incommensurable and call for establishment of some sort of social, environmental or urban indicators, with three characteristics: (1) Relevance, (2) Utility, and (3) Public Acceptance. There are no such indicators available today.

Since there is also a time scale involved, the dialogue is not only about what is happening now, but must include discounted future costs as well as benefits. At this point the problem of uncertainty arises, calling for some popularized treatment of risks and expected values--which is difficult enough when only dollar "costs" are involved alone. The real challenge is two-fold. One, how to balance in an equitable way internal and external costs and benefits? Two, how to devise an expeditious and "fair" transition in our economic, social and political system without causing unacceptable disruptions? A supplementary accounting system is needed which addresses not only the path between Program Costs (A) and Program Objectives (B), but also takes into account the external costs, Undesirable Side Effects (D), as well as demands credit for external benefits, Desirable Side Effects (C), which has not been the practice. The task is to seek some way to better understand and explain the interrelationships and trade-offs of the many different objectives, and the many different costs incurred, in a language that permits dialogues among policy and decisionmakers, ORSA analysts,the intellectual community, industry, or in short, all those who are involved one way or another in collective actions of society.

Emerging Methodological Approaches:

In a total ORSA study both the forecasting and the evaluation parts have to be closely related to the exploration of societal impacts and consequences. The approaches are two-fold:

TOTAL PROGRAM COSTS VS TOTAL PROGRAM BENEFITS

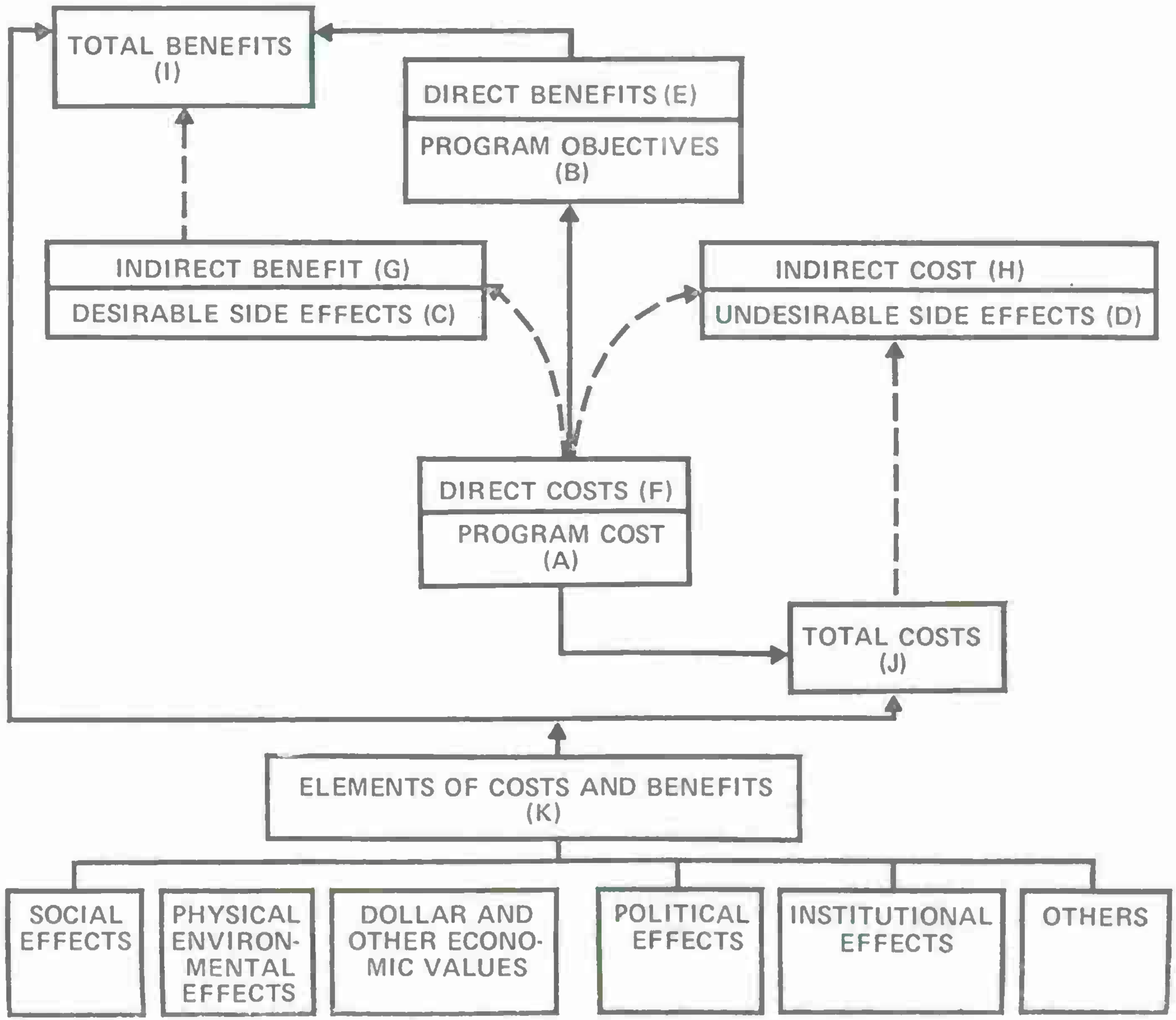

FIGURE 1

(1) To explore and to inventory relevant societal Aspects, Impacts and Consequence.
(2) To explicit the possible interrelationship between these various elements which are supposed to accompany the technological development under consideration.

Hetman enumerated the following list of approaches for a full assessment:

- o Mapping of Societal Consequences
- o The Delphi Method
- o Relevance Tree
- o Event Evaluation & Review
- o Relevance Matrix
- o Cross-Impact Techniques
- o Multi-Discipline Systems Approach
- o Technology Assessment Function
- o Goal-Oriented Methodologies

The study of the relationships between analysts and decisionmakers shows that final choices are essentially political in character, and remain a duty of decisionmakers:

"Whatever improvements might be made in assessment systems, therefore, it is important to remember that the products of such systems ultimately represent no more than inputs into the complex network of decisionmaking processes, private and public, economic and political, that together mold the growth of technology and channel its integration into the social structure," according to the National Academy of Sciences Report, Technology: Processes of Assessment and Choice.

Comment:

Perhaps a hind-sighted look at the reasons that ORSA practitioners have not persuaded decisionmakers to use their studies, might be in order:

First, the ORSA community lived in different worlds than the decisionmakers. Communication was difficult. The decisionmaker had technical breadth, the practitioner, technical depth.
Second, ORSA types tend to be technique-oriented, rather than result-oriented.
Third, the babel of technical jargon which guaranteed that decisionmakers cannot get the message quickly.
Fourth, the tendency to present too much data for the decisionmaker to use, due in part to our modern computers.
Fifth, incomplete staff work.
Sixth, failure to establish the personal credibility necessary to convince decisionmakers.
Seventh, is timeliness or urgency of study.

Based upon these observations what can the analyst do to improve his batting average of implemented studies?

> First of all, the analyst should learn to think like the decisionmaker does (not like the decisionmaker should).
> Second, the analyst must learn to talk the decisionmaker's language both in oral and written reports and recommendations for action.
> Third, the analyst should be solution- not methodology-oriented.
> Fourth, the analyst should attempt to do completed staff work,ready for signature.
> Finally, the analyst must know that he is creating answers for use by the decisionmaker, not creating additional problems, or de-solving the problem.

Although not discussed in detail, any decisionmaker will use ORSA studies as inputs to his decision-process because of his general awareness of benefits, experience with good analysis or analysts, his perception of good reporting, and his success with selling the results of such studies. Enthoven has summarized policy decisions inputs from ORSA studies as "adequate, reliable information, relevant experience, and clearly drawn issues."

He states flatly:

> "Ultimately all policies are made and all weapon systems are chosen on the basis of judgments. There is no other way and never will be. The question is whether those judgments have to be made in a fog of inadequate and inaccurate data, unclear and undefined issues, and a welter of conflicting personal opinions".

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Philosophy for Utilization of Computer Supported ORSA Models at USAWC

Colonel Louis F. Dixon, US Army War College

The purpose of this presentation is two-fold. First, to introduce the US Army War College, its students and faculty, facilities and curriculum. Secondly, to present the USAWC philosophy for applying computer-supported OR/SA techniques and models so that both our faculty and students become effectively involved in their use and continued development. The Army War College is located at Carlisle Barracks, Pennsylvania, the second oldest of all Army installations. The College was established in 1901 in Washington, DC; suspended operations for the war from 1940 to 1950; was reinstated at Fort Leavenworth, Kansas in 1950; and was relocated to its present location in scenic central Pennsylvania in 1951. Our facilities are modern, and include a large library, an auditorium, individual and committee student rooms, closed-circuit television and a time-sharing medium-scale, third-generation computer system. The US Army Military History Research Collection also is located at Carlisle Barracks, as is the Strategic Studies Institute, an integral part of the College.

The mission of the Army War College is to offer a course of study which will prepare its graduates for senior command and staff positions within the Army and throughout the Defense Establishment, and promote understanding of the art and science of land warfare. Perhaps the Army War College mission is more aptly stated in the words of Secretary of War Elihu Root, who is considered to be its founder. In his dedication address at the laying of the cornerstone of the original College building in 1903, he stated our purpose as "Not to promote war, but to preserve peace by intelligent and adequate preparation to repel aggression,..."

The College graduates one resident course of about 230 students each year. Our classes consist of officers (Lieutenant Colonels and Colonels) of all the military services as well as equivalent grade civilians from numerous government agencies. The Class of 1975 has an average age of 43, 20 years government service, most have college degrees and a significant percentage have graduate degrees. Our faculty has 80 military officers and eight civilians, has an average age of 46, 22 years government service, and 79 of them have advanced degrees.

The curriculum of the Army War College is under continuous study so that it anticipates the needs of its students through the remaining ten to fifteen years of their active service. Whereas in years prior to 1974, our curriculum consisted generally of a homogenious presentation of core curriculum courses with concurrent electives and research projects, this year there will be three distinct phases, or trimesters. The first trimester consists of a condensation of the material previously presented throughout the year, followed by an Individual Concentration Period during which students select courses of their own interest, and is concluded by a research trimester. Specifically, the first phase of our course concerns the student with the United States, its goals, purposes, domestic issues and security policies. This is followed by a consideration of the world environment to include regional and worldwide strategic appraisals.

The second major consideration of the core curriculum concerns Command and Management subjects ranging from executive development to contemporary and defense management practices. The final phase of the first trimester involves in depth study of US military forces, weapons systems capabilities, force structuring and a political-military simulation. Concurrently throughout this trimester the students attend Military Strategy Seminars which conclude with each group developing a US Military Strategy for the Mid-range Period.

The second trimester will permit students to select four elective courses from an overall slate of 60 subjects, depending on individual career specializations, areas of interest or possibly areas in which they have had little previous exposure. These courses vary from International Relations to Military Management and Strategy. Although only two courses are considered specifically as OR/SA, there are fifteen which I consider related to OR/SA in its broadest sense.

The final trimester is spent in group or individual research, and provides the student an opportunity to apply the knowledge acquired in the previous two phases. Subjects are selected by the students but must address significant issues, or, in certain cases, take advantage of unique individual qualifications. Certain students spend this period interviewing, recording and analyzing the career of senior retired officers, a program sponsored by the Military History Research Collection.

The academic year concludes with a seminar which puts our students in contact with over 100 distinguished civilian and military guests for assessment of their research efforts and a discussion of national security issues.

The mission of our Strategic Studies Institute deserves more attention because of its relationship with the College, as well as the obvious mission in providing studies to the Department of the Army. The Institute has a broad range of skills, from economists through OR/SA technicians. Its recent major studies cover such subjects as security assistance, reserve component utilization, the middle-east war, precision guided munitions and strategic appraisals. The interrelationship and cross-fertilization of Institute staff and War College students and faculty contributes significantly to the accomplishment of the missions of both institutions.

Finally, let us look at the Army War College's three objectives in use of OR/SA techniques, specifically computer-supported models. First, we feel such models facilitate presentation of the curriculum and student achievement of learning objectives. Second, they eliminate student and faculty data manipulation, making more time available for scholarly deliberation. Third, we feel that by involving the Army's future senior decisionmakers with computer-supported OR/SA techniques, we can gain their confidence in the ease of use and management effectiveness of user-oriented models.

A team effort is required to achieve these objectives. The system design of OR/SA techniques and models used to support the curriculum must be a joint effort of faculty instructor (who knows what he is trying to teach and why) and systems analyst/programmer (who knows what computer resources are available and how to translate faculty member logic into an automated model). The involvement of the faculty member must be greater than merely the classic "statement of requirements." He must be the full time proponent of the system. He must decide the appropriate data source, the logic best suited to problem solution and the form of system output.

Our experience has been that when the above formula is followed a successful product is achieved. A primary objective of all USAWC models is the last stated. That is, to create an environment wherein our students, because of their exposure at USAWC, become convinced that the use of computer-supported OR/SA developed models can be of assistance to them and is feasible in many military management situations. We also hope that our graduates will be more demanding of the OR/SA community in developing systems which achieve the user's needs.

I will be followed by two faculty/analyst-programmer teams who will present the functional user and technical support sides of two of our major curriculum supporting models, as well as some other related activities which we feel will be of interest. In conclusion, I hope the following presentations will demonstrate our adherence to the philosophy stated above, as well as substantiate what we feel to be success in achieving our objectives.

CURRICULAR APPLICATION OF THE USAWC BUDGET PROJECTION MODEL

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US Army War College, Carlisle Barracks, Pa.

This paper describes the utility, and rationale for the use, of automatic data processing in the US and the World Environment Course conducted as part of the common overview curriculum of the US Army War College. The course is one of three common offerings which establish a coherent foundation for the more personalized and specialized remainder of the ten-month academic program. The course serves as an introduction to the study of issues, alternatives, and policies affecting the United States in a mid-range (ten-year) time frame.

While the nature of the War College curriculum has changed over the years in response to changing requirements placed on the senior military officer, a broad introduction to the political, social, economic, and national security aspects of the American experience has been a basic element for many years. The methodology, in general terms, has been a mix of lectures, seminars, and group discussions concerning the domestic and the international environment and studying selected world regions of special interest to the United States.

To focus individual and group work on a specific goal, each seminar group plays the role of a presidential advisory commission. It is called upon to analyze the domestic and international status of the United States, to specify policy objectives, to develop alternatives, and to recommend a broad program of action in both domestic and international affairs for the next ten years. While the specific nature of the requirement, like the course itself, has changed over the years, its general thrust has remained the same.

A factor which was recognized quite early by students and faculty alike is the difficulty encountered by each student seminar group in reaching even a general understanding of the intricacies of the specific issues studied and the interaction of these issues. An additional complicating factor is the necessity to quantify policy alternatives in order to establish program costs even in gross terms.

In Academic Year 1970, the first attempt to systematize the budget portion of the course requirement was undertaken. This attempt recognized three important values to be obtained from this requirement:

1. The requirement to develop a coherent budget estimate constrains alternative proposals to those which are economically feasible and potentially attainable.

2. It allows expression of degrees of enthusiasm for proposed policies and separates pure rhetoric from practical policy formulation.

3. It translates policy intention into a commonly denominated factor which can be discussed across political and social divisions.

These values have been maintained as a cornerstone of the course requirement for the past five years. It was immediately recognized that the automation of certain aspects of the course requirement would have significant impact on the reliability and timeliness of the final product. To this end, a simple program was developed which was the forerunner of BUDPRO, the USAWC Budget Exercise.

This initial program required an "assumed" annual average growth rate for the gross national product (GNP) and asked the student group to estimate the share of federal expenditures allocated to fourteen expenditures categories in the next fiscal year, in this case FY1971, and ten years later in FY1981. Both a manual and an automated system were available to the students.

In both manual and automated modes, the system generated straight-line projections based on the share of the total federal expenditures selected in each case by the student group. In the words of the course directive, it was, indeed, "broad, crude, and general!"

Through four replications and several modifications, both the exercise itself and the supporting computer program have been refined. We shall consider shortly the present edition of the course requirement as it has been executed recently by the Class of 1975 and the current supporting ADP program. First, however, it might well be wise to examine other ADP applications which have been developed to support the course as a whole.

Two ancillary programs have been developed or adopted to support the general objectives of the US and the World Environment Course and the basic BUDPRO model. The first of these, NEXUS, or the National Executive Utility Simulation, permits the student groups to test their BUDPRO analysis in a politico-economic game representing a four-year cycle. The fact that the four-year NEXUS cycle does not match the five year to ten year BUDPRO cycle and certain political anachronisms in the program itself will require major revision if the program is to be of continuing utility. Students who used it this year, with its inherent limitations, found it to be useful, however.

DIDBARS, or the Digital Information Data Bank and Retrieval System, originated in AY1971 as an ADP program specifically designed to enhance and facilitate the accomplishment of learning objectives entailed in completion of international strategic appraisals. Students were frustrated by the necessity to spend long hours researching a wide variety of documents. A demand for the same few documents by many students created bottlenecks which were disfunctional to the academic purposes of the course. To overcome these deficiencies, DIDBARS was instituted. In simple terms, it aggregates about 95 items of information concerning 125 countries and sorts and compiles them in various formats. It does this for three years at this time, 1971, 1972, and 1973, for comparative purposes. When it reaches its full capability, it will amass data over the preceding five years. The program is quite useful as a research tool for students attempting to gather comparative data about a particular country, an alliance system, or a region of the world. The program will catalog and sort data in any of these categories. The information stored in the program is unclassified.

Let us return to a consideration of the basic computer-based model, BUDPRO. The current version of BUDPRO is a dynamic but simplified model of the federal budget. As inputs, it accepts the students' estimate of GNP growth for a ten-year period in two five-year increments. It also requires the student groups to examine and select from among five possible models of federal revenue and to use this "revenue case" as an input. Finally, the students' input includes the actual federal expenditures in the major expenditures categories of the federal budget for the same two five-year increments. The outputs of the model are:

1. The GNP for the terminal year of each five-year increment based on the selected growth rate.

2. The revenues raised by the revenue case selected and the ratio of federal revenues to GNP--a rough calculation of the "federal share" of the GNP.

3. A projection of the expenditures categories in billions of dollars based on the modifications to each category made by each student group.

4. An item which accumulates all federal expenditures to include interest on the federal debt and various adjustments due to transfer payments within the government.

5. A statement of federal budget deficit or surplus for the end year of each five-year increment.

The following paragraphs describe these inputs and outputs in more detail while Figure 1 presents a typical BUDPRO output as received by a student.

INPUTS

GNP Growth Rate. This item is purely an estimate based on prior student knowledge, experience, and research. Students are encouraged to be realistic and to avoid too optimistic or too pessimistic approaches. Usually, each seminar group chooses a figure within a percentage point of the average growth rate experience of the past which is quite in accord with the objectives of the program from an instructional viewpoint. Students may select growth rates for each five-year increment or may elect to project an average growth rate for the entire period.

Revenue. An innovation in AY1975, the consideration of federal revenue was deemed essential to a useful and realistic model. Past experience with a model which projected expenditures only showed a lack of realism and a tendency for students to "play the model." By simply increasing the "federal share of GNP," for instance, a student group could generate whatever amount was required to balance revenues against expenditures. A realistic appraisal of the revenues side was important to the continued value of the program as an educational tool. The faculty recognized, however, that the degree of research required and the level of knowledge necessary to treat federal revenue intelligently used up more time than was available. A simplified treatment of revenue was in order.

The object of the revenue case is to permit student views of fiscal policy to be stated in terms relevant to the program. To accomplish this, five cases were selected. Case 1 projects the current revenue distribution and current policies--in essence, a "no change" option. Case 2 assumes recessionary trends in the economy and proposes tax cuts for both personal and corporate taxes. Case 3 posits a continued inflation which requires conservative solutions: increases in tax levels and a budget in balance or surplus. Case 4, a neo-Keynesian approach, expects inflation to be curbed and recession prevented by more direct federal intervention through intensive management of the business cycle and greater federal participation in the economy in general. Case 5 provides the student groups with a more radical option: partial nationalization of basic industry, shifts in tax burdens from the individual to the corporation, and a growth rate financed principally by federal deficits. (See appendix for details)

Students may select one case for the entire mid-range period or select a different case for each of the five-year increments. The computer program adjusts the federal revenue outputs in accordance with the policies outlined in each case and modifies the growth rate of the GNP when necessary. Although a highly simplified view of federal revenue, the introduction of the revenue cases provides a degree of realism heretofore unknown. The students are required to make hard choices not only in areas of government expenditure, but also among alternative revenue policies.

Expenditure. The model permits student adjustment of fourteen categories of federal expenditures as shown in Figure 1. Changes may be made in the dollar amounts or as a percentage of federal revenue shown on line 03. Lines 16 and 19 are adjustable only indirectly. Interest is a function of changes in the federal debt roughly indicated by deficits or surpluses in line 21. The category of undistributed deductions, line 19, is a function of several other categories and adjusts the budget to account for intragovernmental transfer payments. The program itself accommodates this area. Line 20 simply totals the expenditures categories and line 21 strikes a balance against revenues. The program will make adjustments in the percentages based on changes in dollar values and will change dollar values based on changes in percentages.

Two years ago, a modification to the expenditures portion of the exercise was made to emphasize realism. Recognizing that current estimates place at 75% the portion of the federal budget which is uncontrollable, it is not realistic to reduce many programs without serious consideration of the consequences. To inject this restriction into the BUDPRO model, each expenditures category has been "flagged" at a level below which the student cannot go without major policy and program changes. If a student elects to reduce a category below a minimum level, the item is asterisked in the printout and a statement appears which identifies some of the reasons why a lower figure is questionable (See line 13 in Figure 1). If, after considering the reasons, a student wishes to reduce the program below the established floor, he may do so; however, an explanation and justification is expected in the written portion of the report.

OUTPUTS

Gross National Product. The program generates a projected gross national product for the end year of two five-year increments. This is based on the growth rate which is a student input.

Revenue. For the two years under consideration, the program generates total federal revenues and computes the revenues as a share of the gross national product.

Expenditures. For each of the two years, expenditures in fourteen categories previously adjusted by the student plus two other categories are generated. In each case, the expenditure is identified as a percentage of revenue. A total federal expenditure for the year in question is printed at line 20 (Figure 1). The "interest" and "undistributed deductions" categories are computer-generated as explained previously.

Deficit/Surplus Status. For each year, the total federal expenditures (line 20) are compared with the federal revenues (line 03) and the difference is indicated as a budget surplus or deficit.

The utility of these programs is probably measured best by the student-users themselves. Recognizing the limitations of all three programs and the necessarily simplistic approaches of BUDPRO and NEXUS, students have learned the value of a computer-based system for analysis of issues, compilation of data, and comparison of results. The BUDPRO printout gives a finite product in a standard format which can be used by seminar groups and faculty alike to discover the gist of a proposal, its politico-economic basis in reality, and its relation to other programs and proposals. Similarly, NEXUS permits a rough comparison of a set of policy proposals with political reality. DIDBARS is a working program which supports the research required to amass data needed by both BUDPRO and NEXUS.

The response of our students has been highly favorable over the past three years. A measure of continuing success has been the general increase in favorable responses over time. Several students this year have become interested in the programs themselves, offering constructive and in many cases useful ideas for improvement. This trend is also significant in terms of the observable increase in the sophistication of senior officer-students when dealing with ADP in general and computer-based instructional models in particular. The apprehension of the average student faced with an access device has diminished markedly, pointing up the fact that ADP procedures and techniques have become more commonplace in the last few years. The continuing use of computer-based models in the USAWC curriculum will further enhance this process of education in the age of the computer while it makes a major contribution to the more general objectives of the course in the US and the world environment itself.

FIGURE 1

BUDGET PROJECTIONS: (ALL DOLLARS ARE IN BILLIONS)

01 YEARS BUDGETED	%	FY75 $	%	FY80 $	%	FY85 $
02 GNP GRTH RATE & GNP	0.	1383.50	3.5	1642.79	3.4	1945.97
03 FED REV $ % OF GNP	21.3	295.00	22.6	370.63	22.2	431.67
04 NATIONAL DEFENSE	29.7	87.73	27.0	100.07	25.5	110.08
05 INTERNATIONAL AFFAIRS	1.4	4.10	2.0	7.41	2.5	10.79
06 SPACE RESEARCH & TECH	1.1	3.27	1.1	4.08	1.1	4.75
07 AGRICULTURE	0.9	2.73	1.1	4.08	1.1	4.75
08 NATURAL RESOURCES	1.1	3.13	2.3	8.52	2.6	11.22
09 COMMERCE & TRANS	4.5	13.40	4.5	16.68	5.0	21.58
10 COMMUNITY DEVEL	1.9	5.67	2.9	10.75	3.2	13.81
11 EDUCATION & MANPOWER	3.9	11.54	5.0	18.53	5.0	21.58
12 HEALTH	8.9	26.28	8.0	29.65	8.0	34.53
13 INCOME SECURITY	33.9	100.07	32.9	122.00	34.6	149.20*
14 VETERANS BENEFITS	4.6	13.61	4.8	17.79	4.8	20.72
15 GENERAL GOVERNMENT	2.3	6.77	2.1	7.78	2.1	8.92
16 INTEREST	9.9	29.12	7.1	26.15	5.9	25.46
17 GEN REV SHARING	2.1	6.17	1.2	4.40*	1.0	4.30*
18 ALLOWANCES	0.5	1.56	0.5	1.97	0.5	2.30
19 UNDISTR DEDUCTIONS	-3.6	-10.72	-3.4	-12.76	-3.5	-15.10
20 TOTALS:	103.2	304.43	99.0	367.10	99.4	428.90
21 SURPLUS/DEFICIT	0.	-9.43	0.	3.52	0.	2.77

REVENUE CASE 3

13 INCOME SECURITY
FY85 -- FLOOR = $ 150.00
YOU HAVE REDUCED YOUR ALLOCATION TO THE POINT WHERE YOU MAY NO LONGER MEET THE PENSION DEMANDS OF AMERICAN WORKERS, GUARANTEED TO THEM BY EARLIER LEGISLATION. HOW DO YOU RATIONALIZE THIS

17 GEN REV SHARING
FY80 -- FLOOR = $ 6.30
FY85 -- FLOOR = $ 6.50

APPENDIX

DISCUSSION OF REVENUE CASES

1. General. The following discussion and rationale are presented to the student seminar groups during the United States and the World Environment Course to assist them to identify more clearly the philosophy of each case. Students are able to modify a case in practice through explanation and justification in the written portion of the final report. No change in the case model itself, however, is possible at this time.

2. CASE 1: The Current Situation.

a. You accept the budget statement of the current administration and the economic forecasts which support it with only minor variations.

b. You intend to maintain a balanced "full employment" budget in the mid-range but are willing to accept a deficit in the actual budget.

c. You plan no changes in the sources of revenue or the tax structure.

d. You do not anticipate a large-scale recession.

e. You accept a certain amount of inflation but anticipate that present efforts of government to control recent highly inflationary trends will be effective in the mid-range.

3. CASE 2: Mildly Recessionary Situation.

a. You anticipate that a recession of some severity will take place within the next five years which will reduce inflationary trends, increase unemployment, and increase costs to government for unemployment benefits. Although an upturn in the business cycle may be anticipated in the mid-range, the total effect, without governmental interference, will be mildly recessionary.

b. You intend to apply conservative monetary and fiscal measures to reduce the impact and duration of the anticipated recession. These include an easing of interest rates, a reduction of about 10% in personal income tax rates, and an easing of the corporate tax burden by the same amount to provide more funds for capital investment.

c. Although some deficit spending may be required in the short run, you anticipate a balanced budget in 1985, perhaps even by 1980.

d. To achieve a balanced budget in the mid-range with a net reduction of federal revenues (para 3b) you must make significant cuts in present levels of federal expenditure.

e. Your prediction of GNP growth in the next five years will probably be less than 3.5% to be consistent with your recessionary trend.

4. CASE 3: Inflationary Situation.

a. You anticipate that the present high rate of inflation will continue unless active measures are taken both in the public and private sector to control it. You are not satisfied that the present federal anti-inflationary policies are wise or workable.

b. The rate of inflation may continue in the 8-10% range with the possibility of a serious depression at the end of the spiral. Patchwork solutions may defer this depression until late in the mid-range, however, you are concerned that action must be taken now to avoid this trend.

c. You are unwilling to apply "socialistic" solutions through the takeover of industry, controls on employment, or a long-term price/wage control system.

d. You intend to apply conservative monetary and fiscal measures to reduce the impact of and eventually curtail the high rate of inflation. These include a net increase of 10% in the tax revenues from individual incomes and corporations. No change is anticipated in the social insurance tax structure.

e. A balanced budget is a long term goal. Budget surpluses will be induced to enhance the anti-inflationary impact of the tax increases proposed. These surpluses, averaging about $5 billion annually, will be used to reduce public debt.

f. You accept a moderate rate of unemployment of about 6-7% during the initial phases of your program and recognize the short-term increased welfare costs which unemployment entails.

g. You recognize that certain federal expenditures programs must be curtailed to realize your goals.

h. Although a rate of growth of 4-5% might be anticipated during the early years of the period, it will not exceed 4% in the 1980-1985 period, assuming at least partial success of your programs.

5. CASE 4: Mild Social Engineering.

a. You recognize a need not only to stem inflationary trends but also to reorder federal priorities in a significant way. This reordering will require greater participation by the federal government in economic decisionmaking, as a start.

b. You desire to continue the general policies of liberal administrations of the past 40 years, and you accept as a major premise that a redistribution of the nation's wealth is in order and long overdue.

c. You plan to shift some of the tax burdens from the poor through a cut of about 40% in the social insurance tax revenues and a parallel increase of about 20% in both individual income and corporate tax rates. You plan some additional tax relief for the poorer segments of society through some sort of negative income tax or an increase in low-income deductions.

d. You accept the fact that a small deficit of about $3 to $8 billion is inevitable since you will continue a high level of federal spending in the human resources areas.

e. You consider that a moderate rate of inflation (5-6%) is an acceptable price for the social benefits to be achieved. You will use whatever government controls are necessary, however, to insure that inflation does not get out of control and to alleviate the impact of inflation on the disadvantaged.

f. You plan a moderate shift from government spending for defense and foreign aid to those programs which more closely affect the average American. These could parallel Senator McGovern's defense spending proposals during the 1972 campaign.

6. CASE 5: Incipient Socialism.

a. You are concerned about the quality of life in this country and agree that present programs have failed to help the average American. You believe that only radical solutions can prevent increasing decay in American society.

b. You recognize that a radical change in spending programs and tax structures are only a beginning to the reordering of American life but realize that this reordering can only be accomplished through constitutional means.

c. You wish to impose a tax structure which will eliminate the wealthy class who pay little or none of the costs of government. This will be accomplished through:

(1) A substantial increase in the tax rate for higher incomes and elimination of most or all of the deductions available to this group. Tax loopholes would be eliminated or drastically curtailed.

(2) A drastic increase in inheritance tax rates which could be confiscating for large estates.

(3) An increase in corporate income taxes to insure that business pays its "fair share" of the costs of social progress and to eliminate "excess" or "windfall" profits. This would begin with a 20% increase in tax rates.

d. The costs of social insurance will be paid out of progressive income taxes, relieving the poor of the burden. The separate social security tax structure will be eliminated.

e. A negative income tax plan will virtually eliminate urban and rural poverty in the mid-range period.

f. Priority will be given to domestic programs over international commitments.

g. Regressive taxes at all levels will be abolished.

h. Wage/price controls of a permanent nature will prevent inflation, or at least control its severity.

i. Controls on industry, probably short of outright nationalization, will insure that the industrial might of the nation operates for the general good. Certain key utilities may be federally managed, however, in a manner similar to the Amtrak system.

j. A budget deficit will be required to finance some of the new expenditures programs. This deficit will be considered "normal" if it falls within the $10-$16 billion range.

k. A slowing of economic growth to a rate of 2-3% is anticipated. Economic growth, however, is not considered an end in itself and a lower rate is quite acceptable.

Technical Methodology in the BUDPRO Model and the Application of this Methodology to Other ORSA Techniques

CPT Darryl L. Steiner, US Army War College

At the Army War College, our association with ORSA comes about in two distinct ways. First, the curriculum contains several courses that require computer implementation of ORSA techniques; and secondly, we are often required to support research projects by the students and by the Strategic Studies Institute with these same techniques.

In supporting the curriculum, ORSA is not only used as a tool for building better understanding of the subject of a course but the techniques themselves are often the subject of study. Our support of research projects is not limited to the utilization of long established techniques but also occasionally involves some tentative exploration of new ones. We feel a responsibility to demonstrate the value of ORSA, to our student body of Senior Officers, in such a way that they will become convinced that ORSA can be a valuable aid to them in their future positions.

To do this, we have devoted a considerable amount of effort to presenting our computer applications in a manner that is easy to use and understand. The BUDPRO model is one that we feel is especially important because it is exercised by the students near the beginning of the academic year. For many of the users it is their first personal experience in the use of ORSA techniques and computer technology. We want this experience to be such that they will gain confidence in systems like this and in their ability to use them effectively.

The model itself is a time-share FORTRAN system that requires less than 15K words to execute. It consists of data files and the three programs shown on Figure 1. Using the initialization program, the proponent, normally a faculty member responsible for teaching the course, initializes the base year data file and the 16 seminar group data files. Through the second interactive program, the student users access the base year file and their own seminar group file. They are not permitted to change the base year data (currently for FY 75) but they may enter changes for the two time periods that follow. (Currently these are five-year periods ending in FY 80 and FY 85.) As they enter changes, a revised budget is developed in the arrays of the program which, in effect, become a temporary or current file. Eventually all seminar groups arrive at a final budget projection. The proponent faculty member then uses the third program to run an analysis of the 16 revised budgets.

In order to be a bit more specific, I would like to draw your attention to the Sample Budget Projection on Figure 2. All seminar groups start with an identical projection. Changes are then entered for the two time periods, by line number, using either dollar amounts or percentages. However, changes to certain lines are not permitted:

Line 1 is normally changed only by the proponent in the initial program.

THE BUDPRO SYSTEM

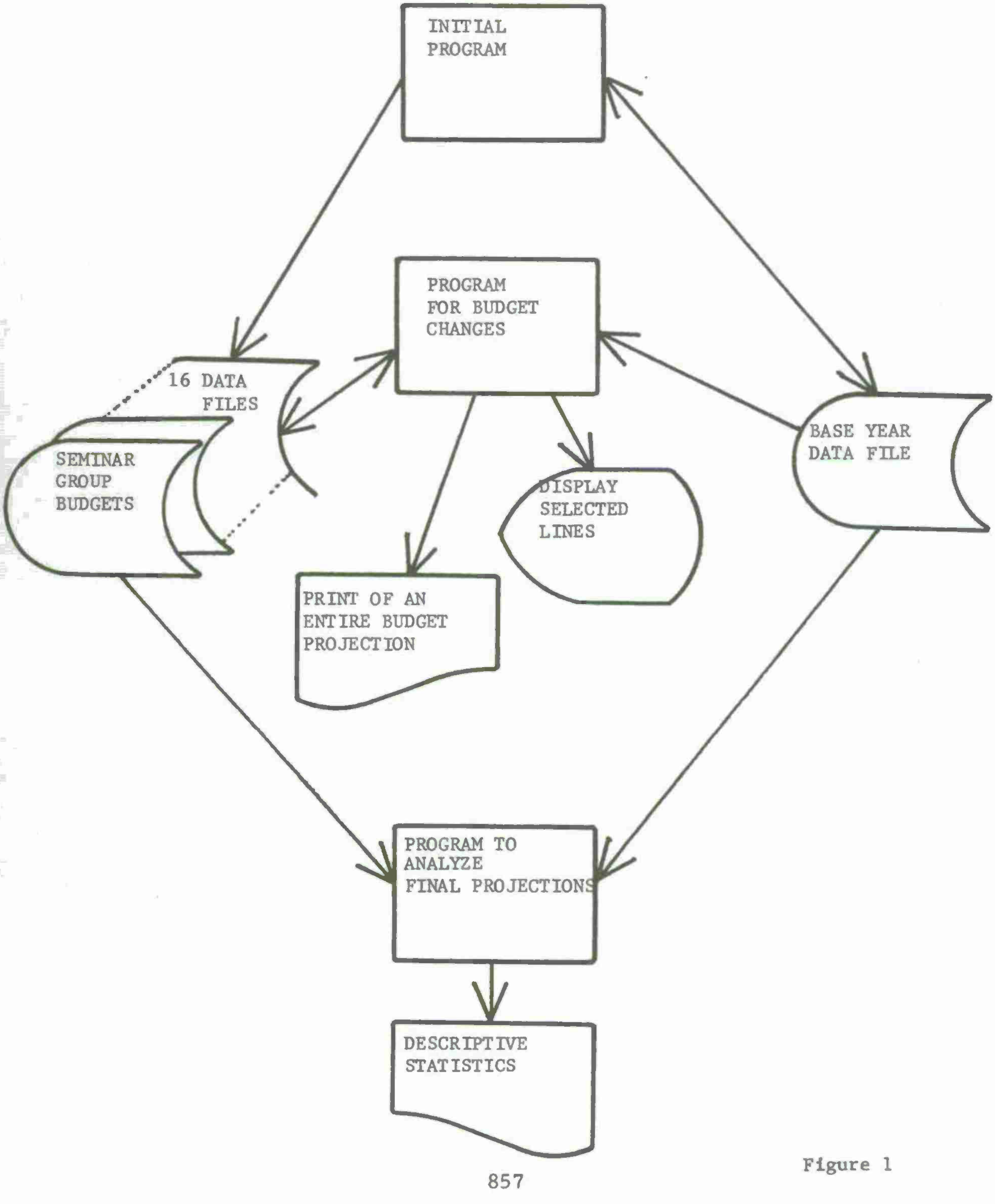


Figure 1

BUDPRO BUDGET PROJECTION
(ALL DOLLARS ARE IN BILLIONS)

01 YEARS BUDGETED	%	FY75 $	%	FY80 $	%	FY85 $
02 GNP GRTH RATE & GNP	0.	1383.50	3.5	1642.79	3.4	1945.97
03 FED REV & % OF GNP	21.3	295.00	22.6	370.63	22.2	431.67
04 NATIONAL DEFENSE	29.7	87.73	27.0	100.07	25.5	110.08
05 INTERNATIONAL AFFAIRS	1.4	4.10	2.0	7.41	2.5	10.79
06 SPACE RESEARCH & TECH	1.1	3.27	1.1	4.08	1.1	4.75
07 AGRICULTURE	0.9	2.73	1.1	4.08	1.1	4.75
08 NATURAL RESOURCES	1.1	3.13	2.3	8.52	2.6	11.22
09 COMMERCE & TRANS	4.5	13.40	4.5	16.68	5.0	21.58
10 COMMUNITY DEVEL	1.9	5.67	2.9	10.75	3.2	13.81
11 EDUCATION & MANPOWER	3.9	11.54	5.0	18.53	5.0	21.58
12 HEALTH	8.9	26.28	8.0	29.65	8.0	34.53
13 INCOME SECURITY	33.9	100.07	32.9	122.00	34.6	149.20*
14 VETERANS BENEFITS	4.6	13.61	4.8	17.79	4.8	20.72
15 GENERAL GOVERNMENT	2.3	6.77	2.1	7.78	2.1	8.92
16 INTEREST	9.9	29.12	7.1	26.15	5.9	25.46
17 GEN REV SHARING	2.1	6.17	1.2	4.40*	1.0	4.30*
18 ALLOWANCES	0.5	1.56	0.5	1.97	0.5	2.30
19 UNDISTR DEDUCTIONS	-3.6	-10.72	-3.4	-12.76	-3.5	-15.10
20 TOTALS:	103.2	304.43	99.0	367.10	99.4	428.90
21 SURPLUS/DEFICIT	0.	-9.43	0.	3.52	0.	2.77

REVENUE CASE 3

13 INCOME SECURITY
FY85 -- FLOOR = $ 150.00
YOU HAVE REDUCED YOUR ALLOCATION TO THE POINT WHERE YOU MAY NO LONGER MEET THE PENSION DEMANDS OF AMERICAN WORKERS, GUARANTEED TO THEM BY EARLIER LEGISLATION. HOW DO YOU RATIONALIZE THIS

17 GEN REV SHARING
FY80 -- FLOOR = $ 6.30
FY85 -- FLOOR = $ 6.50

Figure 2

Lines 16, 19, 20, and 21 are not changed directly but will change depending on changes to the other lines.

Line 3, Federal Revenue, is a special case in that its change is a function of the revenue case being used by a seminar group.

Some cases will also cause a change in the GNP unless a direct change to the GNP is also entered. Changes made in the first time period will automatically result in changes to the second.

In general, that is what the system does, however, I would like to spend some time with the options available to the user as he is entering changes. In formulating these options (shown on Figure 3) we had two general goals in mind:

Allow as much flexibility as possible.

Minimize the amount of time required to run the model.

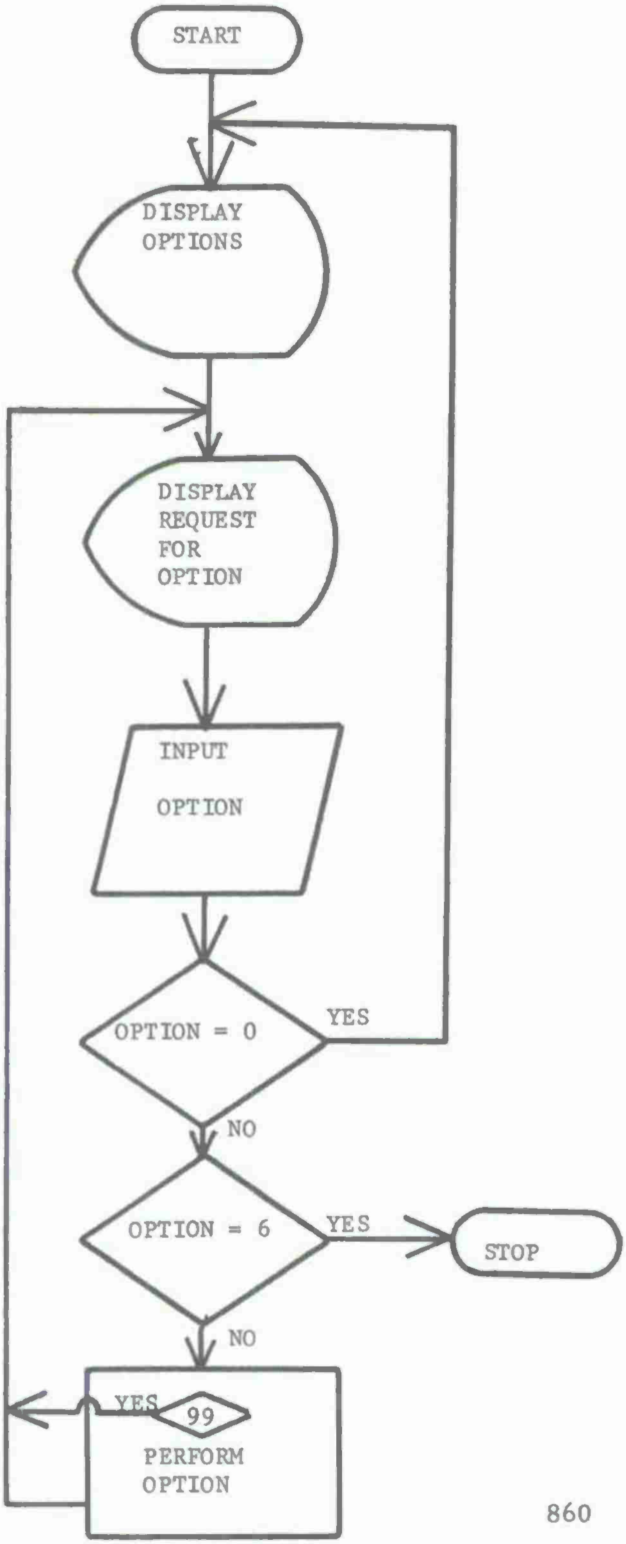
The general concept is that the user calls the program and causes his seminar group and the base file to be attached. He enters changes with option 3. With various combinations of changes he can cause the entire budget to be printed on a high-speed printer with option 4, or he can have individual budget lines displayed at the terminal with option 5. With option 7, he can ask to see if his current budget violates any floors. (By floor here we mean legislated minimums as explained by LTC Burns.) If he likes what he sees in his current file he can copy it onto his permanent file with option 2; if he doesn't like his current file he can reset it by recalling his permanent file. When he is finished, option 6 allows him to stop the program.

Options 9 and 10 are especially convenient for teletype terminals. They enable the user to control the amount of guidance he receives from the program as he exercises it. By reducing the sentences to guide words, option 9 can save a considerable amount of time. The normal commentation can be restored by option 10 if the user finds that the guide words are not sufficient.

Option 0 is also a time saver for the teletype terminals. Once the options are listed at the beginning of the run, the teletype user can refer back to that list when selecting subsequent options. The video user, however, has had the original list erased and he may want to repeat it several times. In either case, option zero allows the user to obtain a list of options whenever he wants it.

The video terminals presented us with a special problem not only with the BUDPRO model but with several of our computer systems. Although they are much faster to use, they do not provide a hard copy and printers for each terminal were not available. An obvious solution is to direct output to a line printer but, for good reason, system design does not make this an easy task. It would obviously be inefficient to allow a terminal to tie up a high-speed printer waiting for interactions to be completed.

BUDPRO OPTION SYSTEM



0 DISPLAY OPTIONS

1 RE-COPY PERMANENT FILE

2 SAVE CURRENT FILE

3 CHANGE CURRENT FILE

4 DISPLAY INDIVIDUAL LINE

5 PRINT ENTIRE CURRENT FILE

6 STOP PROGRAM

7 DISPLAY FLOORS

8 LIST FLOORS VIOLATED

9 SUPPRESS COMMENTATION

10 RESTORE NORMAL COMMENTATION

99 RETURN TO REQUEST FOR OPTION

Figure 3

Originally the solution was to direct the output to a permanent file; then, when the interactive program was terminated, the user could use the computer system's CARD-IN subsystem, access the print-file and a batch environment FORTRAN program to send the contents of the file to the high-speed printer. This worked, but it had shortcomings. A separate print-file had to be maintained for each user group, and the input at the terminal was tedious for users not familiar with the operating system.

Eventually, with the assistance of a Honeywell Tech-rep, LT Ron Parker was able to develop an assembler level routine which performed the same task without requiring any effort on the part of the user and eliminating the need for maintaining the large number of print-files. This routine is shown on Figure 4. The time-share program creates a temporary file on which the output is written. The print routine is then called by the interactive program. This causes the contents of the time-share temporary file to be transferred to a batch environment file along with the necessary job control commands to execute the program that prints the contents of the file on either of two different high-speed printers.

The subroutine can be called several times during a single execution of the time-share program. The effect in BUDPRO is that the user can make a few changes, have the revised budget projection printed and immediately enter new changes to generate an alternative budget projection.

Although this technique was the result of having video terminals without associated printers, we have found that it is very efficient for the teletype terminals also. Watching long printouts being generated on a teletype soon becomes tiring not only for the user but for the guy waiting to use the terminal. With this technique available, the user has little reason to limit the number of alternative budget projections for study.

Having the routine available for entering the batch environment from a time-share program opened the door for much more effective use of other ORSA techniques. It was apparent that, if a batch program could be called to print a file, then any batch program could be called for execution via the time-share system. An immediate application of this technique was to our implementation of the SUMT (Sequential Unconstrained Minimization Technique) routine. This program is too large and requires too much execute time to be efficiently executed in our time-share environment and, in the past, we have had to execute it with card input. Helping twenty Colonels run several iterations of a card job is not one of the best experiences I've had at the College. We had all the problems inherent with card processing; missing cards, extra cards, out-of-order cards, keypunch errors, and so on. At the end of that part of the curriculum last year I was highly motivated to find a better way. The ability to execute batch jobs from a time-share environment gave me a better way and the system shown on Figure 5 is the result. The time-share program not only provides a fast means of data input, it also provides an opportunity for error detection and editing.

OUTPUT TRANSFER SYSTEM

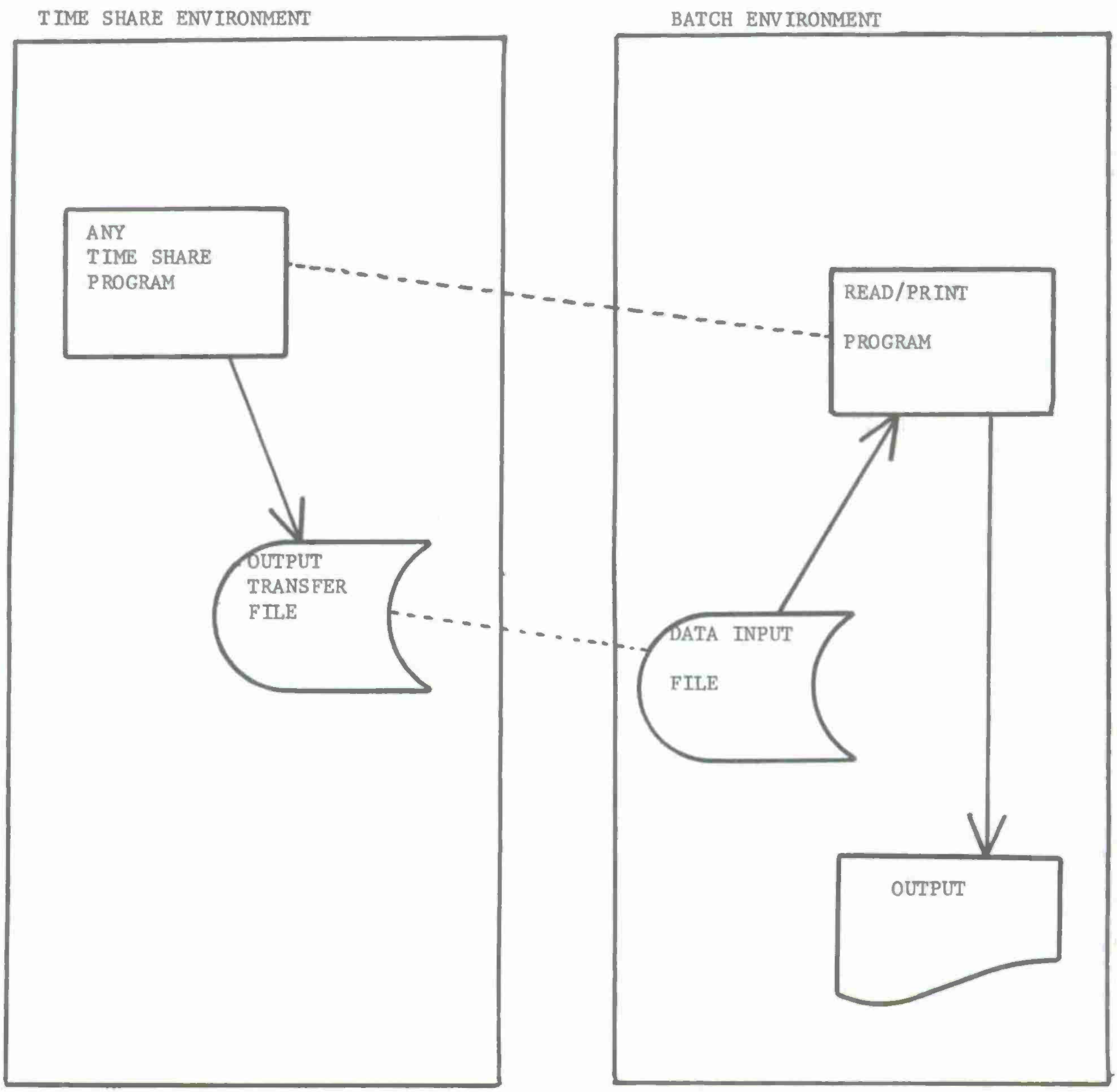


Figure 4

THE SUMT SYSTEM

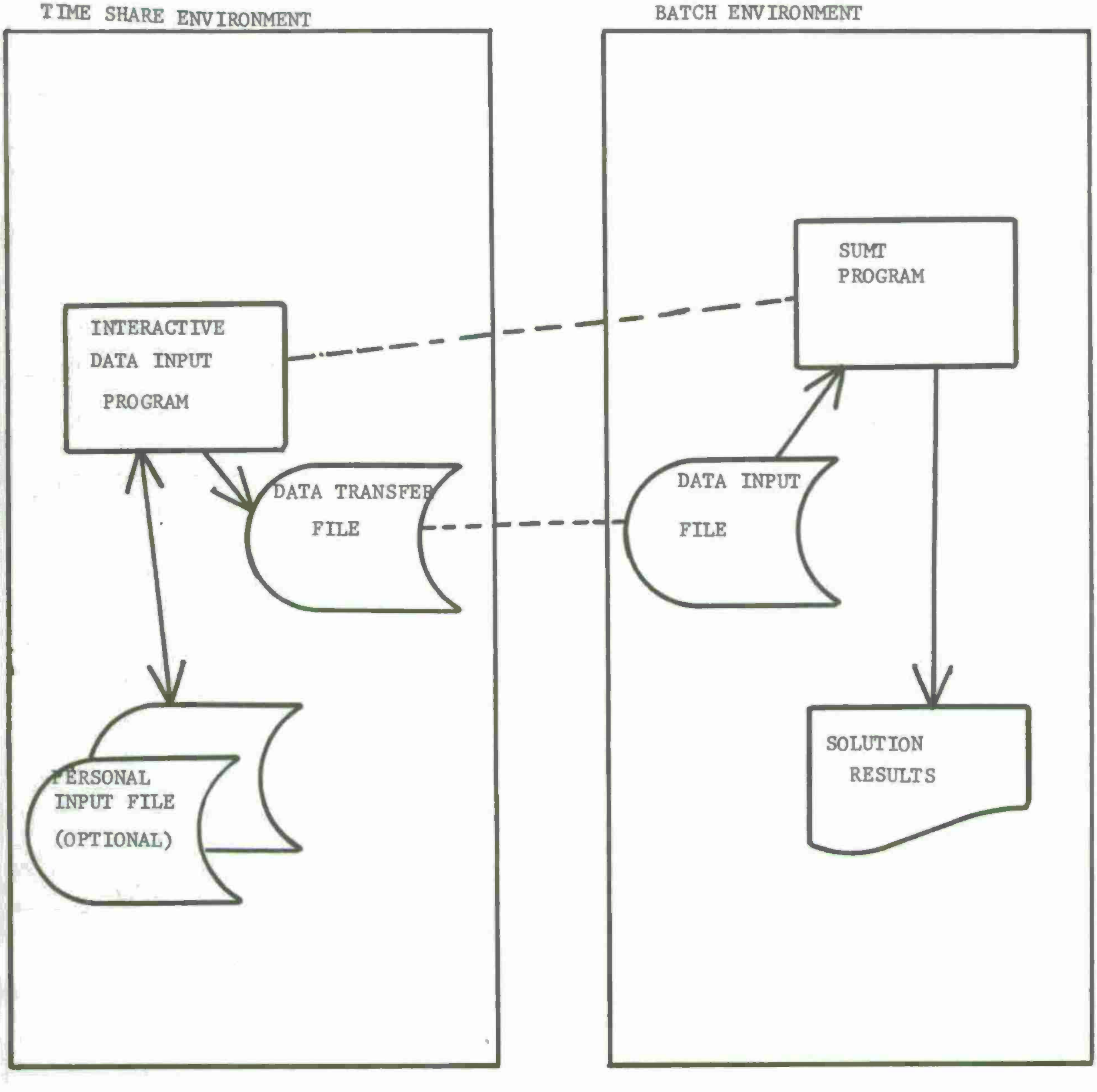


Figure 5

Users who frequently use the program are provided with a permanent file which they can use to save their input problem. When they enter the program they have the option to change a previous problem's initial points or constraint parameters, enter a new problem, or run the previous problem without changes. Users who do not have a permanent file assigned to them have only the option to enter and run a problem without saving it. In either case, the problem parameters are entered on a temporary file as well as certain job control information. This file is then passed to the batch environment and an execution of the SUMT algorithm is effected.

In general, we are greatly concerned with making ORSA techniques readily available to our users in a format that they find easy to use and understand. BUDPRO and SUMT are examples of the direction of our efforts. We hope that systems such as these, because they are effective, will be remembered by the students in their future assignments and that they will seek out ways for ORSA to aid them in accomplishing their missions.

TITLE: The USAWC Force Costing Model

AUTHOR: Colonel Robert T. Reed

AGENCY: US Army War College

A. BACKGROUND. 1. Curriculum Relationship. Force planning exercises contained in the USAWC curriculum closely parallel the ideal of the planning and programming phases of the Planning, Programming and Budgeting System (PPBS) which is used in the Department of Defense. Based on stated and implied national security policy and objectives, student seminar groups develop a military strategy. The next step in the process is to design military objective forces sufficient in size and appropriate in mix to successfully implement that strategy. These objective forces are relatively unconstrained; that is, requirement rather than resource oriented; but must meet the somewhat vague goal of being fiscally responsible, reasonably obtainable and incur no more than a prudent level of risk. Having settled on a preferred objective force consistent with its strategy, the seminar group is faced with the hard realities of resource constraints which force an adjustment (reduction in virtually every case) of its force to satisfy these limiting constraints without causing the level of risk associated with this constrained force to become unacceptably high with respect to the seminar group's previously formulated strategy. This is the practice of what may be called "The Art of the Possible."

2. Definitions:

a. Objective Force. A force level and force mix alternative sufficient to execute a particular military strategy, at a prudent level of risk, which is fiscally responsible and reasonably attainable.

b. Constrained Force. A force level and force mix alternative sufficient to execute a particular military strategy at a prudent or higher level of risk which satisfies certain fiscal, manpower and possibly other limiting constraints.

c. Fiscally Responsible. Referring to objective forces this means that they can be afforded by the nation. It does not mean that the nation is willing to provide the requisite resources.

d. Reasonably Attainable. Referring to objective forces this means that they are physically achievable in terms of industrial capacity, lead times; etc.

3. Costs and Manpower Impacts. Inherent in the process of objective force planning is the requirement to insure that force levels in the aggregate are fiscally responsible and reasonably attainable. This immediately demands that the cost and manpower impacts of various force level and force mix alternatives be explicitly known. The problem of keeping track of manpower levels associated with various force alternatives is a relatively straightforward but necessarily tedious task. The corresponding battle to account for cost differences between force alternatives is not only tedious but is fairly complicated as well. Several factors contribute to this problem.

a. Investment Lead Time. For any weapon/support system there is a lag between the time the decision is made to procure the weapon system and the time the system is available for use by operating forces. This lag is called investment lead time. During this time lag funds must be programmed each year. Lead times vary from system to system and may be affected by the number of such systems desired at a particular time. For purposes of this discussion let us say that for a given system this lead time is represented by X - N, where X is the FY when the system should be operational and the X - N refers to a system for which funds must be obligated N years in advance to insure availability in FY X. The following table illustrates the schema used in the Force Costing Model to account for the funding lead time phenomenon.

Table 1. Funding Profiles

If the funding lead time is:	The percent of total investment cost programmed in each year is:					
	X - 5	X - 4	X - 3	X - 2	X - 1	X
FY X						100
FY X - 1					50	50
FY X - 2				30	40	30
FY X - 3			20	30	30	20
FY X - 4		10	20	40	20	10
FY X - 5	10	10	20	30	20	10

NOTE: This table applies to obligations (TOA) rather than expenditures (outlays).

b. Cost Growth. A term coming into frequent use--and abuse--in recent years, cost growth seems as ubiquitous as the common cold. And no easier cured. When asked to account for cost growth, the tendency on the part of defense manufacturers and, for that matter, military hardware proponents has been to highlight the devastating effects of inflation. While it is true that inflation represents the lion's share of recent cost increases on major weapons systems, some increases would have occurred even in a period of zero inflation. It is the latter category on which we focus, for we are concerned with constant dollars.

The extent to which cost growth occurs is clearly a function of the extent to which the defense program includes the acquisition of major new systems. To get some feel for the size of noninflationary cost growth, we consider the recent report released by the Secretary of Defense, "The Economics of Defense Spending." On a study of 45 major systems, we isolate as primarily noninflationary the following cost increases:

DOLLARS IN BILLIONS

	TOTAL COST GROWTH	NONINFLATIONARY GROWTH INCLUDED IN TOTAL
Engineering changes	4.2	4.2
Support changes	1.2	0.6
Schedule changes	3.5	1.75
Economic changes	4.3	0
Estimating change	4.3	0
Unpredictable (acts of God, strikes, etc.)	0.5	0.5
Other	1.8	0.9
TOTAL	$19.8	$7.95

Now since these changes occurred with respect to an adjusted development estimate totaling $86.8 billion over an average span of about 6 years, we conclude that the annual rate of noninflationary cost growth was about 1.5%. This factor is a parameter in the Force Costing Model.

c. Productivity Increases. During Phase III, some economic forecasting is required. In attempting to assess national priorities 5 or 10 years from now, seminar groups employ a rate of real growth in GNP, chosen after some deliberation as representing their "best guess" for noninflationary growth. But real growth in GNP stems primarily from two sources--a larger labor force and ongoing gains in productivity. Of the two, more than 70% of the Nation's leap in output during the coming decade will probably be attributable to improved productivity.

Thus, in the civilian sector of the economy, as men produce more per man-hour (a frequently used measure of productivity), wages can rise even when the unit cost of a product remains constant. And wage increases stemming from productivity gains would be considered noninflationary.

For Government workers, on the other hand, economists have long assumed productivity remains stable.* Then a projection in "constant dollars" for GNP would implicitly account for noninflationary wage rises in the civilian sector of the economy while a DOD projection in "constant dollars" might consider any future wage rise for DOD employees as inflationary (because of the assumption of zero productivity gain for Government employees). Some common ground must be sought for settlement of this productivity conflict.

It would be extremely difficult, if not impossible, to measure productivity in any meaningful way for most military forces, for no acceptable system has yet been devised for measuring total military output. Fortunately, for our purposes it is not really necessary to do so. Existing legislation provides for Government pay increases in the

*On 30 June 1972, Comptroller General Elmer B. Staats transmitted to the Chairman of the Joint Economic Committee, Senator William Proxmire, the first comprehensive report ever prepared covering trends in the output to Federal employees.

future comparable to those in the private sector. Even in the absence of inflation, wages and salaries in the private economy will rise by roughly the amount of the annual gain in productivity--about 70% of the real growth rate for GNP. Consequently, the defense budget will have to provide for corresponding increases in military and civilian pay.

The cost model is programed to provide an annual increase in operating costs* at a rate equal to 70% of the GNP growth rate selected by seminar groups using the model. The model will accommodate negative growth rates.

The model is initially set with a GNP growth rate of 4% but this is a parameter.

Notice that this method of accounting for productivity can result in a range of possible "constant dollar" costs for a single force alternative. The more optimistic a seminar group is in its growth rate estimate the more costly its objective force becomes.

One final word about this method--the choice of 4% growth rate for initial calculations is totally arbitrary. It is in no sense an "approved solution," not should it constrain seminar groups which find another growth rate more appropriate.

Seminar groups must choose a GNP growth rate before beginning the constrained force exercise, and should then generate a new printout of the objective force which they had previously developed. The force tabulations will not have changed, but cost data will reflect the impact of growth rate choice on expected force costs.

d. Relation of Budget Authority to Outlays. The budget authority appropriated by the Congress for a fiscal year is not necessarily the same as the outlays--or expenditures--in that year. The reason is simple: budget authority for some major procurement, R&D effort, and construction may cover estimated full cost at the time programs are started, even though outlays take place over a number of years as the programs move toward completion.

An example is the case of a major construction project which is requested in FY 75 and estimated to cost $100 million. The FY 75 President's Budget will reflect a TOA (Total Obligational Authority) of $100 million in FY 75, but the construction itself may take five years, during which time periodic progress payments are made. In other words, portions of the total TOA for FY 75 will be expended as outlays in each year FY 75 through FY 79.

It follows that a certain amount (usually quite substantial) of unspent budget authority is always carried over from prior years. Because it has already been earmarked for specified purposes, it is not also available for new programs. Figure 3 illustrates the distinction.

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*It would be more precise to use personnel costs rather than operating costs, but we have restricted the number of cost categories for purposes of simplicity (see also paragraph 1 above).

It has become increasingly important in recent years within DOD to give careful attention to both TOA and outlays. Indeed, the current method by which fiscal constraints are imposed sets a maximum outlay figure for each service in the program year (the first year after the budget year) and a maximum TOA for succeeding years.

The force costing model is structured to provide information, both as to TOA and estimated outlays. In keeping with the usual approach of calculating the total requirements for TOA and then converting them into an estimation of annual outlay requirements, we have described cost calculations in TOA terms in preceding paragraphs.

We must now turn our attention to the conversion of TOA to outlays. The system by which outlays are computed for a given amount of TOA is based on historical spending experience. Several times a year, the OSD Comptroller publishes a tabulation of expected spending rates to be associated with individual appropriations accounts. In fact, such a tabulation is often included as a part of the annual Planning and Programming Guidance Memorandum (PPGM). More than 60 different categories are detailed by the Comptroller, including such diverse accounts as: Military Personnel, Army; Operation and Maintenance, Navy; Missile Procurement, Air Force; etc.

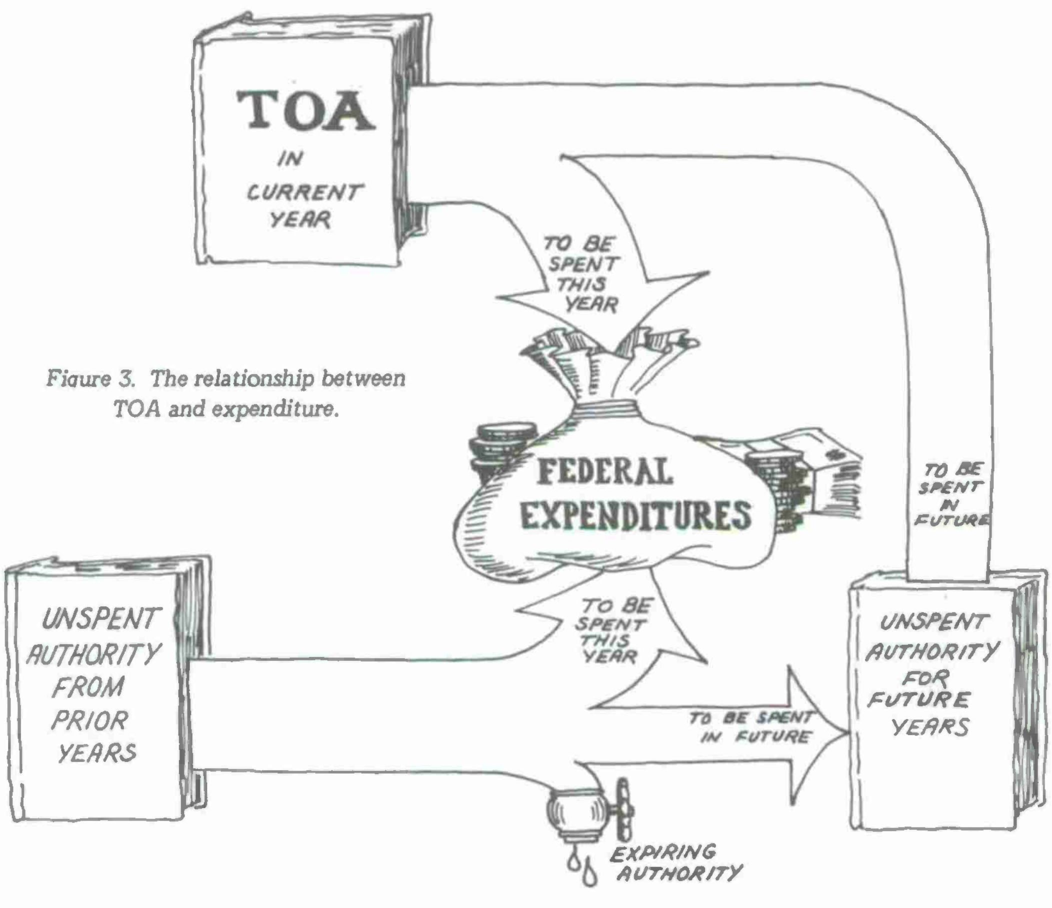


Figure 3. The relationship between TOA and expenditure.

We have limited our own cost categories to only three--R&D, Investment, and Operations. To arrive at a reasonable spending rate expectation for these categories, a weighted average of the Comptroller's more detailed information was employed. The following spending rates are used in the force costing model to compute outlay impacts of student-selected changes to the notional objective force:

COST CATEGORY	OUTLAY SPENDING RATE AS PERCENT OF TOA TO BE SPENT IN:				
	First Year	Second Year	Third Year	Fourth Year	After Fourth Year
Research and Development	53.5	36.7	7.2	1.7	0.9
Investment	20.4	41.7	21.1	9.4	7.4
Operations	93.0	6.3	0.7	---	---

To illustrate the manner in which these factors would be employed, suppose that the total TOA changes included in a seminar group's recommended objective force for the INVESTMENT category are:

	FY75	FY76	FY77	FY78	FY79	FY80
Total INVESTMENT TOA ($ millions)	0	-150	+310	+680	+216	-700

the outlay calculations would be handled as follows:

		Outlays in Fiscal Year (Rounded off to nearest $ million)									
TOA	Year Obligated	75	76	77	78	79	80	81	82	83	84
0	75	0	0	0	0	0	0	0	0	0	0
-150	76	0	-31	-63	-32	-14	-10	0	0	0	0
+310	77	0	0	63	129	65	29	24	0	0	0
+680	78	0	0	0	139	284	143	64	50	0	0
+216	79	0	0	0	0	44	90	46	20	16	0
-700	80	0	0	0	0	0	-143	-292	-148	-66	-51
TOTAL OUTLAYS BY YEAR		0	-31	0	236	379	109	-158	-78	-50	-51

While the specific numbers used in this example are really irrelevant, certain important implications are apparent:

·A large reduction in TOA in the final year of a 5-year program may not yield a very big cut in outlays in that year. In other words, reaching a lower outlay target 5 years from now means examining--possibly cutting--TOA in all the intervening years.

·When big cuts in outlays must be made early (in this case, in FY 76, the first program year), large reductions in investment don't help much, because of the slow spending rates for investment TOA. Not shown in the example, but obvious from the spending rate tabulation, is the fact that outlay constraints early in the program may be met more readily by cutting operating costs (reducing existing forces). Unfortunately, of course, it is not always politically possible to make such reductions (even when justifiable from the standpoint of efficiency), nor is it as easy to put a unit back in the force at some later time as it is to remove it in the first place. There is a certain irony evident here--near-term outlay cuts are easiest to achieve if you cut the most important near-term requirements (existing forces) and longer-term outlay cuts are facilitated by cutting the important future considerations (modernization and R&D programs). It is just this type of dilemma which constantly confronts the military planner as he seeks to achieve the proper force balance which comes closest to meeting strategy requirements while its total cost remains within prescribed levels.

When constrained by outlay targets, the task of structuring a program force becomes much more complex, for no single year of the program may be decoupled from the others.

4. Notional Objective Force. It is convenient, if not absolutely necessary, to begin a force planning exercise with a "starting point" force rather than a "zero" force. Alternatives are generated by applying "plus and minus" changes to this "starting point" which we will call a notional objective force or just a notional force. In the Force Costing Model this notional force is in FYDP format and includes all items in the Defense Program. The level of detail and the number of program elements which are visible and subject to user manipulation are, however, quite different from the FYDP. The notional force is described in detail in the "Forces Costs and Manpower Data Book," published by the College. (Chart 1) This book will be referred to simply as the "Data Book".

B. MOTIVATION. 1. To gain an appreciation for the need for a computer model to assist in USAWC force planning exercises let us consider a typical transaction which might be considered in the course of making choices relative to force size and force mix. Suppose we wish to add a B-1A Bomber Squadron to our force effective in FY81 and further that we wish to consider the fiscal impact of such a change in both obligation authority (TOA) and outlays (or expenditures) for the period FY76 to FY81, a perfectly reasonable consideration for force planning purposes.

2. Data relative to cost and manpower factors associated with this change are found in the "Data Book". (Chart 2) Note that force levels are in squadrons, costs are in millions of dollars and manpower is in thousands.

These data along with the previously discussed investment lead time and cost growth rules produce the calculations shown (Chart 3 & Chart 4), where the investment calculations represent a look up of data and simple multiplication and the cost growth is a compound interest function evaluated over 1 through 6 intervals of time. The operations cost and productivity growth are similar but less involved computations. (Chart 5) Notice that costs must be computed for FYDP Programs 1, 7, and 8.

3. (Chart 6) Applying the rules for outlay conversion the final calculations for the cost impact of the force level change is as shown.

4. While none of the arithmetic is particularly challenging, the number of operations associated with this illustrative example makes manual costing prohibitively time consuming. This is especially true in light of the fact that dozens of such changes are evaluated and discarded or accepted in the process of designing a single force alternative. The illustrative example calculations required about 30 minutes using a desk calculator. Computer support is absolutely essential if students are to be relieved of the necessity for extensive and tedious bookkeeping and endless streams of simple arithmetic. To fill this need the USAWC Force Costing Model was developed.

C. FORCE COSTING MODEL OPERATION. 1. The model is depicted schematically in Chart 7.

2. The model functions as follows: (Chart 8)

a. The Data base is initialized to the notional objective force including currently used cost and manpower factors.

b. Student users input through remote input devices changes (force levels, program dollars or manpower, procurement dollars, R&D dollars) to produce an alternative force. Files are created to keep track of this new force.

c. Cost (TOA and outlays) and manpower impacts of each change are fed back through the remote terminal.

d. This process is repeated at the user's option.

e. A full description of the resulting alternative force in the form of several reports is provided through a high speed printer when requested by the user.

D. EVOLUTION OF THE MODEL. The Force Costing Model evolved over time as follows:

1. 1972 and earlier - Punch card input, no feedback, remote site processing, more than 24 hour turn around for processing.

2. 1973 - Punch card input, no feedback, local site processing, 12 to 24 hours turn around.

3. 1974 - Remote terminal input, no feedback, time share processing, less than one hour turn around.

4. Present - Remote terminal input, instantaneous feedback, time share processing, less than ten minutes turn around for full report.

5. Future - Some refinement of the logic and data base maintenance is envisioned but the model presently does all that is reasonably needed.

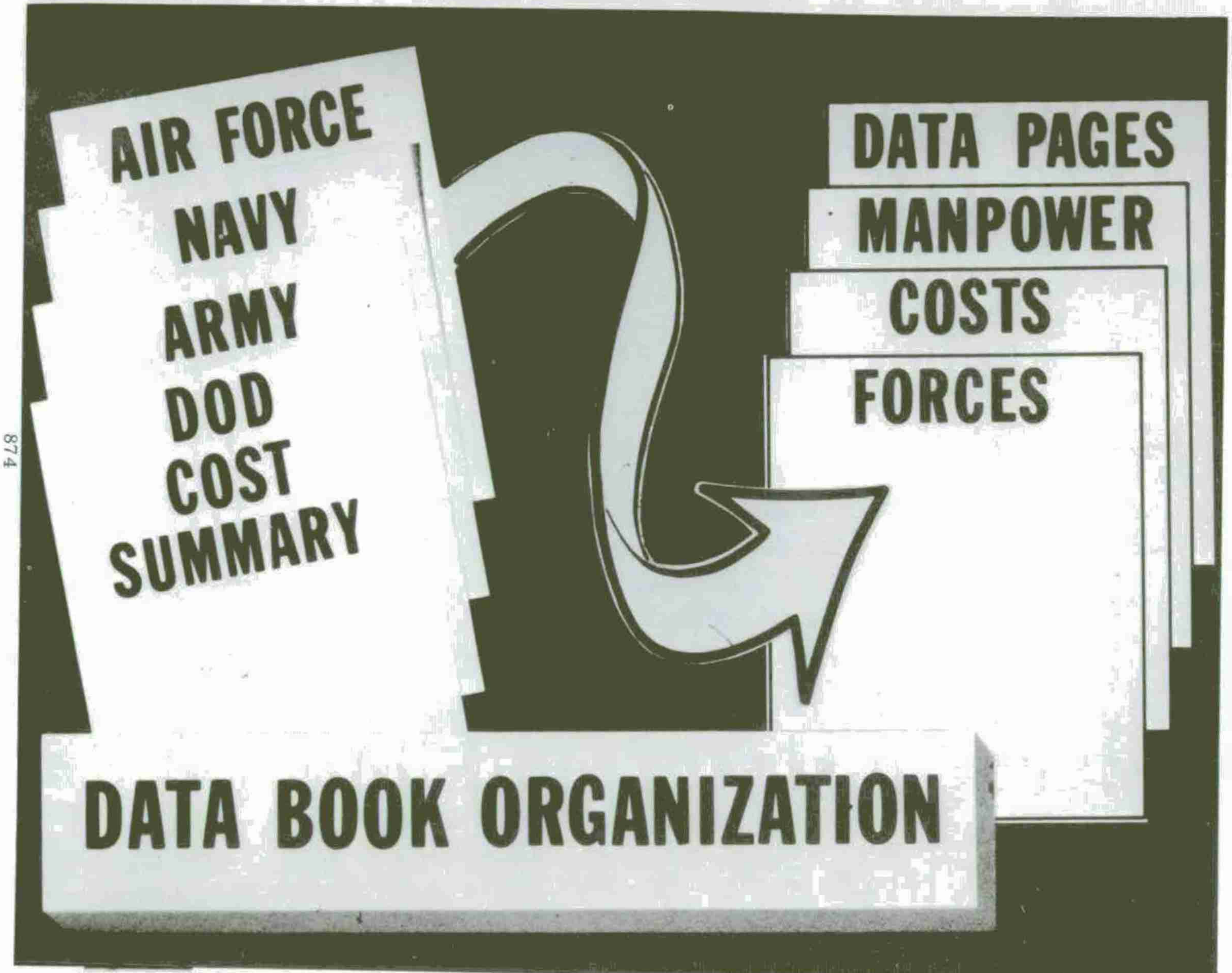

AIR FORCE
NAVY
ARMY
DOD
COST
SUMMARY
DATA PAGES
MANPOWER
COSTS
FORCES
DATA BOOK ORGANIZATION

CHART 1

PROGRAM: 1-STRATEGIC FORCES

DEPARTMENT: AIR FORCE

ELEMENT: B-1A SQUADRONS

COMPUTER ELEMENT CODE: 01-3-05

	FY75	FY76	FY77	FY78	FY79	FY80	FY81	FY82	FY83
FORCE	–	–	–	–	2	6	9	12	12
PROGRAMED R&D FUNDING	330	270	225	180	150	50	10	10	–

PLANNING FACTORS

ELEMENT B-1 SQDN (15 A/C PER SQDN)	FYDP PROGRAM			TOTALS
	1	7	8	
INVESTMENT	526.8			526.8
OPERATING	75.6	7.2	3.8	86.6
MANPOWER	1.55	.08	.15	1.78

FUNDING LEAD TIME: CHANGE FORCE LEVEL IN FY X, FUND IN FY X - $\boxed{5}$

CHART 2

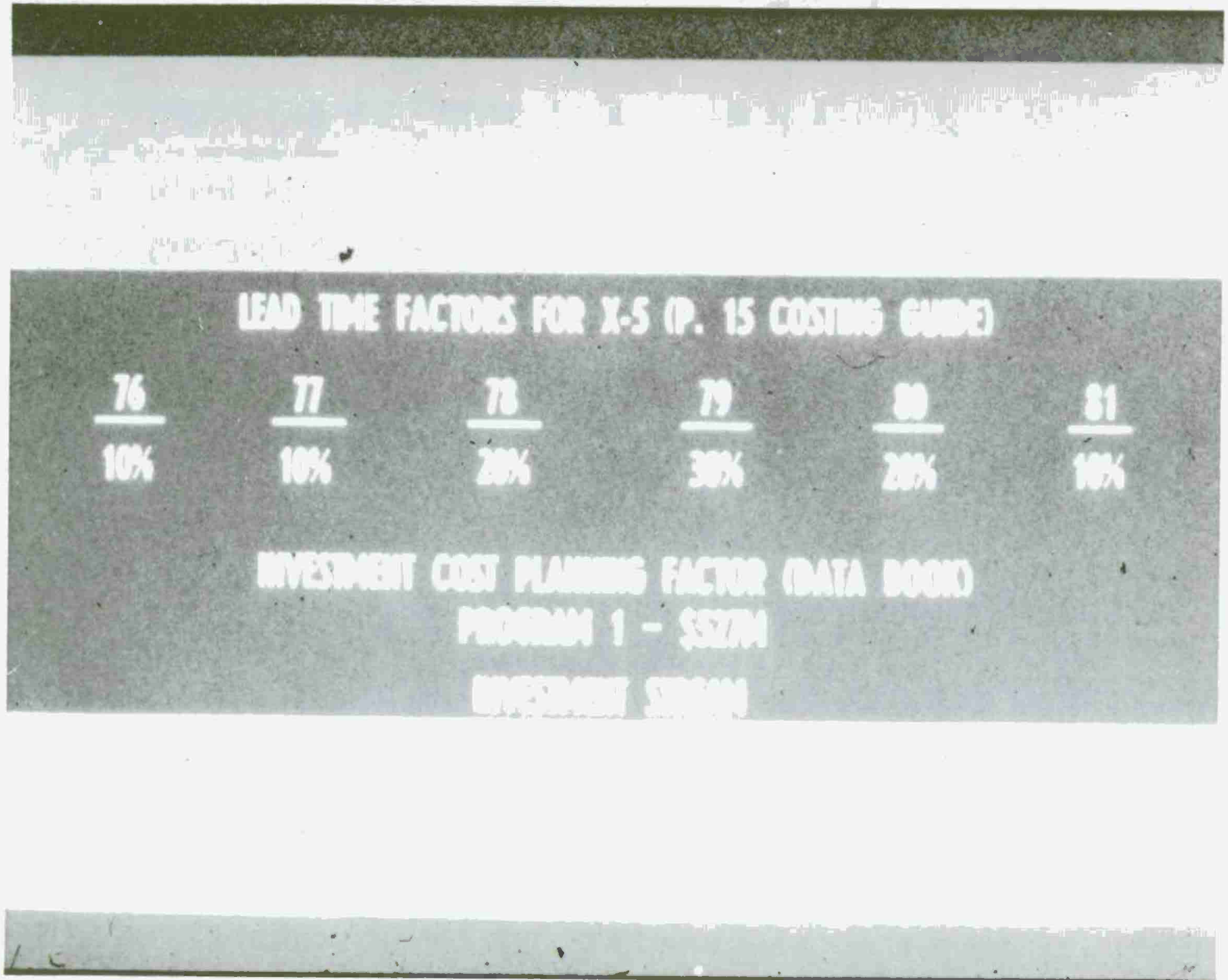

LEAD TIME FACTORS FOR X-5 (P. 15 COSTING GUIDE)
76 10%
77 10%
78 20%
79 30%
80 20%
81 10%
INVESTMENT COST PLANNING FACTOR (DATA BOOK)
PROGRAM 1 - $527M

CHART 3

COST GROWTH ADJUSTMENT – 1.5% COMPOUND ANNUALLY

76	77	78	79	80	81
$52.7\ (1+.015)$	$52.7(1+.015)^2$	$105.4(1+.015)^3$	$158.1(1+.015)^4$	$105.4(1+.015)^5$	$52.7(1+.015)^6$

THEREFORE THE INVESTMENT STREAM ADJUSTED FOR GROWTH IS

76	77	78	79	80	81
$53.5M	$54.3M	$110.1M	$167.7M	$113.5M	$57.6M

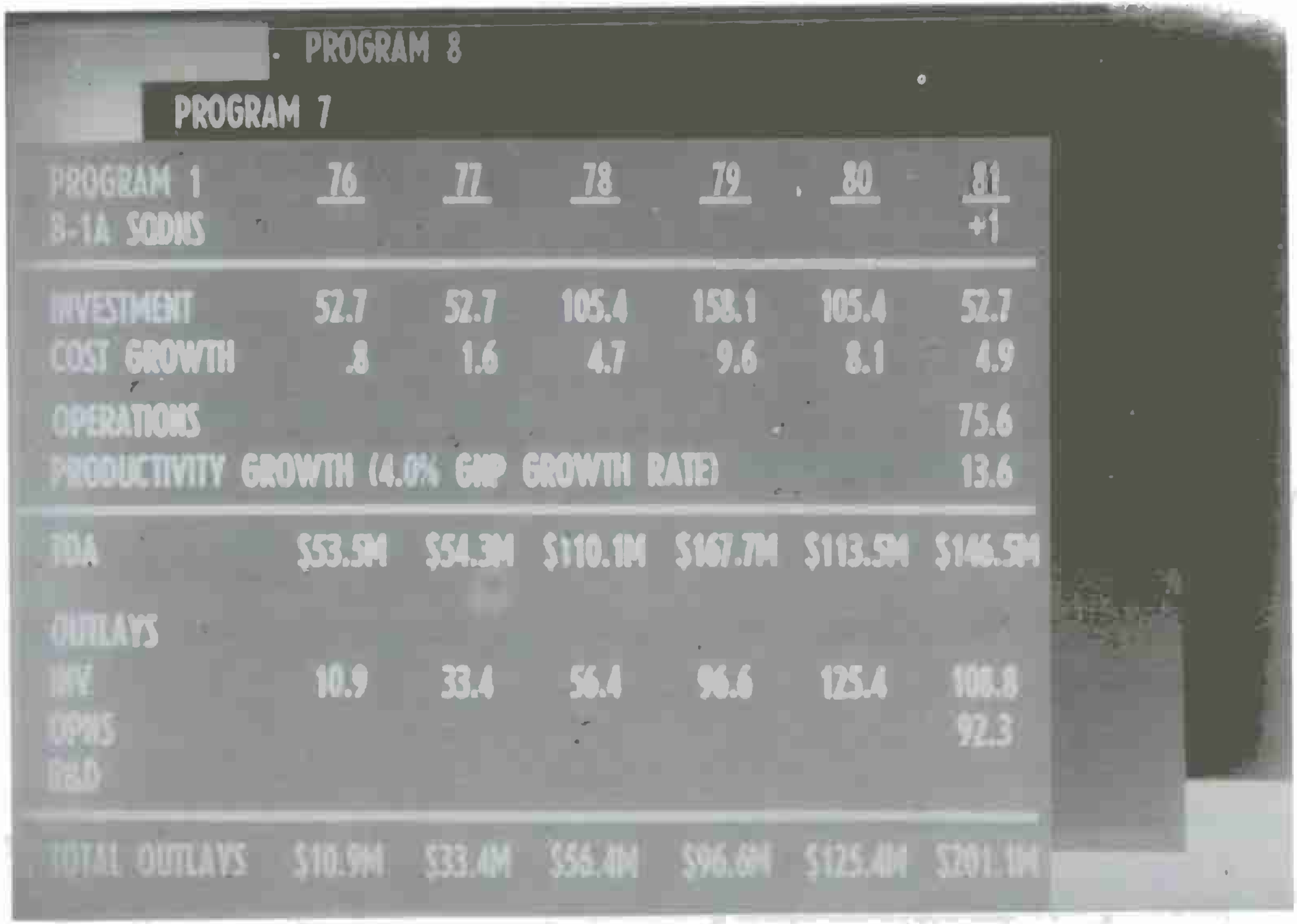
CHART 4

PROGRAM 8

PROGRAM 7

PROGRAM 1 B-1A SQDNS	76	77	78	79	80	81 +1
INVESTMENT	52.7	52.7	105.4	158.1	105.4	52.7
COST GROWTH	.8	1.6	4.7	9.6	8.1	4.9
OPERATIONS						75.6
PRODUCTIVITY GROWTH (4.0% GNP GROWTH RATE)						13.6
TOA	$53.5M	$54.3M	$110.1M	$167.7M	$113.5M	$146.5M

CHART 5


PROGRAM 8
PROGRAM 7
PROGRAM 1 76 77 78 79 80 81 +1
B-1A SODUS
INVESTMENT 52.7 52.7 105.4 158.1 105.4 52.7
COST GROWTH .8 1.6 4.7 9.6 8.1 4.9
OPERATIONS 75.6
PRODUCTIVITY GROWTH (4.0% GNP GROWTH RATE) 13.6
TOA $53.5M $54.3M $110.1M $167.7M $113.5M $146.5M
OUTLAYS
INV 10.9 33.4 56.4 96.6 125.4 108.8
OPNS 92.3
R&D
TOTAL OUTLAYS $10.9M $33.4M $56.4M $96.6M $125.4M $201.1M

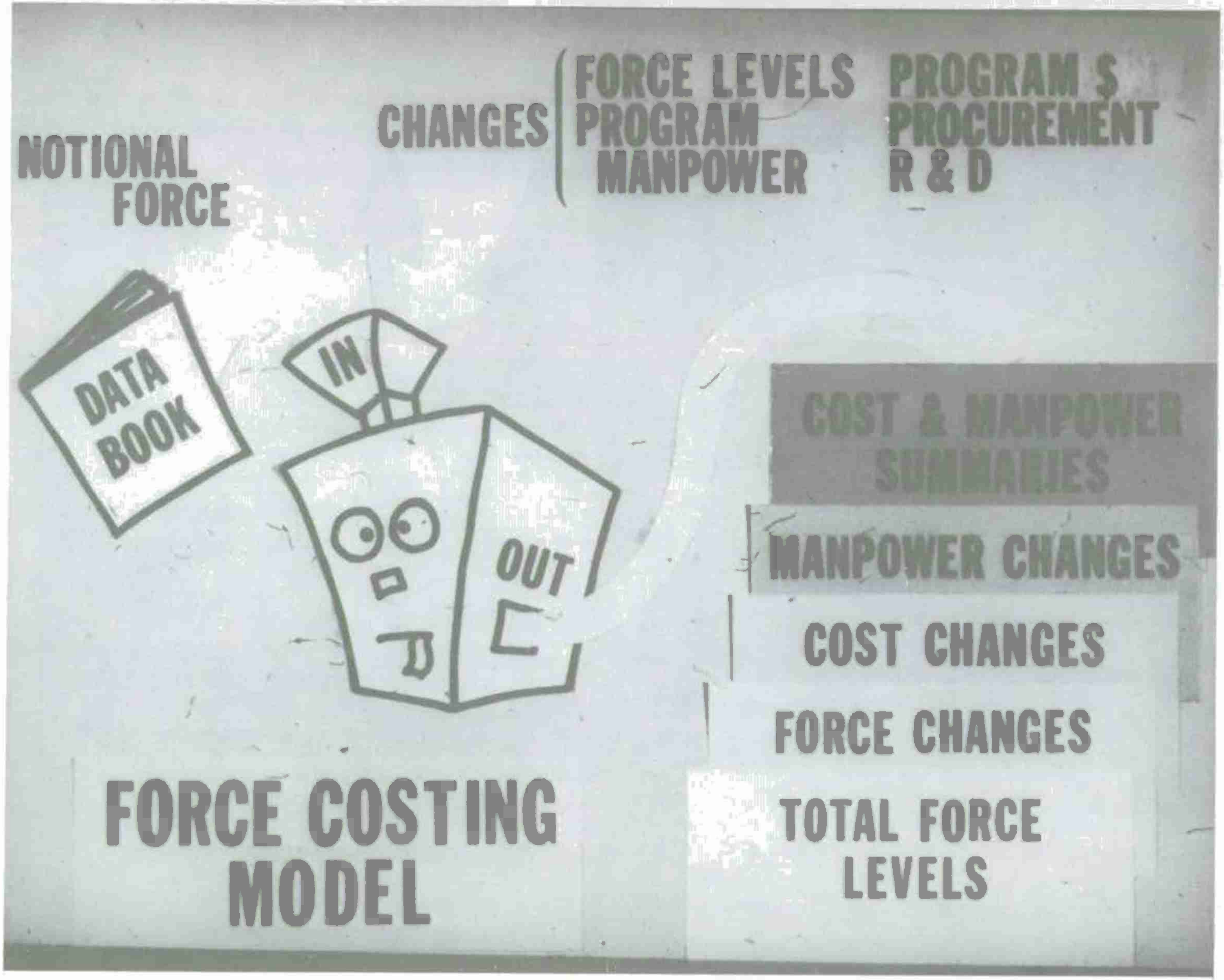
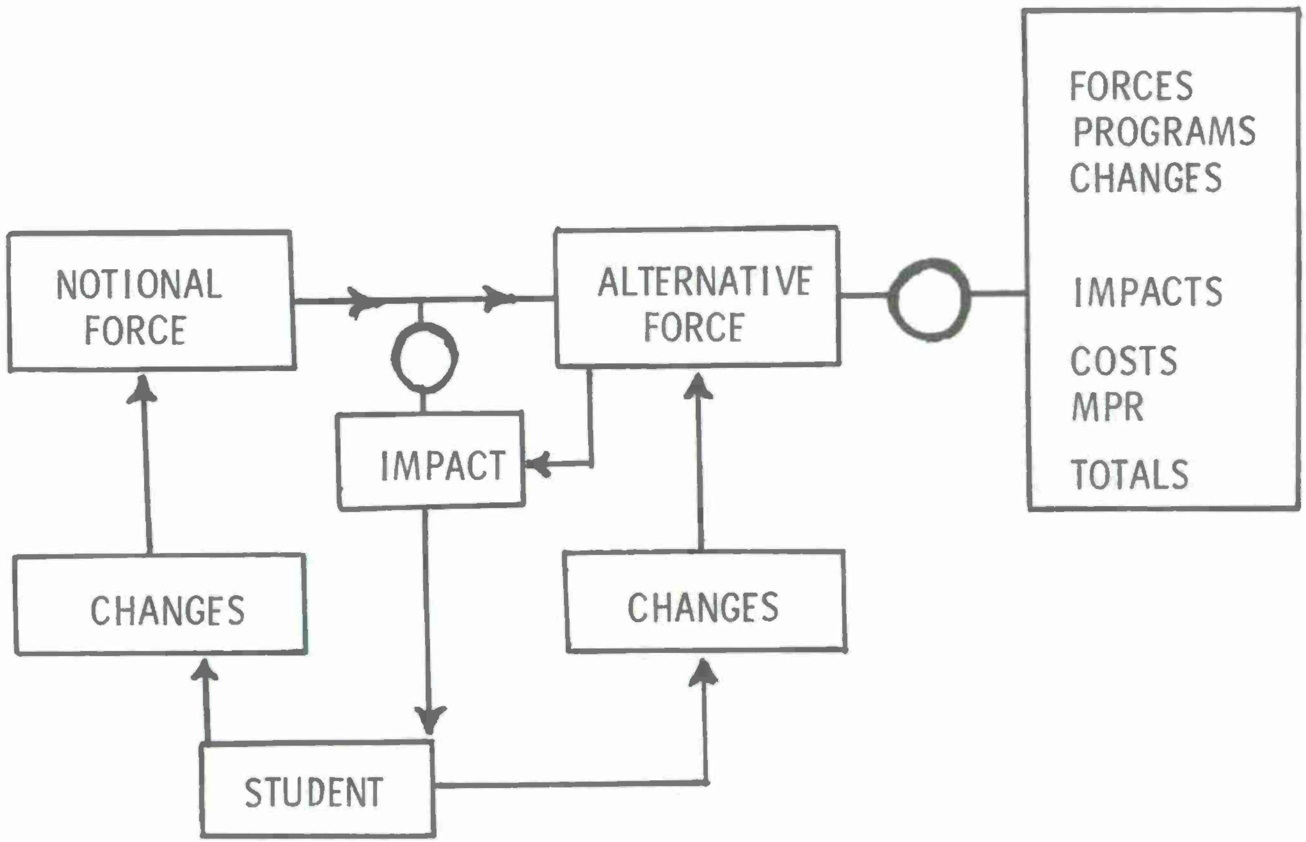

NOTIONAL
FORCE
CHANGES
FORCE LEVELS
PROGRAM
MANPOWER
PROGRAM $
PROCUREMENT
R & D
DATA BOOK
IN
OUT
COST & MANPOWER SUMMARIES
MANPOWER CHANGES
COST CHANGES
FORCE CHANGES
TOTAL FORCE LEVELS
FORCE COSTING MODEL

CHART 7

088



NOTIONAL FORCE
ALTERNATIVE FORCE
FORCES
PROGRAMS
CHANGES
IMPACTS
COSTS
MPR
TOTALS
IMPACT
CHANGES
CHANGES
STUDENT

CHART 8

THE USAWC FORCE COSTING MODEL PROGRAM SPECIFICS

1LT Ronald G. Parker, US Army War College

In the preceding paper, presented by COL Robert T. Reed, he discussed what the FORCE COSTING MODEL is, and why it is used at the US Army War College. In the pages that follow, I'll try to explain how the FORCE COSTING MODEL is organized and how it works.

It seems appropriate to explain how the model works now, by beginning with how it used to work in the past. Three years ago, we didn't have our own computer; we borrowed time on an IBM 360 in a neighboring military installation. The cycle of student use of the model went something like the cycle depicted at Figure 1: the students would deliberate about their force proposals; they would decide on a possible force structure; they would transcribe their decisions onto special forms; our keypunch operators would punch cards from the forms; the ADP project officer (i.e., my counterpart three years ago) would sort the cards and assemble the deck; the deck would be transported to the neighboring installation and run on the computer; the printouts would be brought back to the War College; the students would pick up their printouts; and the cycle would begin again with new deliberations. Total cycle time was about 24 hours. In other words, it took 24 hours from the time the students began their discussions until they had any feedback from the computer.

Two years ago, the Army War College had obtained its own computer, a very old and very slow UNIVAC. The cycle of student use was essentially the same as it had been the year before, but the computer was closer. Total cycle time remained about 24 hours because the computer was so slow.

Some key points to note are: to see results of any single force element proposal, a printout had to be generated--the entire 24-hour cycle was required (for some simple items, hand calculation was faster); the whole force exercise had to last many days so that a significant number of force proposals could be examined (two years ago, the course lasted 18 working days); two years ago, the model was designed to handle nine alternatives for each seminar group so that in each 24-hour cycle, they could examine nine different force structures--however, in general, the students had difficulty keeping track of nine different force structures all being developed simultaneously; and lastly, a single error wasted an entire 24-hour cycle. There was lots of room for errors: the students could miscopy a number while filling out the forms; the keypunch operator could mispunch a card; I could error in sorting the cards and assembling the deck, and unfortunately, the program logic was very order-dependent. In the first type of mistake, the student could blame only himself for wasting 24 hours. But the last two types of errors were the fault of ADP personnel, and as you can imagine, these errors adversely affected our rapport with the students.

Last year we got a new Honeywell computer with new capabilities. The cycle of student use of the model was quite different, as Figure 2 shows. After deliberating and deciding on a force structure, the students entered their proposals into the computer through time-sharing terminals and the computer generated the printouts. Then they could pick up their printouts

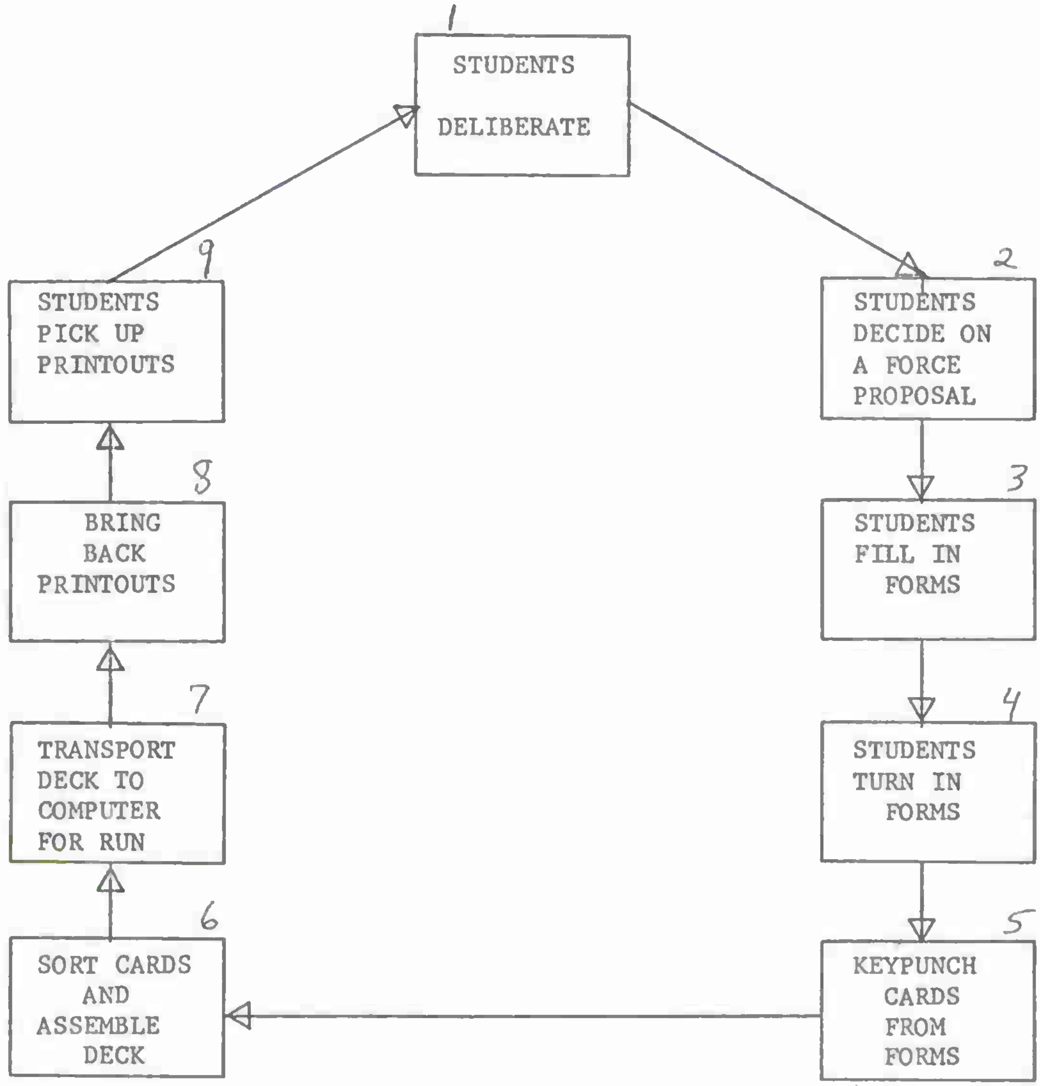

1
STUDENTS DELIBERATE
2
STUDENTS DECIDE ON A FORCE PROPOSAL
3
STUDENTS FILL IN FORMS
4
STUDENTS TURN IN FORMS
5
KEYPUNCH CARDS FROM FORMS
6
SORT CARDS AND ASSEMBLE DECK
7
TRANSPORT DECK TO COMPUTER FOR RUN
8
BRING BACK PRINTOUTS
9
STUDENTS PICK UP PRINTOUTS

Figure 1

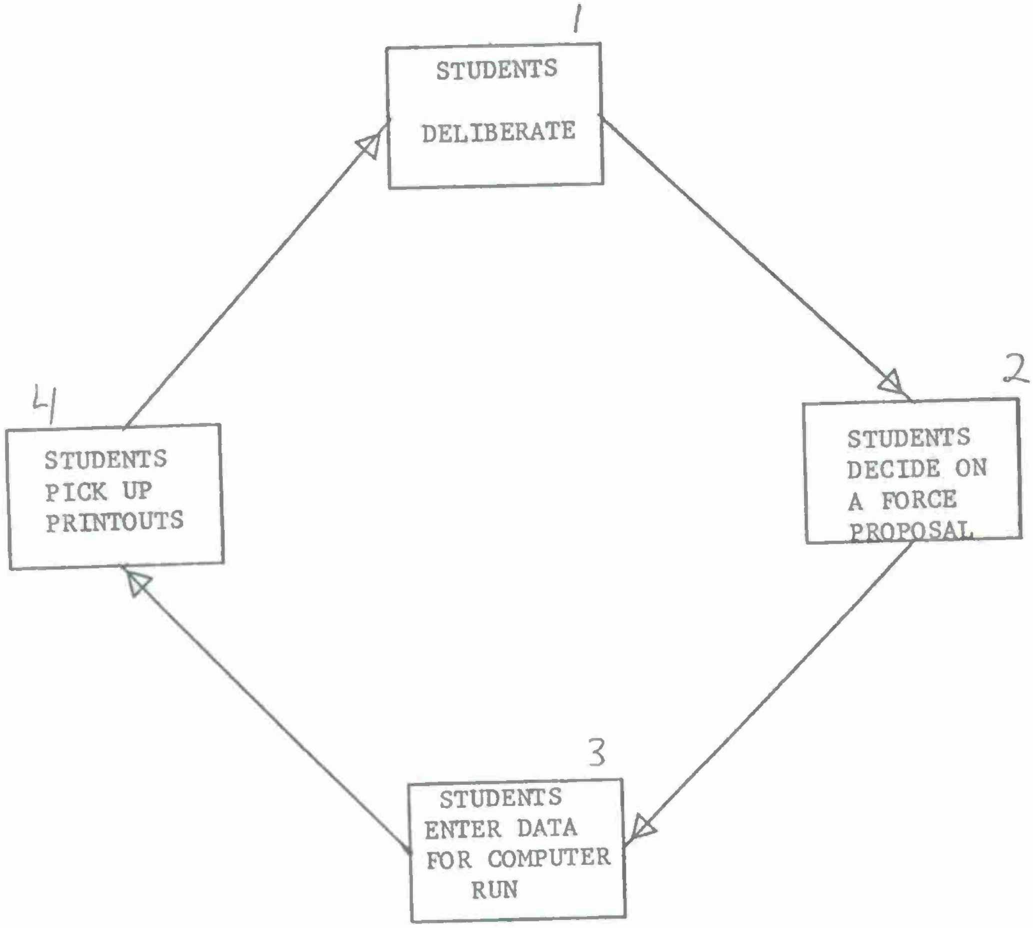

1
STUDENTS
DELIBERATE
2
STUDENTS
DECIDE ON
A FORCE
PROPOSAL
3
STUDENTS
ENTER DATA
FOR COMPUTER
RUN
4
STUDENTS
PICK UP
PRINTOUTS

Figure 2

and go back to deliberating. Total cycle time varied; but from the time a student finished entering his proposals until he picked up his printout, usually only about ten minutes had elapsed.

The key points to note here are: they still had to generate a printout to see the results of a single force element proposal (i.e., there was no feedback to the student at the terminal); they were able to generate more force proposals even though the exercise was only 13 working-days long; there were three alternatives allowed per seminar group so that three force structures could be entered in a single session at the terminal; errors were not so costly (you'll notice we got ourselves out of the cycle so that the only errors were student errors--this helped our public relations a bit); the program logic was rewritten so that it was no longer order-dependent; we had very high-speed CRT-type terminals and virtually uninitiated users (i.e., the students trying to operate the terminals), so lengthy directions were flashed on the terminal screens to lead the students step-by-step through the input procedure. That was all very fine until someone tried to run the program from a teletype terminal. On a teletype terminal, these lengthy and repetitive directions made the interaction so slow, nobody could stand to use the teletypes.

This year, we have a full time-sharing capability; i.e., students can input a force proposal on the terminal and get the results of that proposal back on the terminal in less than one minute. The cycle for student use of the model should go something like Figure 3: during their deliberations, the students will enter a force proposal into the computer and with the immediate feedback on that proposal, they can then decide if they want to keep that proposal. The students need not generate a printout of the entire force structure until they want a hard copy of their total force.

Of the several key points to be noted here, the most important is this immediate feedback feature. Other points are: the exercise this year is only nine days long--that's half of what it was two years ago; there are still three alternatives allowed per seminar group so that three different force structures can be developed in the computer concurrently; errors are no longer significant since they can be detected and corrected immediately.

There are several other features worth mentioning, but rather than just listing them, I think they can best be brought out while going through a discussion of the flow of the entire model.

First, let's take a look at the big picture (Figure 4): At step 1, we begin preparation for the Force Costing Exercise by developing the data base. This is done by COL Reed's office in the Department of Military Planning and Strategy and is a complex task I can't even begin to describe. Once the data base is developed, it must be entered into the computer--that's step 2. This year we have a time-sharing program to create or update the data base, written for the uninitiated user, and have thereby reduced this step to a clerical worker's simple task. With the data base loaded, there is only one thing left to do before the students can begin to use the model. For each seminar group, there are several files on disk that are used to keep track of their forces; and you see at step 3 that these must be initialized. Once again, we have a program to do this, so it's easily done.

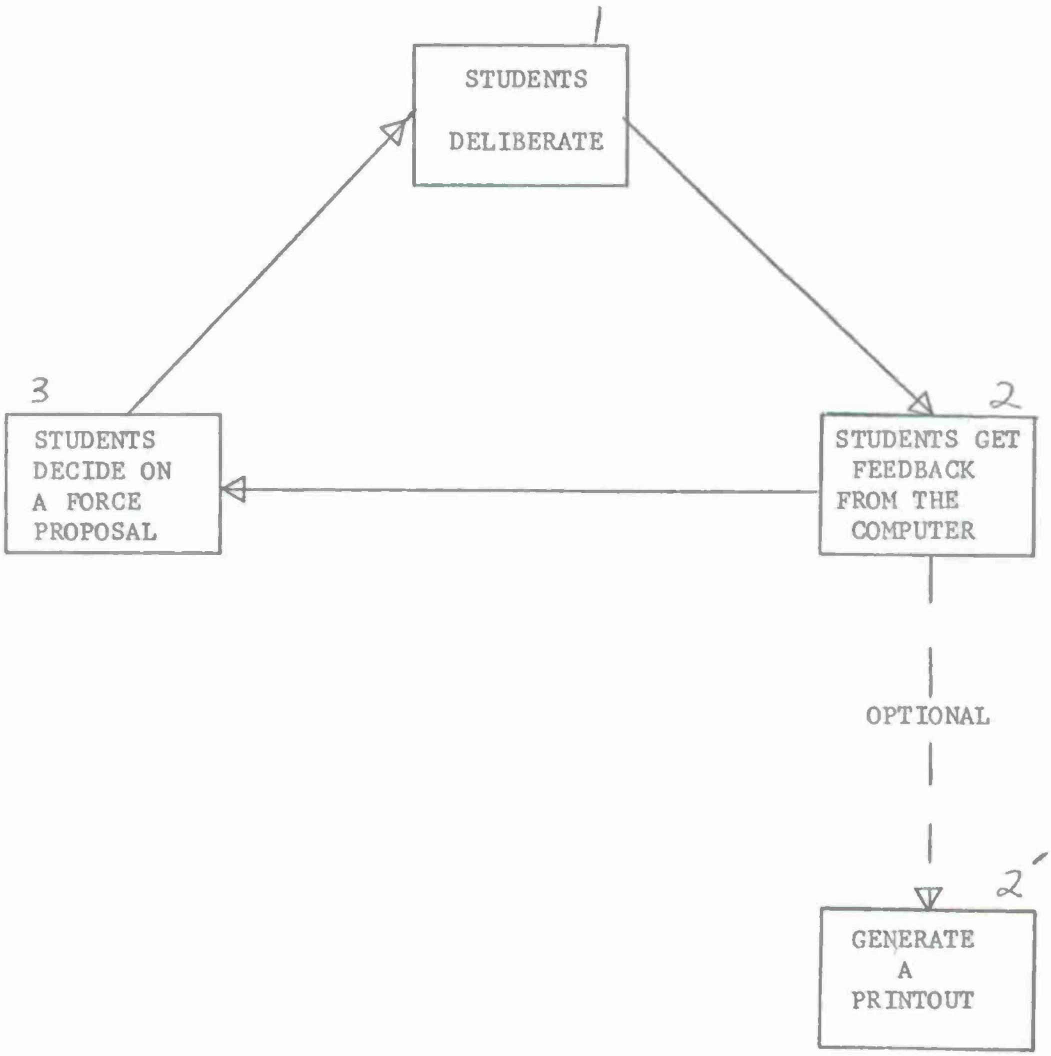

1
STUDENTS DELIBERATE
2
STUDENTS GET FEEDBACK FROM THE COMPUTER
3
STUDENTS DECIDE ON A FORCE PROPOSAL
OPTIONAL
2'
GENERATE A PRINTOUT

Figure 3

STEP 1: Gather DATA BASE

STEP 2: Enter DATA BASE into Computer

STEP 3: Initialize All Seminar Groups' Files

STEP 4: Students Interact with Model for Objective Phase
(Concurrent running of Executive Summary)

STEP 5: Final Objective Executive Summary

STEP 6: Reset Seminar Groups' Files to Individual Baselines

STEP 7: Students Interact with Model for Constrained Phase
(Concurrent running of Executive Summary)

STEP 8: Final Constrained Executive Summary

Figure 4

At step 4, the students begin the objective phase of the exercise--developing a force structure to support their strategy plans. The time-sharing program they interact with should be of great interest, and I'll go into more detail about it in a moment. While the students are playing with the model, we can concurrently run another program called the Executive Summary. This Executive Summary is used by the faculty instructor for monitoring the activities of the class. It enables the faculty instructor to examine the existing student files for any one (or all) of the seminar groups. It provides him with descriptive statistics of class decisions on a single force element or any group of force elements, as well as the Grand Total TOA, Outlays, and Manpower. For example, he can see the high, low, mean, and standard deviations of force levels for elements such as the B-1A Bomber, or for groups of elements such as all the Army Divisions combined. This feedback provided to the instructor by the Executive Summary is one of the features that makes our Force Costing Model a powerful educational tool.

At the conclusion of the objective phase, step 5, the final objective Executive Summary is run and with it, the instructor can prescribe constraints for the constrained phase of the exercise. Also, before the constrained phase begins, you'll see at step 6 that every seminar group's files are reset to that seminar group's objective force; i.e., all seminar groups' baselines can be different. Of course, we have a program to do that, and it's quite simple to do.

The students then play the constrained phase of the exercise, step 7, developing a force that meets certain fiscal and manpower constraints. They interact with the same program as before, and again I promise you more detail on that, shortly. Also, we again have concurrent running of the Executive Summary so the instructor can monitor the progress. Finally, step 8, we run the final constrained Executive Summary so the instructor can use that summary information in his concluding remarks of the force planning course.

With that big picture in mind, we can now look in detail at the little picture, the time-sharing program that the students interact with. Let me mention a few general features of this program before we go through the logical flow of the program. First, the program is able to determine what type of terminal (slow speed teletype or high speed CRT-type terminal) the student is using so that the output can be tailored to the device and provide faster interaction to the teletype. Second, there are two levels of commentation available: the first gives complete explanations of questions the student must answer; the second poses abbreviated questions. This allows the student to speed up the interaction as he gains familiarity with the program. There is also a feature which allows a student who has selected the abbreviated commentations, and then finds himself faced with a brief question he doesn't understand; to toggle the selected level of commentation and have the question restated in its entirety. Similarly, when he is back on familiar ground, he can toggle the levels again and continue in the abbreviated mode.

The third general feature allows the student who has accidentally answered a question incorrectly to return immediately to that question rather than going off on some undesired series of questions. The fourth and last general feature I'll mention, is the simple concept of positive identification of a student's response. For example, if a student is asked a question to be answered yes or no, and the program detects that he did not answer "yes," it does not assume that he answered "no." He may have misspelled "yes." This feature saves the student a considerable amount of frustration that could result when the program takes off doing the wrong thing just because of a typographical error.

Figure 5 shows the overall picture for this part of the model. After initialization and determination of the seminar group's number, the student can do any of three things: (1) special file manipulations, such as creating a special force element, copying one alternative into another, or merging two alternatives together; (2) work on an alternative by making changes to the force structure and by doing a number of other things I'll talk about; or, (3) stop.

Figure 6 shows what all can be done while working on an alternative. After the student selects which of the three alternatives he wants to work on, he can make force changes; make direct money changes; make direct manpower changes; change special research and development funding categories; change the GNP growth rate; reset this alternative to the baseline levels; display selected lines of the summary reports; display the Grand Total TOA, Outlays, and Manpower; generate a printout; or end work on this alternative. The most important option here is the option to make a force change, so I'll briefly trace that logic. When a student makes a force change, he must first identify the force's computer element code. Then the computer will display the baseline levels and, if there is already a change on file, the levels presently selected for this alternative. If the student wishes to change these levels, he enters new levels and then the computer performs a "legality check" to determine if the levels requested are reasonably attainable. For example, you can't order a B-1A Bomber Squadron this year and expect to have it operational next year. If such illegal procurements are found, they are itemized and the student is advised of legal levels the computer will accept. If the student agrees to accept these legal levels then the results of this force change are printed at the terminal. Included in these results are the force levels selected, the change in force levels from the baseline, the TOA Change, the Outlays change, and the Manpower change. If these changes are acceptable to the student, they are kept on file; if not, they're discarded; and either way, the program will go back for the next force element to be considered.

Those of you interested in the technical specifics of the model, might note the following: The programs are written in FORTRAN with four special Assembler Language subroutines. We run the exercise on a Honeywell 6060 computer. The largest program, the one the students use, is segmented to allow overlaying code during execution. Presently, this program takes 16K words of memory to execute. The basic data base is 16 blocks long (a block contains 320 words). Each seminar group has five disk files initially taking up 39 blocks (total). The model can accommodate up to 20 seminar groups and 200 different force elements.

Finally, I'd like to highlight the three basic principles which guided the development of the programs which make up the Force Costing Model.

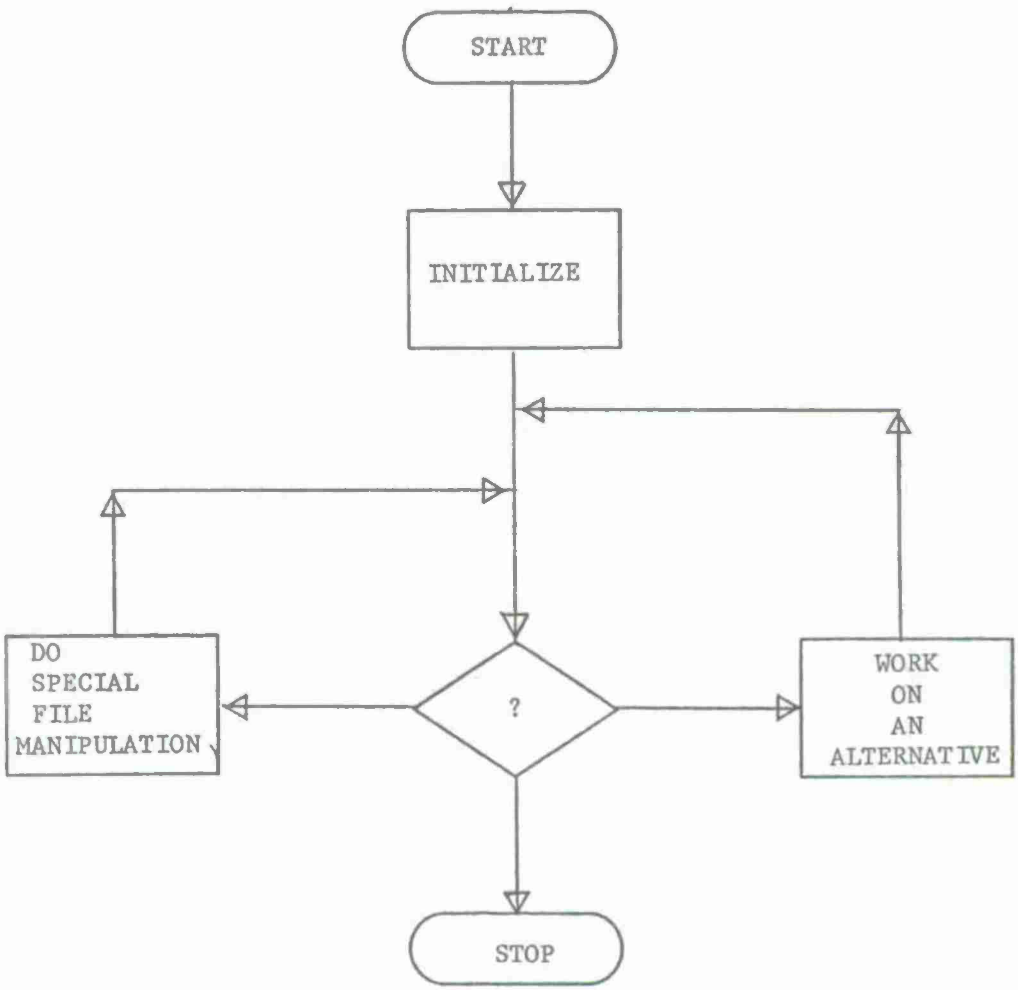
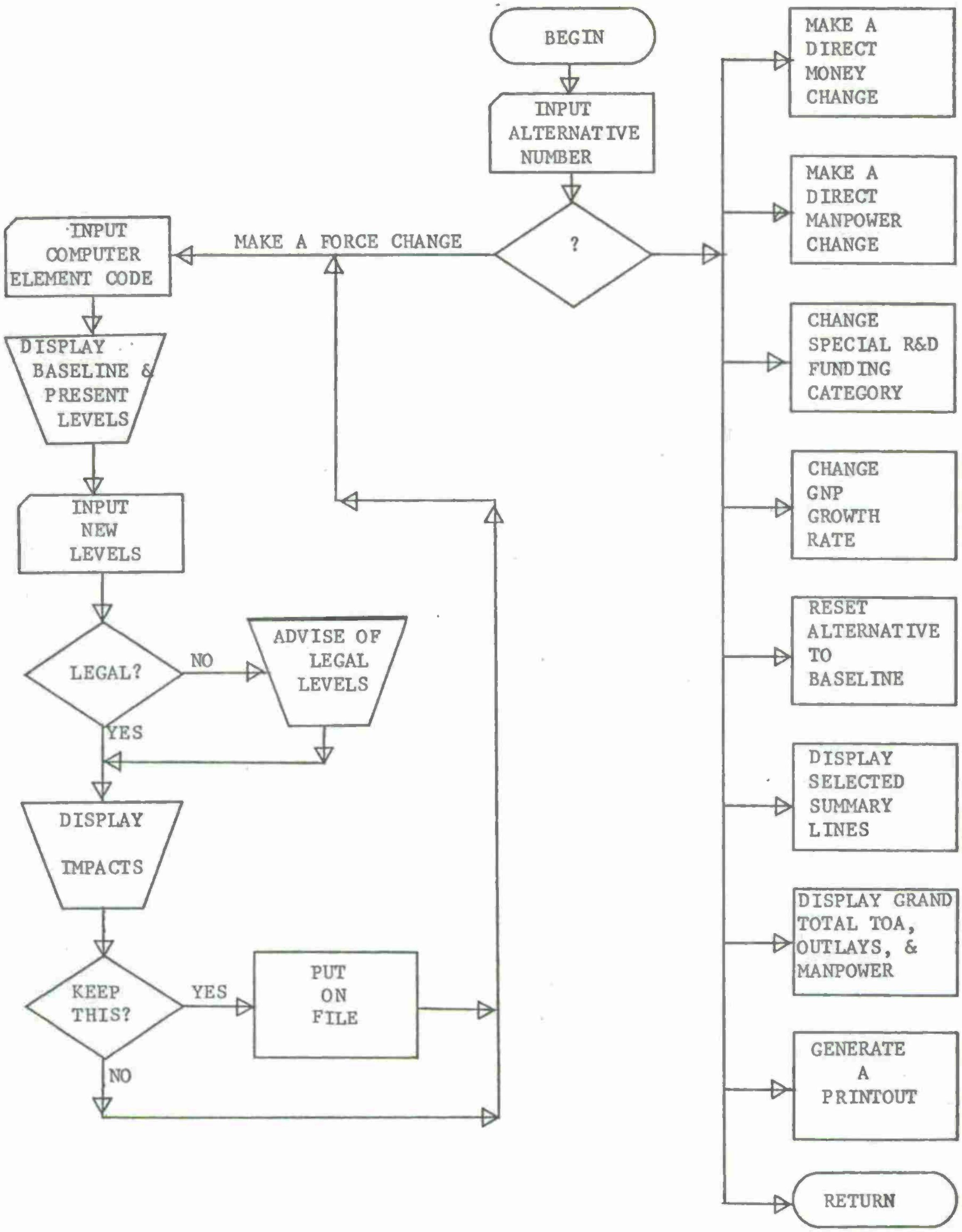

START
INITIALIZE
DO
SPECIAL
FILE
MANIPULATION
?
WORK
ON
AN
ALTERNATIVE
STOP

Figure 5



BEGIN
INPUT ALTERNATIVE NUMBER
?
MAKE A FORCE CHANGE
INPUT COMPUTER ELEMENT CODE
DISPLAY BASELINE & PRESENT LEVELS
INPUT NEW LEVELS
LEGAL?
NO
ADVISE OF LEGAL LEVELS
YES
DISPLAY IMPACTS
KEEP THIS?
YES
PUT ON FILE
NO
MAKE A DIRECT MONEY CHANGE
MAKE A DIRECT MANPOWER CHANGE
CHANGE SPECIAL R&D FUNDING CATEGORY
CHANGE GNP GROWTH RATE
RESET ALTERNATIVE TO BASELINE
DISPLAY SELECTED SUMMARY LINES
DISPLAY GRAND TOTAL TOA, OUTLAYS, & MANPOWER
GENERATE A PRINTOUT
RETURN

Figure 6

First, the program is data base driven. By that I mean all the data (e.g., the force levels, the cost factors, and the conversion factors) are in the data base so that when any of the levels or factors change, only the data base needs to be updated--no reprogramming is required. Second, the program modularity provides great flexibility: the data base has built in code words (and room for more code words); these code words are used to determine how a given force element is to be handled; and finally, the program is divided into modules which handle each different type of force element. This modularity and use of code words allows easy alteration of the model should a new type of element be required or an old type changed.

Third, and last, is the principle of user orientation. One of our goals is to acquaint senior officers with the vast potential of computers and to favorably impress them with the ease of use of our Automatic Data Processing system. This can only be accomplished if they find use of the computer simple and rewarding. To that end I've tried to approach the model with the student's point of view in mind, and thus we have such features as output tailored to the terminal type, two levels of commentation with easy transfer between them, and positive identification of user responses.

In concluding I'd like to emphasize the factors that have helped make the Force Costing Model the success that it is. For one thing, we finally have the computer hardware with the required capabilities. Another factor has been the several years of experience we've had and the feedback we've gotten from the students--we've come a long way in the last four years. And most importantly, we've had a proponent for the Force Costing Model who not only had a need for computer support, but knew what he wanted and was able to communicate his ideas to our ADP staff. With all these factors together, we have finally developed a model that is a realistic tool for the study of force planning, is a flexible model so it can remain realistic in years to come, and is truly an educational experience for the students of the US Army War College.

ABSTRACT OF PAPER PRESENTED DURING SYMPOSIUM
BUT NOT SUBMITTED FOR PUBLICATION

TITLE: Aggregated Methods for Predicting the Fatalities Resulting from Nuclear Weapons of Various Yields Allocated Against Cities Protected by Terminal Defenses

AUTHORS: Colonel R. W. Grayson and Captain S. L. Head
Assistant Chief of Staff for Studies and Analysis
United States Air Force

ABSTRACT: One of the most complex problems in strategic wargaming is the estimation of the urban/industrial (U/I) damage caused by combined attacks of ballistic missile and bomber-delivered weapons in the presence of terminal city defenses. Algorithms have been developed to deal with such problems for particular targets, but an extensive review of the literature showed that no great attention had been given to the highly aggregated total-country attack methodology.

This paper develops four aggregated methods of predicting the damage which could be caused by nuclear weapons against defended cities. The first method shows how to compute damage caused by combinations of missile re-entry vehicles (RVs) of various yields against cities defended by antiballistic missile (ABM) systems. The second predicts aggregated damage caused by combinations of bomber-delivered weapons of various yields against cities defended by surface-to-air missile (SAM) systems. The third calculates damage caused by attacks with a single type of bomber-delivered air-to-surface missile (ASM) against a fixed number of cities defended by SAM systems. The fourth describes an approach by which the first two methods could be combined to compute the damage from a combined attack by both ballistic missile RVs and bomber-delivered nuclear weapons in a specific scenario.

These four simulation techniques rely on two analytical aggregations of nuclear weapons effects:

First, the paper describes the underlying assumptions and computational techniques used to modify the National Military Command System Support Center (NMCSSC) Handbook damage curves and then to predict the aggregated damage which could be caused by combinations of weapons against defended cities. A simple computer program is described which calculates nuclear weapon requirements in a rank order attack against defended cities.

Second, the methodology for computing the equivalent number of "one megaton weapons" (EMT) represented by combinations of weapons--missiles or bombers--of various yields is referenced from a previous report. That report, for which this paper is a special application is entitled "Factors for Calculating Equivalent Megatons of Nuclear Weapons of Various Yields" dated 1 October 1970, published by the United States Air Force Assistant Chief of Staff, Studies and Analysis.

ABSTRACTS OF PAPERS NOT PRESENTED DURING THE SYMPOSIUM

TITLE: A Large-Scale Logistics Simulation Modeling System: From Concept to Application

AUTHORS: MAJ J. Raffiani and MAJ J. L. McHale, III.
United States Army Logistics Center, Fort Lee, Virginia 23801

ABSTRACT: The MAWLOGS (Models of Army Worldwide Logistics Systems) logistics simulation modeling system provides the unique capability to rapidly assemble integrated supply, maintenance and transportation models using a large collection of modular computer routines and an automatic linkage program. The system was developed for the Army under contract and, after an extensive training period, is currently being applied in-house at the United States Army Logistics Center in support of a multi-study Repair Parts Program. This paper would first outline the development of the system, with particular emphasis on the problems encountered during this phase. The training program and the resources needed to bring the capability in-house would then be described. The experience gained during the application of the system will be discussed in detail and potential applications will also be explored.

TITLE: A Model for Predicting Vehicle Fleet Repair Part Inventory Demand Based on Individual Vehicle Age and Failure Characteristics

AUTHOR: Gordon Paul Bradley
Materiel Development Division, Systems Analysis Office
US Army Tank-Automotive Command

ABSTRACT: This paper presents a model designed to predict repair part demand for a vehicle fleet that can be expected to occur during a specified period of time considering the individual ages of vehicles in the fleet at the beginning of the period, and failure characteristics of components and subassemblies of the vehicle system. Also predicted by the model is the earliest time within the specified period a demand for a specific repair part can be expected to occur. The model described is an event based Monte Carlo Simulation.

TITLE: An Analysis of Concepts for War Readiness Spares Kits

AUTHORS: LTC H. P. Kenney and MAJ R. L. Kronz
Office of Assistant Chief of Staff, Studies and Analysis, USAF

ABSTRACT: When an Air Force fighter squadron deploys from its peacetime location to a war zone base, routine logistics support is temporarily interrupted. To fill the gap in logistics support, the squadron deploys a set of spare parts called a War Readiness Spares Kit (WRSK). This paper discusses a study of WRSK concepts and alternatives. Two related mathematical models were created for the study. The WRSK Evaluation Model takes the composition of the WRSK as given and estimates the degree of support provided to the deployed squadron. The Kit Optimization Model computes an optimal WRSK composition for varying levels of support. Both models consider repair and resupply processes along with the failure process in a stochastic parts inventory model.

TITLE: An Improved Approach to Air Force Long-Range Planning

AUTHORS: MAJ Clelland R. Downs, MAJ Edward L. Heinz, CPT Charles G. Simko
Headquarters, United States Air Force

ABSTRACT: The presentation describes early work on a new, experimental approach to Air Force long-range planning. It is structured in two parts. The first part briefly examines the overall study approach, which attempts to derive priorities for near-term decisions from a systematic consideration of the long-term future (out to 20 years).

The second part--which receives major emphasis--reports on the methodology used to identify a range of alternative world contexts for 1995. Preliminary results are also given. The methodology includes development of a primitive model, a basic alternative world context "generator," and a generalized concept of polarity that bridges the two. The model is a taxonomy of future-shaping variables focused on the form of the international system. The generalized concept of polarity addresses the notion that the international environment is shifting from the classical bipolar world to a bi (political-military) -multi (political-economic) polar arrangement. Using political-military and political-economic polarity as the two transformational variables plus selected modulating factors, a globally oriented basic context generator is devised which enables a very high number alternative world future contexts to be postulated. When these contexts are plotted on a grid of political-economic and political integrativeness, a "galaxy" of possible world futures results. A range of alternative contexts is then selected from the galaxy. Using the variables in the model as a basic source, supporting attributes are then developed for each context in the range.

TITLE: Analysis of Helicopter Structural Motions Due to Gun Recoil

AUTHOR: Mr. Thomas D. Hutchings
GEN Thomas J. Rodman Laboratory, Rock Island Arsenal

ABSTRACT: The gun recoil problem in the Air-To-Ground role is complicated by the elastic environment of a helicopter. The accounting of helicopter structural responses to weapon fire is essential to an improved ability to deliver accurate weapon fire.

Delivery errors are predicted by the solution of a system of helicopter modal vibration equations that are coupled to a system of turret dynamics equations. Statistical biases and standard deviation in turret Euler angles are quantified for several turret orientations, weapon recoil loadings, and helicopter rotor loadings.

To support these analyses critical gun recoil data has been collected at the Keith L. Ware Simulation Center at RIA and at the Patuxent River Naval Air Station. The flight testbed at Patuxent River was the Multi-weapon Fire Control AH-1G helicopter, featuring stabilized optical tracking, laser ranging, digital ballistic computation and a testbed turreted 20mm cannon. Analysis of the test data is being used to refine modeling techniques and confirm findings, e.g. that the dispersion due to AH-1J flexure for a 20mm is small ($\sigma < 1$ mrad).

TITLE: Application of Statistical Techniques to Model Sensitivity Testing

AUTHOR: Mr. Jerry Thomas
US Army Concepts Analysis Agency

ABSTRACT: The Department of Defense, other governmental agencies, and private industry have many large scale computer models. These models simulate complex processes with many interactions that make it impossible to accurately predict what affect a change in an input factor will have on an output factor without actually running the model. Since it is desirable to learn how sensitive the output factors are to changes in the input factors, sensitivity analyses are performed. The traditional method of performing a sensitivity analysis has been to change one input factor at a time.

TITLE: Army Maintenance Workloading/Scheduling by Linear Programming

AUTHOR: Mr. Carl L. Barton
US Army Major Item Data Agency

ABSTRACT: This model can be used to determine the actual maintenance workload for each depot for any future year. It can also be used as a planning tool to analyze depot mission changes, depot personnel and tool requirements, depot mobilization plans, and depot closures. The following data files are required by the model and are maintained at the US Army Major Item Data Agency (MIDA): (1) A file of annual maintenance requirements by FSN: (2) A depot mission file which indicates for each FSN which depot is prime and which depot(s) is (are) secondary; (3) The Capability Engineering Data Reporting System (CEDRS) files. One CEDRS file contains the current available manhours in each workcenter at each depot, the maximum manhours per shift in each workcenter, and the manhours reqired in each workcenter to overhaul each FSN. Another CEDRS file contains the current available tool hours for each special tool at each depot and the number of special tools hours required to overhaul each FSN; (4) The total dollars available within each commodity area and the current overhaul cost by FSN are also available. The LP Model will assign requirements into the prime depots until workcenter manhours or tool hour constraints become binding. Then any remaining requirements are loaded into the secondary depots which have available manhours and tool hours. Some requirements may not be workloaded into any depot because of lack of manhours, tool hours, or funds. An output report shows the manhours available (or maximum manhours) and the scheduled manhours at each workcenter at each depot, the tool hours available and the scheduled tool hours at each depot, and the available funds and the scheduled funds by commodity. A list of unscheduled requirements is also produced. The effects of proposed depot closures and depot mission changes can be studied by changing the depot mission file and running the model. Depot mobilization can be studied by using a mobilization maintenance requirements file and the maximum manhours which can fit in each workcenter and multishift operations. The standard output report described above is useful in analyzing personnel and tool requirements.

TITLE: Bayes' Theorem For Limited Intelligence Prediction

AUTHOR: CPT Eric C. Helfers
US Army Special Research Detachment

ABSTRACT: This report examines the pre-Christmas 1972 Vietnam ceasefire situation by comparing the conventional method of intelligence analysis with a probabilistic approach, the odds-likelihood form of Bayes' Theorem. The application of this formula to situations requiring a prediction of an event's occurrence (non-occurrence) proves no more or worse effective (accurate) in predicting the event's occurrence than the conventional method (the analyst's intuitive reasoning). Army strategic analysts can use the Bayesian method in similar situations as a back-up or hedge

against the conventional method's chance possibility of going too far astray. As the analyst if required to judge only a day's or week's reports, he does not have to maintain previously held positions. Due to a lack of previous experience in various situations, the Bayesian method has little credibility. This may be overcome by repeated testing and determination of those specific situations in which the Bayesian method is more reliable than the conventional method of analytic research.

TITLE: Cost Effectiveness Model I

AUTHOR: Mark E. Barkley
US Army Aviation Systems Command

ABSTRACT: The Cost-Effectiveness Model I study presents a methodology that would guide a Product/Project manager (PM) in making an informed selection from among several single prototype aircraft, based upon cost and effectiveness considerations. Measures of effectiveness are defined and a cost-effectiveness index (effectiveness per dollar) is recommended as a basis for selection. A numerical example is presented, demonstrating the application of the model.

TITLE: DECAM - An Interface Between DBM and CEM

AUTHOR: William H. Holter
General Research Corporation,
Operations Analysis Division

ABSTRACT: DECAM (the Deterministic Combat Assessment Model) has been developed as a transform methodology whereby the results of division-level simulations may be used in theater-level simulations for close combat assessment. The model employs a set of differential attrition equations, the parameters of which are estimated from killer/casualty data generated in the lower level simulations. Although DECAM has been tailored specifically to linking up DBM (the Division Battle Model) with CEM (the CONAF Evaulation Model), the concepts which it embodies are sufficiently general to permit its adaptation to other simulations and war games as well. Insofar as the determination of combat losses is concerned, DECAM provides an additional link in the hierarchy of GRC-developed ground combat models of successively higher levels of aggregation from company through theater. The purpose of this paper is to describe the fundamental concepts underlying DECAM, the changes required in CEM for its implementation, and the tests conducted to establish its validity.

TITLE: Decision Risk Analysis
Service Life Extension Program

AUTHOR: Howard M. Gilby
US Army Aviation Systems Command

ABSTRACT: Bell Helicopter Comany proposed to the Government a modification program for the AH-1G (COBRA) aircraft and the AH-1Q aircraft now under development.

The modification program would improve the gross weight capability, the standard day performance and the hot day performance. It would also increase the reliability of the engine, transmission, tail rotor, 90^o and 42^o gearbox, hanger bearings and tail rotor control.

Six alternatives were studied and compared from the standpoint of cost, schedule, and technical requirements. A decision was made based upon the analysis.

TITLE: Economic Retention for Major End Items

AUTHOR: John M. Toler and Aubrey A. Yawitz
Systems Analysis Office
U.S. Army Troop Support Command
St. Louis, Missouri 62120

ABSTRACT: In recent years the Department of Defense has rarely held major end item assets in excess of its requirements. However, inventories of secondary items have often been found to be above the requirements objective. Mr. Alan J. Kaplan, AMC Inventory Research Office, in his study, "Economic Retention Limits" (1969), developed a mathematical model for determining economic retention of secondary items.

Mr. Kaplan's technique, with modified input parameters, is utilized in this paper to apply economic retention to major end items. Specifically an 80 Ton Railway Flat Car problem is investigated, and an economic retention quantity developed. A recommendation affecting assets held at two Army depots is offered, and a subsequent "real world" situation is addressed.

TITLE: Effective Utilization of Player Personnel in Field Experiments

AUTHOR: MAJ Richard B. Cole, Project Analysis Division,
Deputy Chief of Staff, Programs and Project Analysis,
US Army Combat Developments Experimentation Command

ABSTRACT: Constraints influencing the design of field experiments include the required quality of the data to be generated and the time and personnel available. Inherent in these constraints is the requirement that the test designer provide for effective utilization of player personnel.

Implied in this requirement is the need for repeated utilization of players. However, repeated player participation can result in biases due to learning and other human factors. Portions of selected CDEC experiments are discussed to demonstrate how cross-over designs can be used to adjust for these factors and to permit repeated and effective utilization of players.

TITLE: Feasibility of Eliminating Depot Maintenance in USAREUR

AUTHOR: Dr. John C. Sjoberg
Logistics Evaluation Agency

ABSTRACT: Rising overall costs in USAREUR and annual balance of payments deficits coupled with reduced workload in the CONUS depot due to the withdrawal of US Forces from Southeast Asia indicated that it may no longer be economical or desirable to continue depot overhaul of Army materiel in USAREUR.

An interdisciplinary/interagency team under USALEA direction was formed in August 1973 to make a 90-day study of the problem. The draft report, completed 30 October 1973, showed that although CONUS depot and the transportation system had the capability to handle the additional work, a serious shortage of assets required to fill the longer maintenance pipeline coupled with the higher annual costs would prohibit total elimination of USAREUR depot overhaul in FY75. It was desirable and economically sound to return a portion of the program however.

The final report, completed 9 March 1974, incorporated staffing comments and changes in data due to the Energy Crisis and the new Mideast conflict. Recommendations were made to return 89 line items (1/3 of total) to CONUS resulting in a $2M annual operating savings, $5.6M annual balance of payments gain, $1M tax advantage due to added CONUS payroll and a more efficient USAREUR program for the remaining items.

A TAG letter dated 30 May 1974 directed HQUSAREUR and HQAMC to coordinate in implementation of the study recommendations.

TITLE: Initial Evaluation - FRG (DIEHL) vs US Track Design

AUTHOR: Captain Robert Ament

ABSTRACT: Evaluation of the Diehl Track design was initiated to provide management with a tool useful in the decision making process relative to candidate track designs. The study utilizes a determinist math model to compute vehicle cost per mile for the various designs with durability estimates treated as an independent variable. In expressing the resulting cost/durability relationship, a computer printout indicates the estimated vehicle cost per mile for track shoe life (plus or minus 500 miles) and for rubber pad life ranging from 250-4000 miles. As durability estimates are upgraded in conjunction with on-going tests, the resulting cost curves can be utilized to indicate the optimum (lowest cost per mile) alternative for each family of tracked vehicles.

TITLE: Lance Missile Battery Red Team Analysis

AUTHOR: David Tyburski
Systems Analysis Office, US Army Electronics Command

ABSTRACT: During the procurement of the Lance Missile Batteries BA-629 and BA-630 technical problems with the batteries were discovered that caused the batteries to be reworked. Because of this rework delivery of the batteries were expected to be temporarily delayed. The Project Manager Lance asked that a Red Team of technical experts be convened to answer the following questions:

1. Are the batteries without rework technically acceptable?

2. Is the technical basis on which we are proceeding to provide new batteries correct?

This analysis included a risk assessment of technical areas and a structural Red Team analysis format entitled "root cause analysis" which delineates: failure modes, supporting data, refuting data, conclusion and actions/solutions. The analysis highlights the detailed functioning of the Red Team and the lessons learned related to this particular problem and to the effective functioning of Red Teams in general. Conclusions were drawn regarding the technical acceptability of the batteries without rework and the technical basis being used to procure new batteries.

TITLE: Logistics Analysis HLH Engine

AUTHORS: Howard M. Gilby and William Oxandale
US Army Aviation Systems Command

ABSTRACT: The objective of the analysis was to aid in the determination of a logistics strategy appropriate for the Heavy Lift Helicopter (HLH) engine. The strategy was to offer the minimum logistics cost while conforming to the specified availability goal. In addition to this primary objective, a secondary objective as to develop a logistics analysis model suitable for follow-on use to evaluate other HLH sussystems.

The logistics model used for this study was the computer program LOCAM2 written in FORTRAN IV. LOCAM2 is an analytical model and does not contain any optimization routines. Its primary application is to determine life cycle costs and operational availability of a weapon system of supporting equipment for use in analyzing logistics configurations. A number of logistics structures were evaluated using the LOCAM2 model along with varying numbers of aircraft and aircraft deployments.

A baseline logistics structure was developed for use as a comparative reference. The baseline was representative of the "standard" logistics sturcture (Depot, General Support, and Direct Support). Five alternate logistics systems were then theorized and studied.

TITLE: Low Dollar Value Study

AUTHOR: Mr. Alan R. LeMay
US Army Aviation Systems Command

ABSTRACT: The Low Dollar (LDV) Item Study was initiated and subsequently implemented by the United States Army Aviation Systems Command (USAAVSCOM), St. Louis, Missouri. The objective of the study was to determine the potential resource savings (in-house personnel, economic order quantity (EOQ), computer time, administrative, etc.) which could be realized through employment of the ALPHA system to fully automate LDV items. To accomplish this objective, the following approach was pursued: (a) analysis of the acquisition process to include the supply control study (SCS) and procurement work directive processes; (b) construction and validation of computer programs; (c) analysis of computer outputs; (d) briefings to the Commander of USAAVSCOM and relevant Directors: and (e) tracking and monitoring of the implementation on a quarterly basis.

The computer programs produce a forecast of LDV item (federal stock numbers (FSNs), SCSs and PWDs) and workload requirements for the next 0 to 6 and 7 to 18 months. Based upon this forecast, an estimate of resource savings was determined. It reflected resource savings in $500 increments.

TITLE: Major Air Defense Modelling Deficiencies and Their Impacts

AUTHOR: LTC Thomas E. Bearden
SAM-D Project Office
Redstone Arsenal, AL 35809

ABSTRACT: Ten major deficiencies of large computerized wargame models used in major air defense studies are advanced and a historical thesis for their occurrence is briefly developed. Essentially, the effect of these deficiencies has been to linearize the analysis of the air defense battle which is highly nonlinear by nature. Linearizing the air defense battle directly impacts the force structure and defense levels considered to be adequate, and particularly negates the proper degree of consideration of mass(redundancy) in air defense deployments. The extent of these modelling deficiencies brings into question the degree of validity of the force structures, conclusions and tactics based on computerized wargames using the models. Each of the following ten deficiencies in modelling is examined and its impacts on the game outcome indicated: terrain, target, and surface-to-air missile system interaction; fire trainability (sector system aspects); antiradiation missile (ARM) countermeasures; command, control, and coordination; simultaneous interaction of complementary weapon systems; joint and single service firing doctrine; electronic countermeasures and counter-countermeasures; effects of human interaction; simultaneous ground battle and air battle interaction; and the effects of sustained combat. A thesis for the impacts of inadequate air defense modelling on the air defense community, the Army, and the future battlefield is also developed. Impact on weapons development and procurement is detailed, particularly with respect to justification of weapons systems to Congress. Some of the major fallacies that have emerged about the nature of the Air Defense Battle are detailed. Specific recommendations are advanced for correcting the modelling deficiencies. Recommendations to correct the present impacts on the Army are made to include: (1) Need for continuing improvement and updating of modelling tools for major air defense studies, and the budgeting of funds for that specific purpose by a central agency such as the Concepts Analysis Agency. (2) A recommended mix of models to adequately represent and examine the major aspects of the air defense battle. (3) A radically different method of employment of joint service complementary weapons. (4) The incorporation of a large computerized, interactive ground and air battle at the Command and General Staff College level as an essential learning experience for all future Commanders and high level staff officers. (5) Recognition of the need for C&GSC graduates, Major and Lieutenant Colonel, as direct action officers in the continuing development of air defense doctrine, both joint service and single service. (6) Creation of an air defense laboratory at the U.S. Army Missile Command, staffed with both civilian engineers and military officers, to provide a continuing level of effort focussed on standard air defense problems at the technical and operational interface. (7) Broad participation of the air defense community in major, more comprehensive air defense studies under the direction of the Concepts Analysis Agency.

TITLE: Managing the Ammunition Production Base for Mobilization Support; A Model Applied to Improved Conventional Munitions

AUTHOR: MAJ Harry N. White and Mr. Louis M. Smith

ABSTRACT: Peacetime management of the ammunition production base focuses primarily on preparation for wartime consumption. A computer model for simulating an ammunition production base has been generated. The model incorporates the formal methods of planning a base and gives management visibility to the future impact of current decisions to meet ammunition requirements. A relatively unique measure of ammunition support has been developed and OR techniques are utilized to optimize application of funds to provide the best possible support.

TITLE: Nonnuclear Ammunition Rates Methodology

AUTHOR: Charles E. Van Albert
US Army Concepts Analysis Agency

ABSTRACT: The ammunition rates methodology is an example of the application of operations research to an important Army problem. The methodology is used to compute ammunition rates for several hundred munitions. It consists of eight simulation models working in consort to produce ammunition expenditures. The simulation models include target acquisition, artillery fire planning, artillery effects, helicopter against personnel, helicopter against armor, close infantry combat, and tank antitank combat. The results of these models become input to the theater rates model whose purpose is to simulate combat over a broad front for an extended period of time. Discussion is to be oriented around the models, their interactions, and their validation.

TITLE: Optimal Structural Design and the General Eigenproblem

AUTHOR: Professor James E. Falk, Professor Anthony V. Fiacco, and Professor Garth P. McCormick, The George Washington University School of Engineering and Applied Science Institute for Management Science and Engineering

ABSTRACT: This paper is the result of an exploratory study conducted for the US Army Weapons Command. It summarizes our findings in developing a procedure for solving a class of optimal structural design nonlinear programming problems which require the calculation of the minimum eigenvalue of a general eigenproblem to evaluate certain constraints. Eigenproblem solution methods tested were the power method, a conjugate gradient method and a (complete solution) method based on deriving the involved stiffness matrices as sums of outer products of vectors and exploiting this decompositon in an iterative technique. Drawbacks of the various techniques are indicated and an unsuccessful attempt to utilize a

well-known nonlinear programming algorithm (SUMT) in conjunction with the power method is described. Obstacles to efficient procedures are indicated.

TITLE: OR/SA Techniques Applied to a Missile Flight Test Data Report Production Control System

AUTHOR: Mr. Stephen J. Lawrence, US Army White Sands Missile Range, New Mexico

ABSTRACT: A data reduction organization within a missile test range engaged in the Optical and Electronic instrumentation of a broad spectrum and large numbers and mixes of firings is faced with the task of providing hundreds of flight test data reports per month.

In order to conduct orderly transactions within the data reduction processes OR/SA techniques are utilized to maintain higher efficiencies in the environment of diminishing resources.

This paper is concerned with a network production flow diagram of the organizational activities and a remote terminal oriented production control data base system which is utilized to;

(1) Update all current input and output activities and monitor the times and status involved in each ARC of the network.

(2) Develop the statistical history of each test project and each of the data reduction processes associated with the test.

(3) The performance of the intra-organizational elements and individuals for each type of data reduction.

(4) Investigate queuing situations developing as a result of peak work overloads and other exterior and interior factors affecting timeliness.

(5) Make visible in terms of the network all time consuming arcs of the organization activity and procedures so that management and supervisors can take alternative and remedial action.

The combination of the remote terminal production control data base and the network model of the organization has been exceptionally valuable in making visible the majority of the inefficient, time consuming delays and has served as an aid to a rapid monitoring and control process.

TITLE: Probabilistic ADP Simulation System (PASS), a Mathematical Technique for Predicting Automatic Data Processing Equipment Performance

AUTHOR: LTC Robert W. Otto and MAJ John L. Geisinger
Office of the Chief of Staff, Army

ABSTRACT: The need to predetermine the relative size of a computer configuration necessary to perform a specific set of software applications is inherent in the planning, programing and budgeting effort within the Army. The proliferation of multicommand standard systems requires that hardware selection and upgrade be accomplished through a rational, credible, structured planning technique.

The Probabilistic ADP Simulation System (PASS) provides such a planning base. By comparing a small set of technical parameters of the hardware, and subjecting them to mathematical analysis, the planner is able to develop relative machine conversion factors (MCF's). PASS can be used to predict MCFs in either a serial or multiprograming mode. A description of the PASS model to include derivation, is presented along with illustrative examples of its use in the Army automation planning process.

PASS is designed as a simplistic, first-cut approach to the hardware selection process with further refinement generated through empirical data. Used in conjunction with System Capability-Over-Requirement Evaluation (SCORE), another Army developed planning technique, PASS provides technical assistance to the decision maker in the rational design of an ADP system.

TITLE: Reliability and Maintainability of Materiel Items in the Tropics

AUTHOR: J. C. Bryan
US Army Tropic Test Center, Analysis Division

ABSTRACT: The United States Army Tropic Test Center (TTC) sponsored a reliability and maintainability (R&M) investigation of operational commodities in tropic deployment by TO&E units. The investigation included OH58A helicopters, M151A2 1/4 ton trucks, M113 personnel carriers, PRC77 radios, jungle boots and fatigues, M16A1 rifles and MC 1-1 parachutes. Data collection ran for two years. Objectives of the investigation were to (1) provide project managers and AMC commodity commands with recommended test times and risk statements for shortened test durations; and (2) compare tropic and CONUS R&M parameters.

Results include operating characteristic curve plots for helicopters, 1/4 ton trucks, personnel carriers and radios, showing the mean time between failures (MTBF) and the mean time between unscheduled maintenance actions (MTBUMA) required to yield on 0.9 or higher of acceptance for a given test design. Decision risk summaries also resulted showing the test time required to meet the consumer's and producer's risk criteria, assuming neither will accept risks greater than 10%. These analyses assume fixed length test design and exponentially distributed failures. Reliability curves for the above systems also resulted.

Tropic vs CONUS R&M comparisons were made for M151A2 trucks and OH58A helicopters. In general, tropic samples showed higher part replacement and unscheduled maintenance rates. For all items, part subgroups and assemblies with high tropic replacement and unscheduled replacement rates were studies to determine whether the problems were environmentally induced or whether a specific maintenance problem existed. It was concluded that particular subgroups and assemblies have high tropic replacement rates due to the humid tropics; i.e., exhaust systems and electrical systems as well as rubber parts, bearings, u-joints, compressor, main and tail rotor blades attributed many of these problems to salt-laden air, high humidity and moisture condensation. It was concluded that while most end items studied functioned reasonably well in the tropics, particular sybsystems were prone to tropic failure. Since for many subsystems corrosion failures occur after an extended test duration, time-cost considerations preclude testing major systems for the required length. Further tropic failures occur in particular subsystem components which could be tested in advance of the major system, through design of a tropic exposure period at ambient temperatures and then a functioning test simulating integral use with the major systems. The investigation supports the TTC position that tropic testing of components should begin early in the developmental (DTI) phase and thus eliminate extended testing during the DTII Phase.

TITLE: Reliability Notions as an Aid in Structuring Development Programs

AUTHOR: Mr. Abraham S. Pollack
Headquarters, Department of the Army
Office of the Chief of Research, Development, and Acquisition

ABSTRACT: Many programs have suffered as a result of equipment that was not adequately matured during development being introduced into the field. The purpose of this paper is to illustrate how notions arising from reliability theory can be applied during a development program as an aid in the selection of the number of prototypes necessary to achieving stated reliability goals. A program for the development of new

helicopters to replace an existing helicopter fleet is used as a hypothetical example. The new aircraft are to have reduced maintenance and logistics support costs. The paper describes the application of a reliability growth model for estimating the amount of testing needed to meet reliability requirements. It is important that decisionmakers fully understand the implications of this model; especially vital is understanding of the concept that the reliability level of the aircraft is directly dependent on the amount of testing and associated engineering effort devoted to the elimination of failure modes. A number of options are considered with respect to the number of prototypes to be procured for each phase of the development. For each option, the amount of calendar time to be consumed by the test program is determined, based on the estimated amount of testing required and on prior experience with similar programs. It is then possible to estimate the effect of each option upon acquisition costs (i.e., test, prototype fabrication and production costs) and upon the difference in operating costs between the new aircraft and the existing fleet. The paper also indicates a potential for tradeoff between the amount of formal reliability demonstration testing and the amount of testing aimed at removing sources of malfunctions while the design configuration can be changed freely.

TITLE: Repair Part Consumption in Depot Overhaul

AUTHOR: P. R. Fatianow
AMC Inventory Research Office

ABSTRACT: This paper reports some results from a study of forecasting repair past consumption in depot overhaul programs for repairable end items or assemblies. Consumption data reported over a five year period on overhaul programs for various end items were used to simulate requirements forecasting under a number of different forecasting techniques. Comparative evaluations of the moving average, single exponential smoothing, adaptive smoothing and the techniques currently automated in the materiel management system of the US Army Materiel Command are presented. Results obtained with a modified version of the exponential smoothing technique developed in the course of the study will also be given. It was found that actual consumption of parts varies considerably from program to program. This variability obscures the significance of differences in forecast accuracy achieved by the forecasting techniques investigated.

TITLE: Resource Allocation Directives for Research and Development
I. A Computer Assisted Management Structure for R&D Budget Planning

AUTHOR: MAJ Walter L. Perry
Headquarters, Department of the Army
Office of the Chief of Research, Development, and Acquisition

ABSTRACT: This paper is the first in a series of three papers dealing with the allocation of scarce resources to many resource demand points. A computer-assisted, user interactive fund allocation system for apportioning the Army R&D budget is presented. Emphasis is placed on the operating system in dealing with reprograming the approved budget and its effect on the management process.

The allocation model is inserted into the management structure in the allocation process, not to revise the structure, but to enhance its operation. The computer is subordinated to the functional management process. The system features a multi-level user community, "scratch-pad" files and a shopping list of quantitative decision criteria used to generate trial solutions. The allocation process allows for the input of subjective factors by the user at the time of execution. Any "undesirable" solution can be changed thus iteratively converging to a satisfying solution.

TITLE: Statistical Investigation into Pulse Charging of Nickel-Cadmium Batteries

AUTHORS: Mr. Walter Kasian and Dr. Erwin Biser
US Army Electronics Command

ABSTRACT: The common methods of charging vented aircraft nickel-cadmium batteries are constant current, constant potential and modified constant potential (current limited). However, through continuous recharging by these methods, nickel-cadmium batteries develop a "memory effect" caused by passivation of the battery's positive cell plate material (nickel-oxide) and "fadeout" caused by crystal growth of the negative cell plate material (cadmium). These two phenomena gradually and continually lessen charge acceptance which in turn lessens the battery output.

Pulse charging, however, has shown a significant effect in eliminating battery "fadeout" and "memory effect." Thus, pulse charging can eliminate the required periodic cycling to rejuvenate the batteries and possibly increase the battery cycle life.

The pulse charging of nickel-cadmium batteries has been completed on two new and two used batteries in all possible combinations of the following charge variables: three different pulse heights, three different charge rates and two different percent overcharge rates.

This investigation will entail analysis of the mean responses (battery output) and response-variability to determine the optimum combination of pulse height, charge rate and percent overcharge in charging new and used nickel-cadmium batteries. Similar analysis will be performed to determine the optimum combination of the variables for greatest battery efficiency.

TITLE: Statistical Methods Applied to Number Theory for Model Evaluation

AUTHOR: Michael E. Neyer, Logistics Analysis Division, Systems Analysis Office, US Army Tank-Automotive Command

ABSTRACT: Many of the current modeling techniques are based upon prime number attributes which, till now, have been limited to those which have been proven algebraically through number theory.

An attribute, listed as being intuitive but unproven, is that of prime pairs. This attribute states that there are an infinite number of pairs of prime numbers separated by only one number. An extension of this attribute is prime number clustering (a set of M prime numbers in N consecutive integers), which I have shown to be infinite through statistical methods; thus breaking down the algebraic barrier.

One application of this attribute to a model allows the use of prime numbers in queuing simulations when you do not want to assume a Poisson Distribution. Through the expected value formula developed in the proof you can find an interval of numbers with prime numbers having the desired attributes. The bottom heaviness of primes also allows for conditions a Poisson simulation would find hard to cope with: such as mechanical failures being more prevalent in the start of a fleet's life with a tapering off as vehicles are dropped from the fleet.

I would recommend this application only to the analyst without an automated source, who could use a list of prime numbers for failure simulation. As prime numbers become easier to generate this method would become feasible for automated simulations.

TITLE: Systematic Analysis of Ground Vehicle Mine Dispensing Systems

AUTHORS: Lawrence L. Rosendorf and Stanley Kahn
Picatinny Arsenal

ABSTRACT: A multi-attribute analysis of nine (plus variations) conceptual and developmental ground vehicle mine dispensing systems was conducted. The systems varied in complexity from fully automated electro-mechanical to completely manual to propellant activated. Each system was evaluated in a subset of scenarios developed for scatterable mine war games. A set of 15 evaluations criteria, including cost, flexibility, reliability and logistics, were developed and employed as objective measures of system worth. A numerical system of weights and performance factors enabled the computerization of results and the sensitivity to changes in the evaluation criteria.

TITLE: Systems Analysis Study of the TACOM Rebuild System

AUTHOR: Robert Olds, LTC Laurence Smith, Daniel Palmer, Logistics Analysis Division, Systems Analysis Office, US Army Tank-Automotive Command

ABSTRACT: The TACOM Rebuild System, over a period of years, has failed to provide a consistent and timely response to the requirements of the Army in providing rebuilt vehicles and/or components on a scheduled basis. This study, performed in two phases, was undertaken to determine how the system could be improved to the extent that it would meet the established system performance level. The one restriction placed on the analysis was that the study effort concentrates on the PEMA Secondary Items aspect of the rebuild program.

Phase I of the analysis encompassed the following areas: 1) definition and documentation of the rebuild system, 2) analysis of secondary item supply control studies which influence the rebuild system, 3) analysis of TACOM-Depot mortality data, 4) analysis of the Special Program Requirements (SPR) System, 5) nature of linestoppers and causitive factors, 6) impact of nonstockage policies on the rebuild system, 7) analysis of program fundery and timing and 8) availability of technical guidance. The follow-on study (phase II) effort concentrated on repair part support and rebuild standards. A random sample of repair parts (1200 FSN's) were selected from the PEMA Secondary Item rebuild program as a base for data collection in the study.

The completed study documents the current system and its problems and recommends some corrective action in several areas of the rebuild system.

TITLE: Terrain Effects on SAM Capability

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ABSTRACT: A set of interrelated computer programs has been developed which operate upon terrain elevation data for a prescribed geographic region to produce various types of outputs useful in the analysis of air defense weapons and their effectiveness against very low flying targets. The input terrain data for the programs consists of digitized elevation grid values. Other data inputs include the geographic coordinates of the site being analyzed, the height of the sensor, and the flight altitude of the targets. The target flight path profile is generated from a choice of two options. The first option assumes the target remains at an exact specified height above the terrain, with no consideration of g constraints. The second option assumes the target is subject to positive and negative g constraints, remaining as close as possible to the specified height. The primary forms of output are: (1) graphical displays of target visibility from fixed sites, (2) graphical displays of intercept capability of surface-to-air missiles fired from fixed sites, and (3) statistical data describing target visibility and missil intercept capability. The paper consists of two parts. The first part describes the models with examples of the various outputs while the second part describes their use for an evaluation of SAM siting as single sites and as deployment.