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A RAND NOTE

The Army's Conventional Munitions Acquisition Process

Kenneth Girardini

July 1989

RAND

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Report

This ~~Note~~ describes the Army's conventional munitions acquisition process from the generation of the estimate of the requirements for munitions to the decisions on what mix of munitions will actually be funded. Particular emphasis is placed on the description of the models used by the U.S. Army Concepts Analysis Agency to estimate the conventional munitions war reserve resupply requirements, which represent the bulk of the total requirement. The author describes the models used to simulate a theater conflict and the methodology used to combine the results of the models. He also makes several suggestions for improving the requirements estimation and procurement processes. The author recommends that the current procurement process be altered to analyze investment options other than larger stockpiles to respond to the variability and/or uncertainty associated with the wartime demand for munitions. He also suggests a structure for a measure that stresses the critical early stages of a conflict and allows munitions planners to quantify their preferences for the mix of munitions to be produced.

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PREFACE

This Note primarily describes, but also evaluates and suggests improvements to, the Army conventional munition acquisition process. The acquisition process is defined to include the calculation of requirements and the imposition of budget and production constraints during procurement. This research is part of the study entitled, "Review and Improvement of Munitions Acquisition Processes," sponsored by the Assistant Secretary of Defense for Production and Logistics. This Note is one of several to be published on the munitions acquisition processes of the services. The research has been carried out in the Acquisition and Support Policy Program under the National Defense Research Institute, RAND's OSD-sponsored Federally Funded Research and Development Center.

SUMMARY

This Note describes the Army's conventional munition acquisition process from the generation of the estimate of the requirements for munitions to the decisions on what mix of munitions will actually be funded. Particular emphasis is placed on the description of the models used by the United States Army Concepts Analysis Agency (CAA) to estimate the conventional munition war reserve resupply requirements, which represent the bulk of the total requirement. The dollar value of the estimate of the total munition requirement has historically far exceeded the available budget for munitions. Hence, this Note includes a description of the procurement process that establishes what mix of munitions is actually funded in light of budget and production constraints.

The Army munitions requirement is composed of a war reserve requirement and peacetime losses. The war reserve munitions requirement is the sum of the ammunition initial issue quantity (AIIQ) for each piece of equipment in the force structure, the predicted resupply requirement, operational projects for special contingencies, and mobilization training. Peacetime munition losses include expenditures during peacetime training and testing of inventories.

The most complex part of the Army's munitions requirement calculation is predicting the resupply requirement. An estimate of the resupply requirement is calculated by the Concepts Analysis Agency, which uses a hierarchy of models including the Combat Sample Generator (COSAGE), Attrition Calibration Model (ATCAL), Concepts Evaluation Model (CEM), and Ammunition Post Processor (APP) to simulate a theater conflict. This Note describes the models and the methodology used to combine the results of the models to simulate a theater conflict.

It also comments on and evaluates the current methodologies, making several suggestions for improving the requirements and procurement processes.

No process or individual can predict what the demand for munitions will be in a future contingency. The current requirements process, however, calculates in great detail the expected value of the demand associated with a single reasonable worst case or global scenario. The procurement process treats the estimate of the requirement as the de facto demand. No attempt is made to analyze the effects that real world or statistical uncertainty would have on the prediction of the demand for munitions. By focusing on a single estimate, ammunition planners increase the risk that there could be large

differences between the projected ammunition consumption rates used for planning and procurement and the inventories desired in an actual contingency (possibly with catastrophic results).

Simply increasing the point estimate of the demand for munitions (a worst "worst case") to account for uncertainty results in increasingly larger inventories of munitions appearing to be the only solution. The current procurement process must be altered to analyze investment options other than larger stockpiles to respond to the variability and/or uncertainty associated with the wartime demand for munitions.

It currently can take more than a year to complete a study of the munition requirement for a single theater. It may be possible to streamline the methodology by improving the flow of information and reducing the extraneous detail in the models. The current process is too complex and has too many inputs ever to be responsive enough to deal with the effects of real world uncertainty. The Army should consider the development of a simpler methodology that is not based on simulation to operate in place of or in parallel with the current process and that can be used to analyze the effects of uncertainty on the predicted wartime demand for munitions.

Even if the single estimate of the demand were correct, it is not clear that the Army is producing the most combat-effective mix of munitions possible. The problem is the lack of a measure that can be used to evaluate the difference in combat effectiveness associated with producing different mixes of munitions. This leads to conflicting or unclear objectives in the decision processes associated with munition production. A structure is suggested here for a measure that stresses the critical early stages of the conflict and allows munition planners to quantify their preferences for the mix of munitions to be produced.

Currently, the Army uses far too much effort and too many analytical resources to calculate a single estimate of the unconstrained munition requirement and too little to determine how to allocate resources to the demands that may occur.

ACKNOWLEDGMENTS

Special thanks go to the Army's military and civilian personnel, particularly the analysts at the Concepts Analysis Agency, who aided the author's understanding of the processes described in this Note. The author is also indebted to numerous colleagues at RAND who contributed time, particularly Lt. Col. John Bondanella (ret.), Maj. Sam Cantey (Army Fellow), Brian Leverich, and David Kassing. Any errors of omission or commission are the author's responsibility.

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TABLE

GLOSSARY

AAO	Army Acquisition Objective
AIIQ	ammunition initial issue quantity
AMC	Army Materiel Command
AMCCOM	Armament, Munitions, and Chemical Command
AMIP	Army Model Improvement Program
APP	Ammunition Post Processor
ATCAL	Attrition Calibration model
CAA	Concepts Analysis Agency
CAS	close air support
CEM	Concepts Evaluation Model
CINC	Commander in Chief
CONUS	Continental United States
COSAGE	Combat Sample Generator
DA	Department of the Army
DCOPS	Deputy Chief of Staff Operations
DCSLOG	Deputy Chief of Staff Logistics
DCSINT	Deputy Chief of Staff Intelligence
DESCOM	Depot System Command
DG	Defense Guidance
FEBA	forward edge of the battle area
FORCEM	Force Evaluation Model
GS	general support
HE	high explosive
HQDA	Headquarters, Department of the Army
ICM	improved conventional munition
K-V	killer-victim
LIN	line item number
LOGSACS	Logistic Structure and Composition System
LOS	line of sight
MRC	Materiel Readiness Command
MSC	Major Subordinate Command
MICOM	Missile Command
OPS	operations
OSD	Office of the Secretary of Defense
PDIP	program development increment package

P-rate	program rate
PGM	precision guided munition
pK	probability of kill
POM	program objective memorandum
RDA	Research Development and Acquisition
TAA	Total Army Analysis
TOA	total obligation authority
TOW	tube launched, optically tracked, wire guided
TRADOC	Training and Doctrine Command
VIC	Vector in Commander
WR	war reserve
WRSA	war reserve stocks for allies

I. INTRODUCTION

This Note will describe and evaluate the process used by the Army to establish the requirement for and procurement of conventional munitions (see Fig. 1). The information was obtained from numerous Army documents and discussions with knowledgeable individuals.

The part of the process used to determine the expenditure rates for war reserve (WR) munitions is shown in Fig. 1 as the box labeled "Programming Study." The WR expenditure rates, or ammo rates, are defined as the quantity of each munition that the forces would expend disregarding budget, production, and munition logistic constraints.[1] The ammo rates are calculated by the Concepts Analysis Agency (CAA) based on a two sided force-on-force simulation of a theater conflict. Different computational methodologies are used to calculate the munition expenditure rates depending on whether the munition is directly represented in the simulation. The rates are expressed as a function of theater and time. The models and methodologies used to complete the theater simulation are discussed in Sec. II.

The rates calculated by CAA are used to develop a total force munition requirement. The expenditure rates derived by the theater simulation(s) are used to establish war reserve (WR) resupply requirements for the total force. Test requirements, training requirements, Operational (OPS) projects, and ammunition initial issue quantities (AIIQ) are added to determine the total force requirement. The total force requirement is reviewed and approved, approval being the last step of the requirements process (see Fig. 1). The above calculations are described in Sec. III.

After the total force requirement has been generated and approved, the procurement process begins. First, the current inventory status must be determined and subtracted from the total force requirement to establish the unfunded requirement, which greatly exceeds the budget available to procure munitions. Hence, budget and

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[1]By definition, munitions are missiles and ammunition. The programming study done at CAA determines munition resupply, WR requirements for ammunition, missiles, and some equipment that would not be precisely defined as munitions (e.g., engineering materials). Although imprecise, the term *ammo rates* will be used to refer to all of the above.

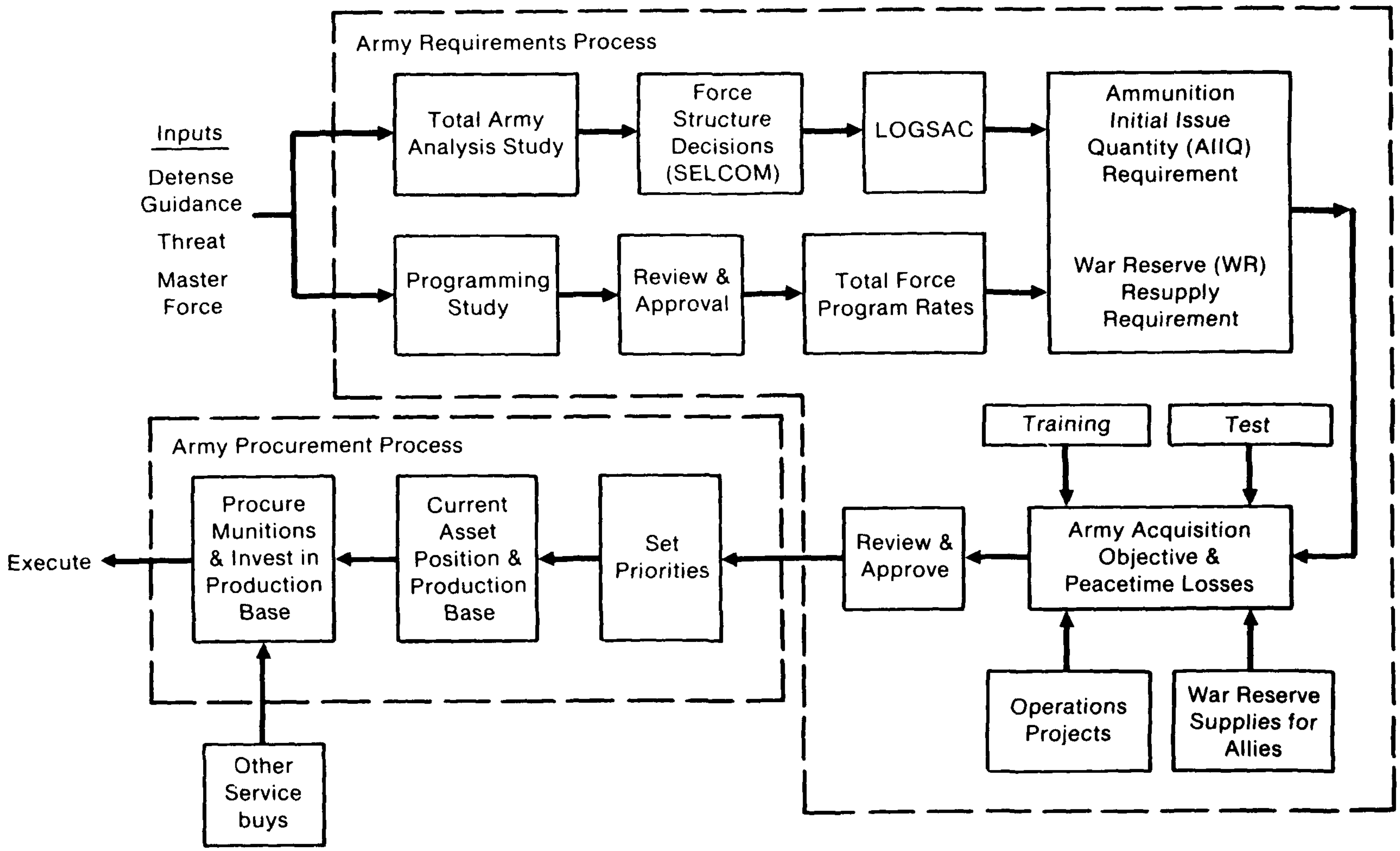

Fig. 1—Overview of the Army's conventional munitions acquisition process

production resources must be allocated to the unfunded requirement in a manner that reflects the Army's priorities. Section IV describes the Army's munitions procurement process.

II. AMMO RATES

This section will describe how CAA uses a hierarchy of models to simulate a theater conflict using assumptions that make it possible to determine the unconstrained WR resupply munition requirements. In the terms of the overall process, the discussion in this section is limited to the "Programming Study" box in Fig. 1. The process of completing a theater simulation is referred to as a study or programming study.

The calculation of WR munition expenditure rates is just one part of the Wartime Requirements for Ammunition, Materiel, and Petroleum (WARRAMP) study, which is also used to determine wartime replacement factors (WARF) for major items of equipment and wartime fuel factors (WAFF). WARRAMP is run for the predicted force structure of the last year of the Program Objective Memorandum (POM, the five year defense program). This implies that the study is executed for a force structure six years in the future. That is, the study done in 1987 is for the 1988 budget year and a 1993 force structure. Some of the models used in the WARRAMP study are also used in other studies; hence, any modifications to the models must be made in light of their use in other studies.

In calculations of the ammo rates, the force structure is fixed and munition logistics constraints are not considered. Referring to Fig. 1, the force structure is used as an input to the theater simulation and in calculating the AIIQ requirement. The goal is to determine the quantities and mix of munitions that would be consumed before the budget, production constraints, and munition logistic constraints are considered.

The WARRAMP process begins when CAA receives a directive from the study proponent, Deputy Chief of Staff Operations (DCSOPS), DAMO-FDL. DCSOPS derives the directive from the Defense Guidance (DG) issued to all the services by Office of the Secretary of Defense (OSD). Each study done by CAA involves only a single theater. Successive studies are based on the major theaters on a rotating basis. Each study, whatever the theater, is done in the context of the illustrative scenario of the DG. The directive includes such information as the study year, theater of operations, scenario, and forces involved. This includes which units will be deployed to the theater and the timing of their deployment, the composition of the units in terms of personnel and equipment, the weapon systems on each type of equipment, and the munition types to be expended by each type of weapon system.

The remainder of this section will describe the models and how they are used. An overview of the hierarchy of models is given first. Then each of the main elements of the hierarchy, Combat Sample Generator (COSAGE), Attrition Calibration model (ATCAL), Concepts Evaluation Model (CEM), and Ammunition Post Processor (APP), is described in more detail. Since the Army is in the midst of the Army Model Improvement Program (AMIP), possible changes are summarized.

OVERVIEW

The derivation of Army WR munition requirements is to a large extent based on ammo rates expressed in rounds/tube/day developed for each theater by the Concepts Analysis Agency. CAA derives the ammo rates using a hierarchy (COSAGE-CEM-APP) of models to describe the dynamic interactions of theater combat.

Figure 2 indicates how the hierarchy of models is used to calculate the ammo rates for a particular theater. The first step is to run the Combat Sample Generator, which is a mid-resolution simulation of a division level engagement, for several tactical postures. COSAGE is a data intense model (all the models are data intense, but COSAGE requires a particularly large number of inputs) so several preprocessors and data libraries are used to expedite the preparation of input. The flow of information into CAA from different agencies is depicted in Fig. 3. The time required to complete a study can be substantially increased if the input data is delayed. Approximately 40 percent of the time required to complete a study can be attributed to collecting and waiting for data. Some of the inputs are developed at CAA.

The results from the detailed analysis of division level engagements may be used to evaluate the combat outcome of engagements that occur in the theater model. Because a theater simulation contains many engagements involving different forces, the results of division combat are extrapolated as a function of the forces involved in the engagement using the combat samples from COSAGE, where the forces involved in the engagement are known, to solve for the coefficients of direct and indirect fire attrition equations for each tactical posture. Different coefficients must be used for each posture because the equations are valid for changes only in force structure, not in doctrine and tactics. To evaluate the results of an engagement in the theater model, first one must determine the posture so that the correct coefficients are used in the attrition equations. Then, the attrition equations are solved to determine the equipment attrition and munition

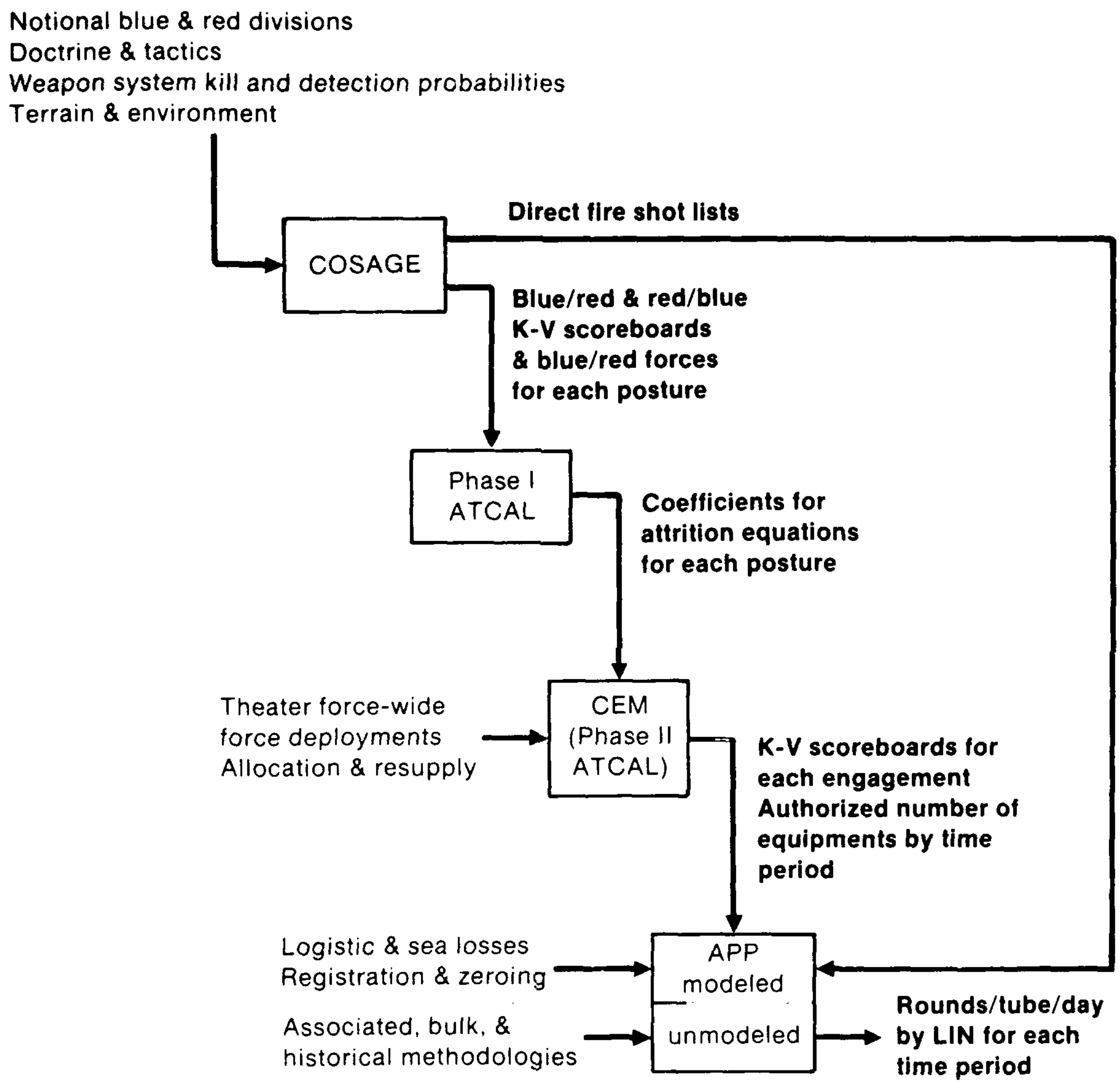

Fig. 2—Overview of the theater simulation process

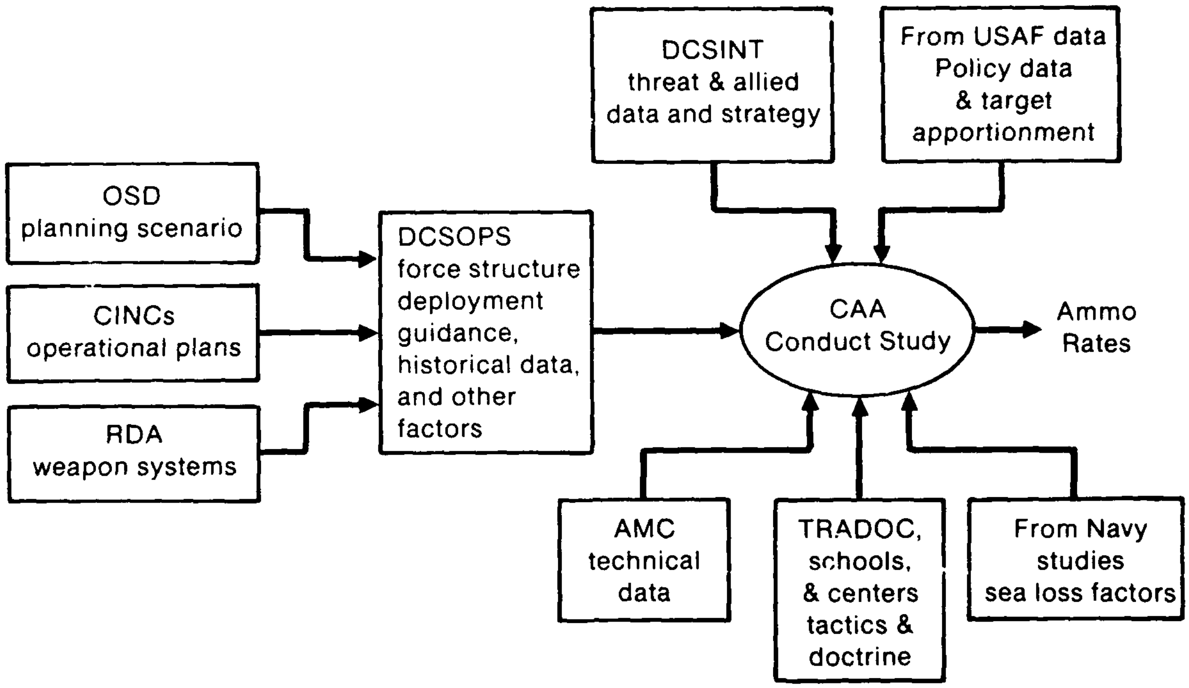

Fig. 3—Flow of information into CAA

expenditures. Solving for the coefficients of the attrition equations for each posture is referred to as Phase I of the Attrition Calibration Model (ATCAL).

The Concepts Evaluation Model (CEM) is a deterministic model used to simulate a theater level conflict and includes force deployment schedules, theater resupply, etc. The CEM is organized in theater, army, corps, and division echelons. Conflicts are simulated down to the brigade level. In each echelon, an estimate of the situation is formed and a mission chosen based on that estimate. The ATCAL attrition equations, along with the appropriate coefficients for the posture, are used in CEM to evaluate the equipment attrition and munition expenditures of the numerous combat engagements that occur during the theater simulation.

The next program in the hierarchy is the Ammunition Post Processor (APP), which does the necessary calculations to convert the outputs of COSAGE and CEM into ammo rates in rounds per tube per day. The APP also adds in expenditures and losses not modeled in COSAGE and CEM, such as logistic losses, sea losses, etc. The APP analysts exercise separate methodologies based on the theater results to determine expenditure rates for munitions that are not directly modeled in COSAGE.

Each of the models accommodates a different number of weapon systems and equipment types. COSAGE is the most general model and may be used to model any number of equipment types each with as many weapon systems as desired.[1] For direct fire weapon systems, the most effective probability of kill (pK) against a target versus range is determined and input to the simulation. The munition that provides the most effective pK for the target range combination is determined later in the APP. Hence, each direct fire tube is considered a single weapon system but may generate requirements for several different munitions. For example, the main gun of a tank can generate requirements for both high explosive (HE) and armor piercing fin stabilized discarding sabot munitions. Different ammunition types change the characteristics of indirect fire weapon systems, hence, the same equipment must be modeled as a different weapon system for each type of ammunition it expends. For example, a 155mm howitzer will be modeled as a different weapon system on the same equipment based on whether an HE or an improved conventional munition (ICM) round is used, although the same tube fires both types of rounds.

CEM equipment types must be included in one of seven equipment categories:[2]

- armor [12]
- armored personnel carriers (APCs) [12]
- artillery [8]
- antitank and mortars [12]
- helicopters [5]
- personnel [1]
- tactical aircraft [1]

Since CEM is a theater engagement, it must include allied as well as U.S. equipment types. COSAGE can include more types of equipment than CEM, so there may be a shortage of available equipment types in the CEM equipment categories. When this occurs, the equipment densities, target kills, and munition expenditures of more than one equipment from COSAGE must be aggregated into a single equipment in CEM. Also,

[1] Any number implies there are no limitations hard coded in the model. In reality, the memory capacity of the computer imposes limitations.

[2] The number in brackets denotes the maximum number of equipment types that can be accommodated by each category.

each equipment in CEM is limited to two weapon systems—that is, two tubes on each equipment for direct fire and two round types for each equipment for indirect fire. For an equipment that has more than two weapon systems (e.g., tank) or types of munitions (e.g., howitzer), the target kills and round expenditures must be aggregated. Precision guided munitions (PGMs) are treated as direct fire munitions associated with the sensor/designator. For example, remotely piloted vehicles (RPVs) are considered the weapon system associated with Copperhead rounds. The two weapon systems associated with each type of artillery tube refer to the same tube using either ICM or HE rounds.

The APP is restricted to 30 equipment types, but each equipment can have as many weapon systems or round types as desired. This may require aggregating the results of different equipment types because CEM supports 51 equipment types, many of which, however, do not require that munition expenditures be counted (e.g., allied equipment types and unarmed jeeps and trucks). Once different equipment types have been aggregated, the kills of that type of equipment and munition expenditures from weapon systems on that equipment type must maintain the same proportions that occurred in COSAGE. The different models in the hierarchy were developed or were adapted from programs that existed before the current process for calculating ammo rates was completely defined. This resulted in the inconsistencies in the number of weapon systems and equipment types accommodated by the different models in the hierarchy.

COMBAT SAMPLE GENERATOR (COSAGE)

The simulation of a theater conflict requires the analysis of combat engagements between different force structures, in different tactical postures, occurring on varying terrain/environment, and with resupply and logistical support for equipment and personnel. It would be prohibitively expensive and time consuming to do a detailed simulation of each division or brigade level engagement that occurs in a theater conflict. COSAGE simulates in detail the representative division level engagements that determine the results of engagements occurring in the theater simulation. In Fig. 2 COSAGE feeds the ATCAL model, which is used in the theater model CEM.

COSAGE is a mid-resolution, stochastic, two sided force-on-force simulation. It simulates 24 hours of combat between blue and red forces under the assumption that a division operates independently of resupply, except for munitions, for that period. Munition resupply is not modeled. Instead, the desired type and quantity of munitions are assumed to always be available for weapon systems to fire (perfect munition resupply and unconstrained munition stockpiles). This does not imply that the firing rate is unconstrained, which is simply the weapon system's maximum firing rate, but that the firing rate will not be reduced because of lack of munition availability. The firing rate in rounds per day is determined by doctrine, force structure, tactics, and opportunity, all of which are modeled in the simulation.

The Representative Engagements

Force structure, posture, and terrain/environment are the three main sources of variation in determining the representative engagements. The computer resources and time required to prepare input for and execute COSAGE, however, restrict the number of runs that can be made. Hence, it is necessary to account for all combinations of the above factors with as few runs as possible.

Terrain/environment is handled stochastically so that the simulation does not have to be run for different combinations. The terrain is represented statistically by line of sight (LOS) and movement rate data determined from actual samples taken from the theaters. Various environments (e.g., open, woods, or town) are also represented statistically. Day/night is differentiated and affects sensors accordingly.

The number of weapon systems and equipment types in a division, henceforth referred to as force structure, provides an almost limitless number of possibilities in a theater conflict. Because of attrition and resupply at the theater level, the force structures of red and blue divisions are constantly changing. Rather than play all possible combinations of red and blue force structures at the detailed COSAGE level, a single force structure determines the results of engagements in the theater model using a notional division (often referred to as a stylized division). The COSAGE output must be used to determine results of engagements during the theater simulations, so all of the equipment types and weapon systems to be played in the theater must be represented in the notional division, which does not exist as an actual division, but represents a mixture of all the divisions in the theater (e.g., armor division, light infantry division, etc.) along with an appropriate corps slice. The corps slice includes corps level assets, such as air defense and general support (GS) artillery, that would be shared among several divisions. One of the main inputs to COSAGE is the composition of the red and blue notional divisions. Figure 4 depicts the methodology used to build a notional division.

Tactical posture is related to force structure in that varying unit strengths between red and blue would result in different doctrine or tactics being used. For example, a

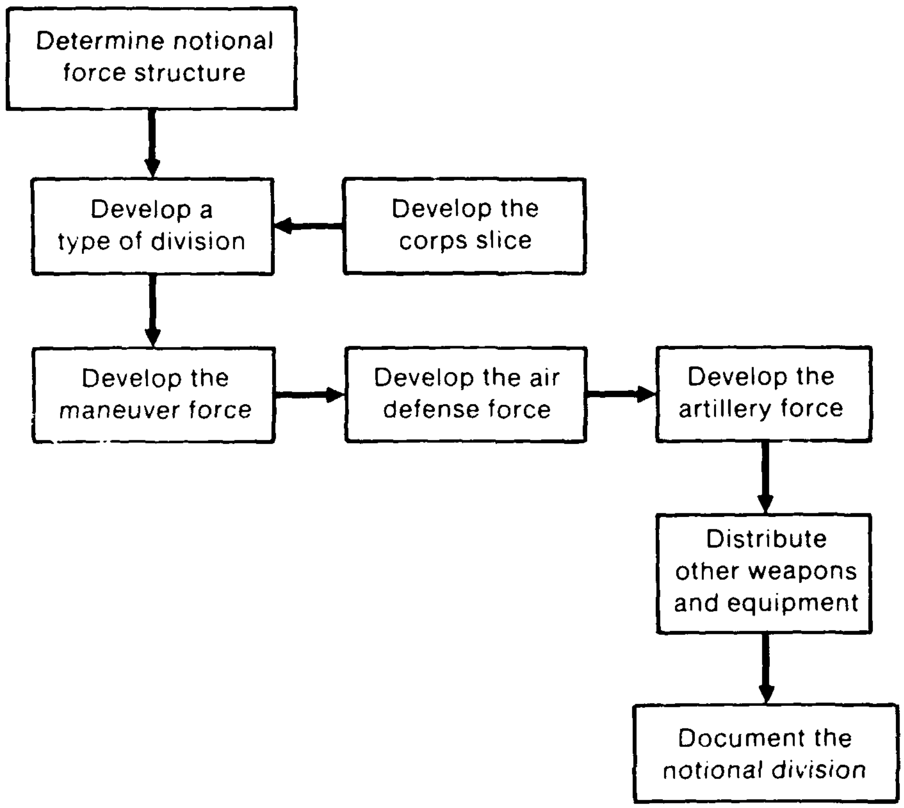

Fig. 4—Methodology for building a national division

heavily outnumbered unit may be more inclined to defend than to attack. Tactical postures are defined from the blue perspective. Four tactical postures are usually considered: attack, defense intense, defense light, and delay. The blue force remains constant at one notional division while the strength of the red force is varied by multiples (not necessarily integer) of a red notional division to achieve an appropriate force ratio for the posture to be simulated. For example, defense intense could be defined as one blue notional division against three red notional divisions, or attack as one blue notional division against a half of a red notional division. Loop C in Fig. 5 depicts the methodology for preparing the four different tactical postures used to calculate the equipment attrition and munition expenditures during engagements in the theater simulation CEM. Many of the inputs to COSAGE, particularly those dealing with doctrine and tactics, will change depending on the posture being simulated.

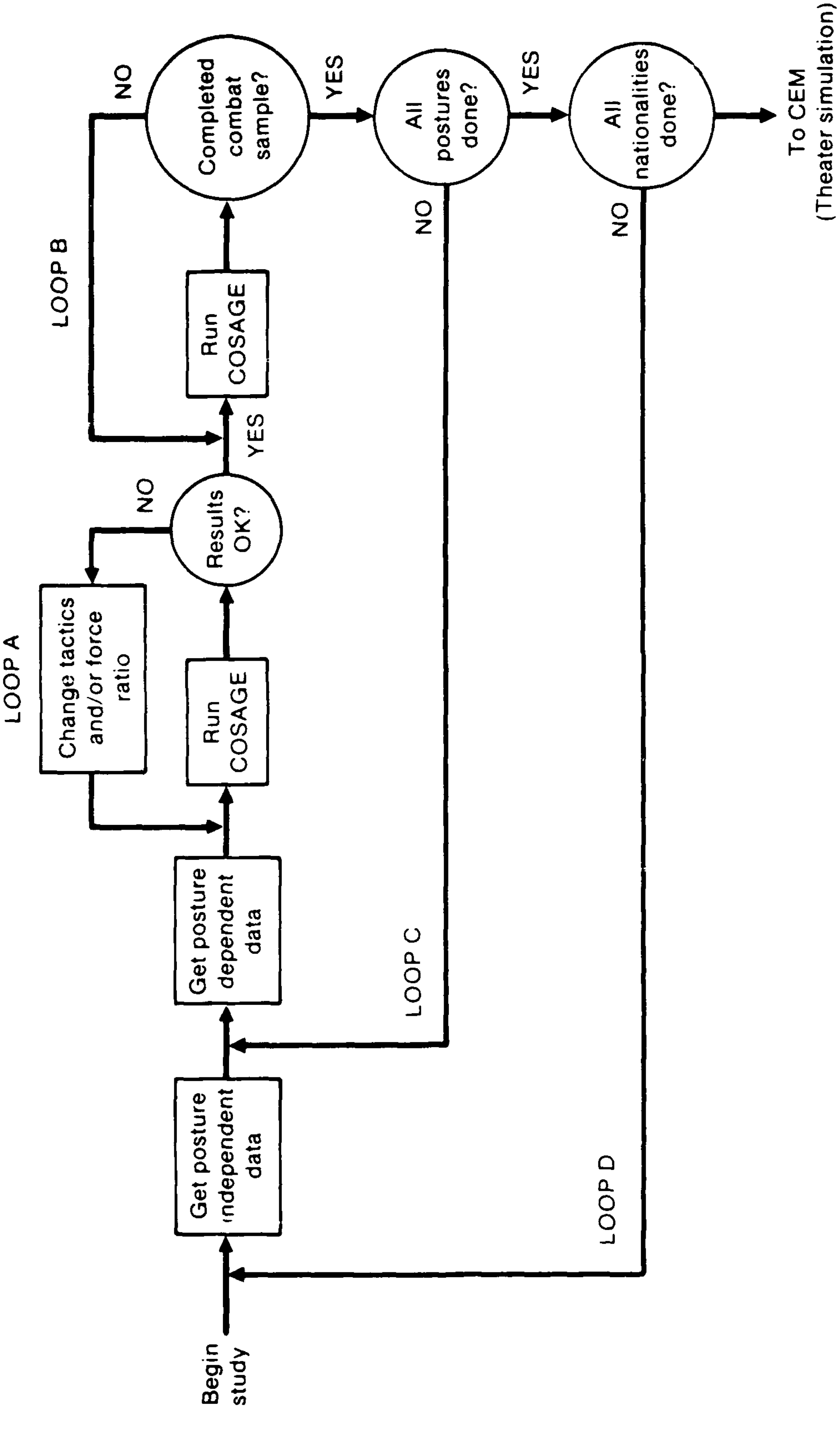

Fig. 5 - COSAGE methodology

The above description assumed that the simulation was for U.S. forces. In a theater simulation, however, there may also be allied forces. Hence, the entire process must be repeated for different allies so that detailed simulations of representative engagements exist for all the forces involved in the theater simulation. This is denoted as loop D in Fig. 5. When simulating Europe, more than one ally may be grouped together as one notional division.

Four combat samples (one for each tactical posture) are generated for U.S. forces and four for each of the allied notional divisions. These detailed simulation results are fed forward to the ATCAL model. How the results of the COSAGE engagements are used to determine the results of the numerous engagements that occur during the theater simulation will be discussed in the section on ATCAL. Figure 5 is a detailed illustration of the box labeled COSAGE in Fig. 2. The other loops denoted in Fig. 5 are discussed below.

Input, Execution, and Output

COSAGE requires large volumes of input data to run. In fact, collecting and waiting for data are the most time consuming tasks involved in the calculation of the ammo rates.

Once the composition of the red and blue notional divisions has been decided on, the user must provide a technical description of each piece of equipment in the simulation, including the probability of detecting and being detected by each target type, the types of weapon systems on the equipment, pK for each target type for each weapon system on the equipment, rate of fire for each weapon system, etc. Other inputs describe doctrinal issues, such as which weapon systems will fire at a target, the level of damage to critical equipment that artillery should attempt to inflict, and the level of attrition at which a unit will break off from an engagement. The battlefield dimension, a description of the battlefield terrain by line of sight (LOS) and movement rate data, etc., must also be input.

The basic modeled entity, which is referred to as a unit, is a platoon for blue and a company for red. Each unit is composed of equipment armed with weapon systems whose capabilities have been described. Each unit is also given an initial position on the battlefield and an order set describing how maneuver units will move about the battlefield or giving the distance artillery units should maintain from the forward edge of the battle area (FEBA). The order sets are input as data files and are meant to reflect the doctrine and tactics that would be representative of the study year. The order sets for the maneuver units that reflect a given doctrine are not unique. How a set of doctrine and tactics are interpreted into order sets that are input to the model will vary among analysts. This is not a criticism of the process. Military judgment is used to some extent in the development of all the inputs, even in the preparation of the technical data.

COSAGE is a discrete time simulation with an initial input that describes when certain events are scheduled to occur. For example, a maneuver unit may have the order to move forward at a specified time and attack if it detects an enemy unit. Every order has contingency orders to be executed depending on the success or failure of the previous order. Hence, one event may set in motion many events.

Movements of maneuver units are tracked at the macro level until until they are in sufficient proximity of enemy units. At that point, the control is moved to more detailed routines that check for LOS or other sensor detection. Detection is represented stochastically by a probability of detection for the modeled sensor. COSAGE does not model fratricide, so only enemy units engage in battle.

When a unit is detected, all of the equipment in that unit is detected simultaneously and is at the same range with respect to the detecting weapon systems. Each of the detecting weapon systems fires at the type of target that poses the greatest threat. If there is more than one target of a given type (e.g., M1 tanks), a stochastically determined percentage of the individual targets are fired on depending on whether the firing unit and the target unit are moving or stationary.

The single shot pK is input as a function of range and may be modified by degradation factors for target in defilade, target movement, and/or shooter movement. For direct fire weapons, the highest pK versus range is input. Hence, the most effective munition for the range is assumed available and used. When totaling expenditures, the APP determines which type of munition was fired. The probabilities of kill are played stochastically by drawing random numbers to determine the attrition for the engagement.

An engagement ends when one of the units involved disengages itself. Disengagements are the result of maneuver units maintaining a user input range from the enemy (referred to as the withdrawal range) or a decision based on the quantity of critical equipment remaining (the unit suffers substantial casualties before moving within the withdrawal range). With regard to the latter, a unit whose losses of critical equipment exceed a specified upper bound is considered destroyed and no longer combat effective.

Units may call for artillery or air support during an engagement or their sensors may detect appropriate targets without an engagement actually occurring. Other sensors not associated with maneuver units, such as counter-fire radar, may also call for artillery or air support. All requests for air and artillery support are placed in the appropriate queues in a manner that reflects the priorities of the doctrine and tactics. The number of artillery volleys required to kill the desired percentage of critical targets or achieve the desired lethal area is calculated for HE and ICM munitions. The munition type that achieves the desired effect at a lowest total weight (rounds in volley × pounds per round) is used. Special logic, which is determined by doctrine, is used to invoke the use of precision guided munitions (e.g., Copperhead).

The outputs of each of the four postures simulated by COSAGE must satisfy three criteria before they can be used to determine the results of the numerous engagements occurring during the theater simulation. First, the results for each posture must represent an average day in a 180-day conflict for both the red and the blue team. For example, a strategy that was disastrous for either red or blue (although it could occur) would not be repeated throughout a protracted theater conflict and therefore would be unacceptable for determining the results of engagements throughout the theater conflict. Also, given the posture, the combat intensity in that posture must represent the average intensity for a 180-day conflict. For the same red and blue forces different combat intensities can be simulated. For example, the point was raised earlier that interpreting a doctrine into order sets is not a unique process. Because the COSAGE runs are used to evaluate combat outcomes in the theater simulation, the combat intensity of the COSAGE run will be reflected in the each of the engagements that occur in the theater simulation.

The second criterion is that threshold force ratios must be identified that would be appropriate for use in differentiating between postures in the theater simulation. This is different from the point above, which stated different combat intensities can result for the same posture and force ratio. The tactics and doctrines associated with different postures vary and result in different combat intensities in terms of munition expenditures and equipment attrition. For example, depending on the threshold force ratios, the results of an engagement in CEM will be based on either the attack, delay, defense intense, or defense light results from COSAGE.

The third criterion is that there must be sufficient interaction among all the weapon/target combinations in each of the postures. Since probabilities of kill are played stochastically, the number of times a weapon fires at a particular target represents the sample size for a zero-one random variable. For example, if only one shot is fired and hits (misses), the pK passed forward to ATCAL will be one (zero). Because pKs are input as a function of range and other factors, the sample size must be large enough to reflect the average pK over the range of conditions that occurred during the simulation.

The process of determining an output that meets the above criteria (depicted as loop A in Fig. 5) can be quite time consuming. Labor-intensive efforts are required to review the output to insure no unexpected results occurred.[3] Because COSAGE is a Monte-Carlo simulation, two runs with the same input will result in a different outputs (assuming that the random number seed is not reset). Hence, it is often necessary to review multiple outputs generated from the same input. It may be necessary to change the inputs (each time reviewing multiple outputs) for each posture.

Because the results of the combat samples are used iteratively in the theater simulation, the adjustments made in loop A of Fig. 5 will have a strong effect on the final estimate of the WR resupply munition requirements for the theater being simulated. There are numerous inputs to COSAGE and uncertainty about the appropriate value for each input. The three criteria are used only to define an acceptable combination of the inputs but do not in any way account for the range of uncertainty associated with each of the inputs. The effects on the outputs of changing the inputs will be referred to here as *real world uncertainty*.

Once a given set of input files has been accepted for one of the postures, it is necessary to run approximately 15 simulations to get a representative set of runs (because COSAGE is a Monte-Carlo simulation). These runs are referred to as *production runs*, and the process of generating them is depicted in loop B in Fig. 5. The mean of the production runs is referred to as a *combat sample*, of which there are four, one for each posture. The munition expenditures and equipment attrition associated with the four combat samples are passed forward to the theater simulation by using them to solve for the coefficients of the ATCAL equations.

Considerable statistical analysis is done on the production runs, but only the mean or combat sample is passed forward to the theater simulation. Any uncertainty or variability in the munition expenditures suggested by the production runs is not reflected in the final estimate of the ammo rates. Hence, the resulting estimate of the demand for

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[3]This is often the only way to detect some input data errors.

munitions is based on a single realization (related to the central tendency) of the possible demands for the inputs and assumptions used. The variability in the result that could occur because of different realizations for the same inputs will be referred to as *statistical uncertainty*. The same inputs were used to generate each of the production runs for a given posture, so statistical uncertainty is clearly different from real world uncertainty.

The production runs that make up a combat sample can in fact show significant variation (statistical uncertainty) in terms of munition expenditures and target kills attributed to different weapon systems. Table 1 depicts the variation that occurred for a few selected rounds. The total expenditures summed over all targets, referred to as x in the table, are given for weapon systems A, B, and C for postures 1, 2, and 3. The variations observed are a result of the processes that are represented stochastically in the simulation. These include the single shot probability of kill, detection, delay at a minefield, allocation of targets, etc. The variability in Table 1 is to be expected because COSAGE models a series of dependent, dynamic stochastic events. For example, whether a unit wins or loses a battle based on the results of the random draw for pK will affect the rest of the simulation, or whether two units do or do not detect each other based on a random draw for probability of detection may result in substantially different engagements. Despite the variations shown in the table, the FEBA movement is quite invariant for each of the runs.

There are usually no more than 20 production runs in a combat sample, so it is not possible to determine the underlying distribution for the munition expenditures.

Table 1

COMBAT SAMPLE STATISTICS

	Posture 1			Posture 2			Posture 3		
	A	B	C	A	B	C	A	B	C
E[x]	86.6	57.9	59.3	4.9	2.9	3.2	56.4	73	104.5
σ	36.4	32.3	36	4.1	3.9	4.4	24.1	52.3	32.5
σ/E[x]	0.42	0.56	0.61	0.84	1.34	1.38	0.43	0.71	0.31
min	26	6	14	0	0	0	14	9	35
max	168	121	146	11	12	17	99	240	157

However, the row $\sigma/E[x]$ shows that a significant increase from the mean estimate would be required to insure that the rate did not exceed the mean plus one standard deviation.

Table 1 suggests that there is considerable statistical uncertainty associated with the expenditures of a given munition. However, the total kills (summed over all blue shooters) of a given red target show substantially less variability between runs or realizations of the process $\sigma/E[x] = 0.05$ to 0.02 for the major target types). This indicates that the variability is to a large degree associated with the competition (based on opportunity, attrition, etc., represented stochastically in the model) between different blue shooters that are capable of defeating the same targets. The kill potential of the inventory that would be suggested by any one of the realizations would show less variation (although the mix of munitions would differ substantially), which could explain why the FEBA movement is fairly constant from run to run.

Table 1 also brings out the strong dependence of expenditures on the posture (tactics and force ratio) being simulated, which is why it is necessary to derive a combat sample for each of the different postures simulated. The increased $\sigma/E[x]$ ratios for posture 2 reflect the smaller number of trials from the underlying stochastic processes in the simulation due to less intense activity.[4] For a constant pK, more intense activity results in more target kills, where the number of target kills is r.

As mentioned above, only the mean estimates of the expenditure rates are used in evaluating the results of engagements in the theater simulation. Results such as those in Table 1 could be used in a method to estimate the theater-wide variability in the expenditure of munitions. Such information, particularly the variability among munitions, would be useful in making procurement decisions. Given the statistical uncertainty associated with predicting the mix of munitions that will match the demand, options other than stockpiling munitions should be considered to provide a more robust supply of munitions.

The variation in the output of production runs relates only to statistical uncertainty. Although that variation can be significant, the variation from real world uncertainty (varying the inputs within a range of acceptable values) should be greater.

[4]Assume the only stochastic process is a single type of weapon system firing at a single type of target with probability of success pK (i.e., Bernoulli trials). The ratio $\sigma/E[x]$ is equal to $\sqrt{(1-pk)}/\sqrt{r}$, where r is equal to the expected number of target kills. The expected number of expenditures and, hence, the expected number of target kills is smaller for lower intensity engagements.

Also, there is statistical uncertainty associated with each input. Accounting for real world uncertainty would change the central tendency of the production runs, as well as still containing the variation about the central tendency because of statistical uncertainty. If the effects of real world uncertainty greatly change the estimate of the requirement, then one must question the high degree of detail to which a division level conflict is modeled in COSAGE.

Two main outputs from each posture simulated using COSAGE are passed forward in the hierarchy of models. Both are based on the mean of the production runs that make up a combat sample. The killer victim scoreboards, one blue/red and the other red/blue, summarize the attrition for of each type of equipment modeled. Another file summarizes the expenditures (number of shots) of weapon systems against targets (enemy equipment types). The other main output is the files that provide a more detailed description (shooter unit, target unit, simulation time, etc.) of the munition expenditures (referred to as direct and indirect fire output files). These files are used in the APP to determine the expenditures by type of direct fire round.

ATTRITION CALIBRATION MODEL (ATCAL)

The Attrition Calibration model extends the results of the combat samples derived using COSAGE to account for the different force structures occurring in a given posture during the numerous engagements of a theater simulation. Given the number of each type of equipment attrited (e.g., 10 T80, 12 T55, 7 M1A1, 5 M3) in a COSAGE combat sample in which the number of each type of equipment initially engaged is known (e.g., 20 T80, 30 T55, 10 M1A1, 10 M3), it is possible to calculate the average number of each type of equipment engaged using an exponential relationship (e.g., 13 T80, 16 T55, 8 M1A1, 7 M3). The average number of each type of equipment engaged can be used to solve for the coefficients of the equations for attrition due to direct and indirect fire. In the nomenclature of the ATCAL model, this is referred to as a *backward solution* or *calibration of the attrition equations*. The backward solution of the equations is done for each posture, resulting in one set of coefficients for each posture.

To calculate the attrition during an engagement in CEM in a posture given the number of each type of equipment initially engaged (e.g., 30 T80, 10 T55, 20 M1A1, 0 M3, which is different from the number of each type equipment initially engaged in the COSAGE for that posture), the equation coefficients for the appropriate combat posture are used along with the *average* number of each type of equipment engaged (because attrition is not known, the average is not yet defined) to solve the attrition equations in the forward mode (Phase II of ATCAL) for the number of each type of equipment attrited. The average number of each type of equipment can be thought of as the independent variables and the number of each type of equipment attrited as the dependent variables. This description, however, is not completely accurate because the average (through an exponential relationship) is a function of the attrition. The average number of each type of equipment engaged is assumed to equal the number of each type of equipment initially engaged (attrition equals zero) and the solution is approached iteratively.

The pK for each weapon system/equipment combination is set equal to the pK for that combination in the COSAGE combat sample. Dividing the attrition associated with a given weapon system/equipment combination by the pK summed over all equipments that weapon system attrited gives the number of rounds expended.

For each posture (combat sample) from COSAGE, the initial number of each type of equipment engaged and the number of each type of equipment attrited are known. Hence, the average number of equipment of type i (η_i) engaged can be solved for using the exponential relation below:

$$\eta_i = \frac{-\Delta N_i}{\ln\left[1 - \frac{\Delta N_i}{N_i}\right]}$$

where ΔN_i is the attrition and N_i is the number of initially engaged equipments of type i. Defining the following variables:

$(\Delta N_k)_{ij}$ = Attrition of equipment k by weapon system j on equipment i in one 24 hour period.

η_i = The average number of equipment i present during the 24 hour period. This is based on an exponential rate of attrition between initial and final values with no equipment resupply.

$(RATE)_{ij}$ = The rate of fire for weapon system j on equipment i. This is not the maximum fire rate, rather it is the number of rounds fired during the COSAGE engagement.

P_{ijk} = Probability of killing equipment k with weapon j on equipment i during the detailed simulation. Ratio of kills over expenditures from COSAGE, which includes the effects of shots fired at different ranges (P_{ijk} versus range), target in or out of defilade, target moving/stationary, and shooter moving/stationary.

A_{ijk} = The fraction of the time that an equipment k can be fired on by a weapon j on equipment i, referred to as the availability.

k' = The index of the equipments that are of higher priority than equipment k for weapon j on equipment i.

$(RATE)_{ij}$ is known for all weapon systems and P_{ijk} is known for all equipment/weapon system combinations modeled. The target importance, which is derived from the killer-victim (K-V) tables output from COSAGE, times P_{ijk} determines the priorities (e.g., k' for a given k) of the targets for each weapon system. That is, the threat times the probability of scoring a kill determines priority. Hence, the direct fire attrition equation can be used to solve for the availabilities (A_{ijk}) in order of priority.

$$(\Delta N_k)_{ij} = \eta_k \, (RATE)_{ij} \, P_{ijk} \left[1 - (1 - A_{ijk})^{nk}\right] \prod_{k'} (1 - A_{ijk'})^{\eta_{k'}}$$

Since fratricide is not modeled in COSAGE, the availability of equipment k to weapon system j on equipment i is equal to zero ($A_{ijk} = 0$) if equipments i and k are on the same side.

The availabilities are stored in a frontage independent form by dividing by the factor:

$$1 - e^{\frac{-(RANGE)_{ij}}{WIDTH}} \, .$$

The average range of engagement and width of the battlefield are taken from the COSAGE results.

The values of A_{ijk}, P_{ijk}, and $(RATE)_{ij}$, and the priorities of the equipments k for weapon system j on equipment i will be referred to collectively as the *equation coefficients*. Different coefficients are derived and stored for each combat posture. Hence, each combat posture uses the same form equation, but with different coefficients.

COSAGE simulates a 24 hour engagement; however, the theater simulation, CEM, evaluates combat outcomes every 12 hour division cycle. After the availabilities have been solved for the variable $(RATE)_{ij}$ is divided by two to account for the shorter time duration.

When an engagement occurs in CEM, a mission is chosen based on the known strength of friendly forces and an estimate of the enemy strength. The mission selection determines the posture (the coefficients that will be used in the attrition equation). Then, the number of each type of equipment initially engaged is used as a first estimate of the average number of each type of equipment engaged in the attrition equation. The solution procedure iterates between the attrition equations for $(\Delta N_k)_{ij}$ and the exponential equations (the equation with the natural log function) for η_i until the equipment attrition predicted by each equation agrees for each equipment type. This is the Phase II operation of the ATCAL model, which is used to assess the results of combat in CEM.

The solution of the ATCAL equations always constitutes an extrapolation because different equation coefficients are derived for each combat posture simulated using COSAGE. The only data point for each posture is associated with the force structure used in the COSAGE run. It is not valid to do interpolations based on the number of each type of equipment associated with the different combat postures because that would imply interpolating across tactics and doctrine that are not represented in the equations.

The P_{ijk} from the detailed COSAGE run is held constant and used in the ATCAL equations. Hence, the ATCAL equations are extrapolating how the equipment attrition would be reallocated among the different weapon/target combinations based on the changes in the force structure. The attrition for a given weapon/target combination divided by P_{ijk} determines the munition expenditures of the weapon against the target. Hence, ATCAL can also be thought of as reallocating the way weapons expend munitions against targets based on changes in the force structure, but not changing the percentage of shots that result in a kill.

There is a different equation for indirect fire, but the basic ideas are the same. For indirect fire, however, the pK is a function of target density and is not held constant to the value in COSAGE.

The outputs files from COSAGE are run through a preprocessor to prepare them for use in Phase I of ATCAL. As illustrated in Fig. 2, Phase II of ATCAL is actually a part of the CEM simulation.

CONCEPTS EVALUATION MODEL (CEM)

CEM is a deterministic, theater-wide combat simulation. The commander's decision processes and utilization of resources (e.g., reinforcements, air, and artillery) are fully automated at all echelons from division through theater. The primary inputs to CEM are the forces and resources allocated to the theater by the opposing sides and information required to evaluate the outcome of combat engagements. As discussed above, the coefficients of the attrition equation for each posture derived during the execution of Phase I of ATCAL are required to determine combat outcomes.

The echelons of command represented by CEM are theater, army, corps, and division. The theater decisions are allocation of reinforcement artillery battalions, close air support (CAS) sorties, and logistic resupply operations (for materiel other than munitions). The army decisions then work within the constraints of the theater decisions and involve assigning reinforcing divisions to corps, assigning army reserve pool divisions to corps, mission selection, reserve corps commitment, realignment of corps frontage, and allocation of artillery and air support to corps. The corps decisions are mission selection, reserve commitment, realignment of division frontages, and allocation of fire support to divisions. The division decisions take the form of estimates of the situation, determining the mission or posture that results in the most favorable outcome (based on known strength of friendly forces and an estimate of enemy force strength), and resupply.

The execution of CEM occurs in theater, army, corps, and division cycles. In each of the cycles, an estimate of the situation is formed from imperfect information, represented as the status during the previous cycle, supplied by the lower echelon. In the division echelon, the estimate is based on the outcomes of the engagements. With this estimate, the decisions listed above are made automatically in the appropriate cycle based on the estimated force ratios. For example, the theater decision of allocating reinforcement artillery battalions depends on the proportional number of divisions in the armies. The actual form of the decision rule is embedded in the logic of CEM, although the decision rule may be affected by model inputs that reflect doctrine and tactics.

Each echelon decides on a mission based on its current information (knowledge of one's own force strength and an estimate of the enemy's force strength). Engagements occur along the front in subsectors, which are boundaries used in the model to partition the front along the organizational structures of the opposing forces. The combat posture in CEM is based on the mission selection chosen in the subsector in which the engagement will occur and may be different from the mission selected in the higher echelons. The combat postures are represented by the coefficients used with the direct and indirect attrition equations. The equipment involved in the engagement is used with the indirect and direct fire attrition equations to determine the results of the engagement. Because each division cycle is 12 hours, all engagements last at least that long. Although that may result in attrition greater than the break point used to disengage units in COSAGE, it does not appear to result in significant errors. Engagements may continue for additional 12 hour cycles. The higher echelon decisions simply determine what force structure will be involved in the engagements by allocating reinforcements, artillery, and air support.

A tactical air submodule in CEM simulates air-to-air, interdiction and air reconnaissance, air defense, and air-to-ground operations. Close air support is included in the force structure and reflected in the ATCAL equations because COSAGE included it. Expenditures are not calculated for Air Force munitions. Interdiction is accessed as delays in supplies (less munitions) and reinforcements to the ground combat. There is an Air Force liaison officer permanently stationed at CAA to observe and aid in the modeling of the theater air assets.

The principal outputs of CEM are FEBA movement and equipment attrition. Equipment attrition can be used to determine munition expenditures by dividing by the pK (which is equal to the COSAGE pK for direct fire, but varies for indirect fire). K-V scoreboards are output periodically and can be accumulated to determine the overall theater combat outcome. The FEBA movement is determined from a two dimensional table that has percent attrition of each side as the indices. The table was initially derived based on historical rates and subjective judgment and has been in use ever since. FEBA movement occurs only if one of the sides assumes an aggressive posture; otherwise it is static regardless of attrition.

AMMUNITION POST PROCESSOR (APP)

The APP uses four methodologies to determine ammo rates: (1) modeling, for munitions that are explicitly modeled in COSAGE; (2) association, for weapon systems that are not modeled but are on equipment that is modeled; (3) bulk rates, for munitions not suited to simulation but whose expenditure rates can be related to the number of personnel in theater; and (4) historical rates, for munitions or items that are not suited for simulation whose usage is based on historical rates. Figure 6 shows an overview of the information flow in and out of the APP.

The APP computes the expenditure rates for modeled munitions predicated on the results from the COSAGE and CEM simulations. The outputs from COSAGE required by the APP include the blue killer/red victim scoreboard and the direct fire shot list for each posture along with several input files from COSAGE describing the quantity of equipment used in COSAGE. These inputs may be used to determine the direct fire munition that was implemented by default in COSAGE. It is also necessary to

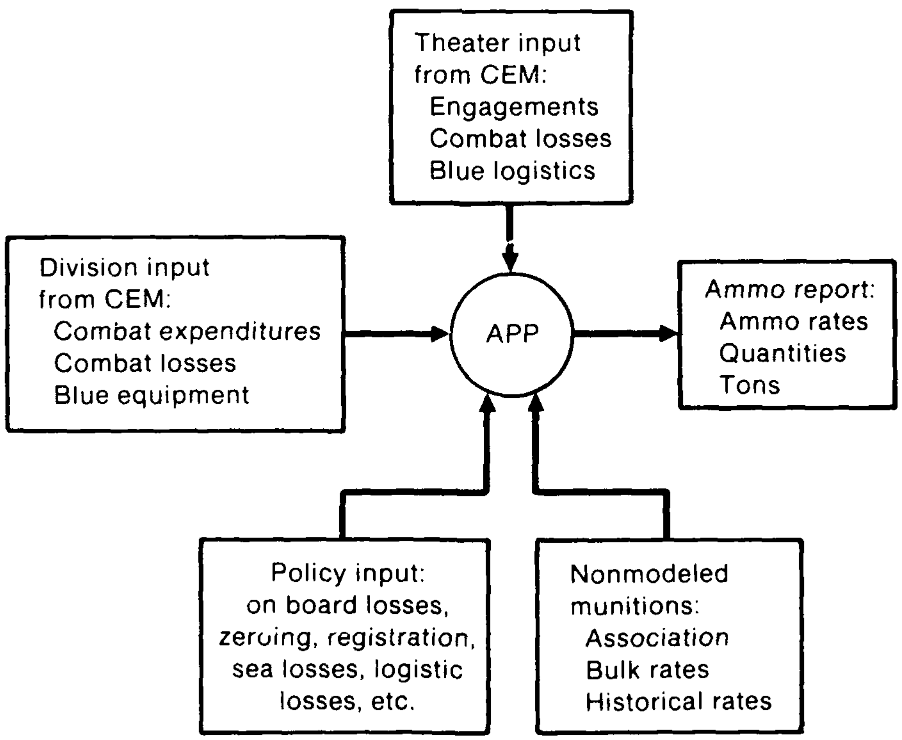

Fig. 6—The APP

extrapolate the division expenditures to the theater level. The outputs required from CEM include the deployments, replacements, quantity of weapons engaged, and equipment kills. The equation for total expenditures (TE) is given below:

$$TE = \frac{\text{red targets killed in CEM}}{\sum_{bk}\left[\left[\frac{\text{bk in CEM}}{\text{bk in COSAGE}}\right] \times \text{red kills in COSAGE}\right]} \times \frac{\text{bk in CEM}}{\text{bk in COSAGE}} \times \text{rounds fired in COSAGE}$$

where bk denotes blue killer.

The equation above uses only the posture profile and total red kills from the CEM output. The kills are then assigned to shooters according to the proportions in COSAGE. The munition expenditures are determined by dividing the red kills assigned each equipment by the pK calculated in COSAGE. The latest version of CEM (VI), however, provides enough information to attribute kills to weapon systems and total munition expenditures directly without having to extrapolate from COSAGE results. The APP still uses the above methodology because the coding has not yet been adapted to take advantage of the more detailed output from CEM VI. CAA has been reluctant to devote time to updating the APP code, because the current code will probably be replaced as part of the AMIP. However, this change would result in more fidelity in the final expenditure counts, and the current methodology unnecessarily complicates the process.

Several policy add-on expenditures are accounted for in the APP, including munitions required to account for (1) expenditures at suspect targets for direct fire, (2) support target firing for indirect fire (taken as a factor of total expenditures), (3) logistic losses (taken as a factor of total expenditures), (4) sea losses (taken as a factor of total expenditures), (5) zeroing direct fire weapon systems, (6) registration of indirect fire weapon systems, and (7) expenditures for rear area security.

There is also a methodology for determining the number of rounds lost on board destroyed equipment. However, rounds lost on board do not represent a resupply requirement as long as the AIIQ of all the equipment in the force structure at the outset of the conflict and any equipment deployed or redeployed after repair[5] during the conflict are included in the total requirement (see Sec. III).

[5] A percentage of the non K-kills that are repaired and redeployed can be assumed to have lost their on-board munitions, requiring an AIIQ on redeployment.

The rounds fired at modeled targets are combined with the policy add-on expenditures to get the total expenditures for a given time period. The ammo rate is calculated by dividing by the number of days in the time period and the average table of equipment (TOE) authorization for the number of tubes during the period. The result is in rounds/tube/day for each of the periods considered (0–15, 16–30, 31–60, 61–90, 91–120, 121–150, and 151–180 days). The rate includes the effects of attrition because the expenditures are divided by the *average authorized* number of tubes as opposed to the *actual average* number of tubes (attrition does not decrease the "authorized" number of tubes).

The ammo rates for associated munitions are taken as a percentage of a weapon system on the same equipment modeled. For example, there may be a weapon system on a helicopter that is not modeled but for which expenditures can be predicted based on the expenditure rates of a modeled weapon system (munition). This category also includes prop charges and fuses associated with projectiles. The calculation of expenditures for associated munitions is a manual process requiring careful review of the CEM output.

There are many munitions and related items for which expenditures cannot be practically computed from the weapon systems modeled in COSAGE. For example, barrier and denial (other than mines) for defensive positions, military construction materials, and small battle items such as grenades. These are modeled with a bulk munition methodology that uses the CEM deployments and the results of the CEM simulation. For example, a withdrawing unit would be expected to use smoke grenades. The APP analyst must manually go back through the CEM output to determine these expenditure rates for each of the time periods. Hence, they use the CEM outputs on the quantity of troops in the theater and the types of engagements they take part in.

As the name implies, the expenditure rates for historical items are based on historical rates and multiplied by the number of weapons fielded to get the total expenditure. For example, this category would include bullets for pistols. The predicted expenditure rates would be based on actual expenditure rates for similar weapons issued during World War II or the Korean conflict.

Most of the inputs required to calculate the nonmodeled munitions are obtained from Training and Doctrine Command (TRADOC). The automation of the methodologies for nonmodeled munitions is being considered. Although this should be pursued, efforts to reduce the time associated with all the models in the hierarchy must be made to substantially decrease the time required to complete a theater study.

CHANGES TO THE METHODOLOGY

The introduction of highly lethal modern munitions (e.g., Copperhead) has complicated the calculation of ammo rates. The theater simulation is run for a force structure between five and six years in the future, so some of the munitions and/or weapon systems may not yet be deployed. Any delay in their deployment affects the predicted rates for the other munitions in the study, particularly those used for similar missions.

Although all munitions expenditures are in reality affected by budget and production constraints, these constraints may be particularly visible for modern munitions because of high unit costs and/or incomplete or untested production facilities. Allowing unconstrained expenditures at unattainable levels of modern munitions may result in lower than expected rates for other more established munitions.

The above considerations have resulted in CAA running a high tech ammo rates study and a low tech excursion. The only difference is the inclusion in the high tech run of a few of the more sophisticated modern munitions. This is a recent change to the ammo rates process and may take on increased importance from a planning and programming perspective as more "smart" munitions are introduced.

There have also been changes to the Army's doctrine and tactics. The models currently in use, COSAGE and CEM, are not capable of simulating all of these changes. CEM does not include distribution and logistics, envelopment or bypass operations, communications and electronic warfare, detailed rear area operations and combat support, or deep targets. COSAGE does not include distribution and logistics or envelopment/bypass operations. All of the above would take on increased importance on the modern battlefield. However, the effects of their inclusion in the models must be measured in terms of how they would affect the munition expenditures predicted by a theater study.

A different hierarchy of models was developed under the AMIP with the intention that these models would replace the COSAGE-CEM combination for developing ammo rates (both hierarchies include an APP program). The new models, Vector in Commander (VIC) and Force Evaluation Model (FORCEM), would address some of the shortcomings in COSAGE-CEM mentioned above. VIC is designed to be used similarly to COSAGE, to simulate division level combat and pass samples forward to the theater level model FORCEM. The current status of these models for use in the WARRAMP study does not appear to be completely decided.

In my opinion the new models will introduce increased levels of detail in an already overly complex process. Introducing more detailed models is like adding more detail to a calculation for which accuracy of the solution cannot be defined (nobody knows what munition expenditures will be in a future conflict, there are only acceptable and unacceptable predictions). As suggested earlier, real world and statistical uncertainty could greatly affect the final output, which is not currently acounted for. More detail will make it harder to deal with the issue of uncertainty. How will the introduction of new models affect the estimates of munition expenditures (will the estimates become more acceptable) and how well will CAA deal with the effects of uncertainty (an ability that is currently very limited)?

COMMENTS

Calculation of theater ammo rates is a complex and difficult process, the end result of which is expenditure rates for WR munitions in rounds/tube/day. Successive studies are then used to establish expenditure rates for each of the major theaters. These expenditure rates represent the estimate of the WR resupply requirement for the theater modeled. The expenditure rates are expressed for different time periods of the theater conflict for both the low tech and high tech cases. For modeled, historical, and associated munitions the rates are in rounds/tube/day, where tubes refers to weapon system/equipment combinations. For nonmodeled munitions calculated using the bulk methodology, the rates are stated as a function of the authorized troop strength. Both bulk and modeled expenditure rates are based on the average TOE authorization for the time period and hence include the effects of attrition.

The Army has developed a very sophisticated and detailed methodology for estimating its WR theater resupply requirements. The requirements represent an inventory objective for the Army. Because there is no empirical data with which to check the result, it is impossible to determine the accuracy or correctness of the estimate. In fact, there is clearly no "correct" answer to this problem, only answers that are acceptable and unacceptable. The remainder of this section will discuss five issues:

- substitutions
- coordination among the services
- relation to war fighting measures
- the treatment of uncertainty
- responsiveness of the methodology
- summary of comments

Substitutions

The Army may have numerous weapon systems/munitions that can be used against a single target, suggesting that certain munitions may be favored over others because of effectiveness or economic efficiency. In establishing the munition requirement, the Army has stressed effectiveness. To do otherwise would be inconsistent with the assumptions and methodology used by the Army to calculate the unconstrained requirement. It is the procurement process, which enforces the budget constraint, that must take into account the issue of economic efficiency (see Sec. IV). This subsection will summarize the methods used in the requirements process to determine which munition is to be expended.

Substitutions among modeled munitions that are fired from the same tube are handled automatically in COSAGE. Because the results of engagements in CEM are extrapolated as a function of force structure from the COSAGE results, the above statement holds on a theater-wide basis. For direct fire weapon systems, the most effective munition for the target range is assumed available and used. Given the assumption of unconstrained availability to define the requirements process, this is the correct method for determining which direct fire round is expended.

Another aspect of substitution among direct fire rounds is which of several weapon systems should fire at the same target. COSAGE, however, inherently deals with the concept of opportunity to fire. For example, the choice of munition is a function of which weapon system and at what range the target is detected. There is no tradeoff or decision to be made assuming unconstrained munitions availability. This is considerably different from threat based models where opportunity is not modeled and targets are allocated a priori to the different types of weapon systems. By comparison with the Army's methodology based on two sided simulation, the assumptions used to allocate targets in a threat based model are far more aggregate.

For indirect fire munitions, an HE or ICM round is chosen based on which round can achieve the desired effect (lethal area or damage to critical equipment) at the lowest weight. Although this decision rule appears on the surface to be rather complex, the selected round is generally easily determined based on the target (e.g., hard or soft) and the environment (e.g., open area, or woods, or a town). When there is more than one indirect fire weapon system (e.g., 155 howitzer, 8" howitzer, etc.) that can accomplish a fire mission, the deciding factor is the availability of the firing platform.

Another source of substitution is between preferred and nonpreferred munitions fired by the same weapon system. Preferred munitions are those included in the requirements study, munitions for which there is a nonzero requirement. Nonpreferred munitions are munitions that are still in the Army's inventory for which there is no requirement generated. For example, when an improved round is developed for an existing weapon system it becomes the preferred round (because it is generally more effective) and the existing round becomes the nonpreferred round. Nonpreferred rounds can still be fired by weapon systems in the current force structure, so they retain some effectiveness against threat targets.

Nonpreferred munitions are not expended or accounted for in any way in the theater simulation that establishes the WR resupply requirement or in the calculation of the AIIQ requirement. This is the result of the assumption of unconstrained availability of munitions used during the requirements calculations.[6] The methodology for determining the preferred munitions (developing a new round to supersede an existing round) is the cost versus effectiveness that is done during R&D and is not a part of the requirements process.

Nonpreferred rounds usually retain some effectiveness against some targets, if not the target that the munition was originally designed to defeat, as long as the weapon systems that expend them remain in the force structure. Hence, some nonpreferred rounds would in fact be employed if the inventories of the preferred rounds were

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[6]Trying to develop requirements for nonpreferred rounds that may be fired out of existing tubes in the current requirements process leads to a catch-22. Assuming the preferred rounds are more effective than substitutable nonpreferred rounds, the decision rules embedded in the logic of COSAGE would always result in the expenditure of the preferred round. Use of the nonpreferred rounds would occur only if the stockpile of the preferred rounds were exhausted, which is a violation of the assumption of unconstrained availability. This would introduce a programming decision into the requirements process. That is, when should the stockpiles of the preferred rounds be assumed to be exhausted?

depleted, particularly when one considers that the dollar value of the requirement far exceeds the available budget. The Army has recognized that nonpreferred munitions can contribute to sustainability, and substitutability factors are being developed.

Coordination Among the Services

Coordination with the other services with respect to transportation resources (sea and air lift) is taken from the DG and affects the deployment times of the forces to theater. This information is generally included in the directive that CAA receives from DCSOPS.

The only direct Army interface with the Navy is the sea loss factor, which describes the percentage of munitions that are lost in transit from CONUS to theater aboard ships and is applied to all munitions. The requirement associated with the sea loss factor is a small percentage of the total and is independent of the methodology the Army uses to calculate its requirement.

The Army requires considerable coordination with the Air Force to complete a theater simulation. The Air Force has permanently stationed an officer at CAA to aid in the modeling of theater air assets. This could be taken one step further by actually calculating Air Force munition expenditures, sortie rates, red kills, and attrition during a theater simulation and comparing the results with actual Air Force programmed values. That is, the Army should consider the amount of air support that can be counted on after the imposition of Air Force budget constraints. Without such a comparison, it is difficult to assess how well the services are coordinated.

The importance of using actual programmed values for Air Force munitions cannot be overstressed. Because the Air Force acts largely in a support role in land battle, overestimating that support could have serious consequences. This implies that the requirements models of the Army should result in the consumption of ground attack Air Force munitions that closely matches the Air Force's actual stockpiles. Some target overlap may be desirable, but the quantity should be specified based on prudent planning. The lead in this area must come in the form of guidance from the Joint Chiefs of Staff (JCS).

Relation to War Fighting Measures

The Army methodology for estimating the demand for WR munitions is based on a two sided force-on-force model. It treats attrition, equipment resupply, and equipment repair as it occurs and calculates expenditures rates as a function of the time period (0–15, 16–30, 31–60 days, etc.). Hence, the process can be said to relate well to actual combat measures. The requirements process, however, is not a munitions capability assessment tool. The availability of munitions is considered unconstrained and cannot be used to influence success on the battlefield. All that can be definitely said is that if munitions were constrained, as they are in reality, the performance of the blue force would deteriorate (to what extent is unknown).

The problem with the current process is that only the expenditure rates of the munitions are passed forward from the requirements process. No measure of how munitions contributed to combat effectiveness or success is calculated, although killer-victim scoreboards are generated.

Treatment of Uncertainty

The end result of the Army's theater simulation process is a single (or high and low tech) estimate of the demand for munitions associated with the theater conflict described by the model inputs. Many realizations (demands for munitions) are possible for the same inputs because a theater conflict consists of numerous stochastic, dependent dynamic processes. The variability associated with different realizations of the same process has been referred to here as statistical uncertainty. The estimate of the demand used by the Army is based on the mean (central tendency) of the realizations. Hence, the estimate does not account for statistical uncertainty (there is no explicit consideration of confidence interval).[7]

The use of a two sided force on force simulation requires numerous detailed inputs. For example, the inputs used by the Army suggest perfect knowledge of force deployment (when and where), the tactics that will be used, and the effectiveness of the weapon systems (some of which are not yet fielded). Furthermore, the inputs require the same information about the threat forces.

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[7]The combat sample or mean of the stochastic simulation COSAGE is used to calibrate the deterministic model CEM.

The detailed input required for a force-on-force simulation relates to a more important source of uncertainty which will be referred to as *real world uncertainty,* stating that it is not possible to know the exact values of the inputs. Hence, the Army's estimate of the demand for munitions is particularly sensitive to real world uncertainties. Changing the inputs to the model (e.g., the scenario, threat, tactics, weapons performance, intensity of combat, etc.) would result in a different estimate of the demand for munitions (associated with which there would be statistical uncertainty).

The final output of the theater simulation does not address either statistical or real world uncertainty. By using a stochastic simulation to evaluate the division level combat results, the Army has some of the information required to evaluate the effects of statistical uncertainty. Unfortunately, probably because of the tight schedule of the requirements process and the demand for a point estimate (for external rather than internal Army use), information such as that contained in Table 1 is not passed forward.

The current process is too detailed and lengthy to deal with the effects of real world uncertainty. The uncertainty of the process being modeled implies that there are numerous equally valid inputs. Hence, those with different views on the input data will always be able to voice valid criticisms of the results.

Responsiveness of the Methodology

Responsiveness is defined as the amount of time and effort required to complete a theater study or P-study. This topic takes on additional importance in light of the comments made above on uncertainty. If a single (or a low and high tech) estimate of the demand for munitions is deemed inadequate, a method that evaluates the effects of uncertainty is required (e.g., multiple runs of the current models).

Currently, the Army may take more than a year to complete a single theater simulation. Finding reasons for the unresponsiveness of the process is much easier than finding solutions.

The generation of conventional munitions requirements is a very complicated process involving numerous agencies. The first priority in such a process must be to derive a detailed flowchart of all the activities involved. Many, and maybe all, of the subcomponents shown in Fig. 2 have flowcharted their activities, but they must all be tied together to determine the critical path. Other agencies that supply input or use output from CAA must be included. This is particularly important because CAA is so dependent on timely reception of input data from other agencies. As previously mentioned, collecting and waiting for data can account for up to 40 percent of the time required to complete a theater simulation. CAA has recognized this problem and made efforts to expedite the process of data collection, including working with other agencies.

The streamlining of an activity may involve automating steps that are currently done manually. Automation should not result in a loss of detail and may even increase the fidelity of the activity. One example is the linkage programs that have been developed at CAA to aid data transfer between the main models. Another example is that the APP be adapted to calculate the theater-wide requirements based on the K-V boards output directly from CEM. There is, however, a limit to the increase in responsiveness that can be attained by automating the links between the models used in the current process. Eventually, further progress will require that the models be simplified. Judging by the number of inputs and amount of detail in the current models, large increases in the responsiveness of the methodology cannot be made without decreasing the detail in the models. An analysis may be required to determine if the detail lost substantially alters the results of the process.

CAA is under pressure to increase the detail of the simulations to make them as realistic as possible so that commanders are willing to accept the results. The current level of detail, however, does not make sense when one considers the uncertainty associated with the input data and the desired use of the end result. Unnecessary detail in the computer simulations may substantially slow the overall process because there is always competition with other projects for computer resources. A costly solution to the above problem is to get a bigger, faster computer, but that is only a temporary solution. Also, a faster computer will not help collect any additional input data required to add detail to the model.

Another factor that greatly affects the responsiveness of the requirements process is the learning curve associated with operating a complex set of computer programs and methodologies. As analysts become more familiar with the process, the time required will decrease and the time for analysis will increase. This is mentioned because the Army requirements process seems to be in a state of almost constant revision, which generally increases rather than decreases the detail in the models.

The introduction of new models developed as part of the AMIP may cause further decreases in the responsiveness of the methodology because of the learning curve effect. If it is deemed that the new models are essential for the acceptance of the munition requirements, then every effort should be made to implement them in parallel with the current process. If this is done, the differences between the results can be explained. Sudden unexplained changes in the expenditure rates may cause a lack of confidence in the new methodologies. If there is no substantial change in the results, the simpler models should be retained.

The current methodology is unlikely to take into account the effects of uncertainty even if it were considerably streamlined. The current process is too complex and there are far too many inputs for it to be possible to account for the effects of real world uncertainty. It could, however, produce a single estimate of the demand in a more timely manner. This would allow more time to analyze the output of the models. Eventually, a faster running methodology (model or set of models) that replaces or runs in parallel with (perhaps calibrated by) the current process will be needed to evaluate the effects of uncertainty.

Summary of Comments

Below is a summary of the more important comments on the Army's methodology for predicting the consumption rate of WR munitions.

- Under the current assumptions, the models used to estimate the demand for munitions are not capable of addressing the availability of nonpreferred rounds. Some methodology needs to be developed so that the existing inventories of nonpreferred munitions can be accounted for when procurement decisions are made.
- The models used to predict the wartime demand for munitions should be used to generate a measure of combat effectiveness for the major munitions.
- The Army must make a judgment as to the amount of detail required in models used to predict the wartime demand for munitions for use in planning munition procurement.
- The uncertainty associated with predicting the wartime demand for munitions should be explicitly represented in and output from the requirements process.

The inability to deal with uncertainty is, in my view, the greatest failure of the current requirements process.

III. CALCULATION OF THE TOTAL FORCE MUNITION REQUIREMENTS

The previous section described how CAA simulates a theater conflict to predict the WR munition expenditure rates and is denoted in the overall process as the Programming Study box in Fig. 1. The requirement for munitions, however, is not limited to resupply for a single theater, but is a total force requirement. This section will describe how the expenditure rates from the theater simulation described in Sec. II are used to derive the total force WR munition requirements, referred to as the Army Acquisition Objective (AAO). This section will also describe how the peacetime losses are calculated. The peacetime losses plus the AAO equal the total force munition requirement.

The war reserve resupply rates, the weapons density and deployment, mobilization training, AIIQ, additive operational projects, and war reserve stocks for allies (WRSA) are included in the calculation of the AAO that represents the total WR requirement. The above information is prepared by different agencies and submitted to Research, Development, and Acquisition (RDA, SARD-RPI), which provides guidance and control for the calculation done at the RDAISA computation center. The whole process is referred to as the Army Procurement Requirements (APR) computation methodology. The equation for computation of a munition AAO is given below.

$$AAO = \sum_{LIN} \sum_{theater} \sum_{period} [rate \times density + AIIQ] + WRSA + OPS\ proj + Mob\ trng$$

The war reserve resupply rates are established by time period and theater for each equipment, denoted by a line item number (LIN),[1] that expends the munition. In the above equation, rate × density accounts for the resupply requirement determined by the programming study. In addition to the predicted resupply requirement, the AIIQ is added for each LIN. WRSA represents an allied resupply requirement that is generated external to the process described here. Finally, mobilization training requirements and

[1]The same equipment (LIN) may have several weapon systems (e.g. helicopters have several weapon systems) and the same weapon system may be deployed on several different types of equipment (e.g. TOWs may be deployed on sever .l different equipments). The rate and densities (and AIIQ) in the above equations would be subscripted based on the LIN, time period, and theater and summed to determine the total AAO for a particular munition.

OPS projects are added. Each of the above, except WRSA, is explained in more detail below.

DCSOPS, the proponent for the theater study, also chairs the committee that reviews and gives final approval to the theater expenditure rates. This process is represented as the Review and Approval box that immediately follows the Programming Study box in Fig. 1. The purpose of the review is to insure that DA staff evaluate the munition expenditure rates, rather than accepting whatever output the computer generates without questioning it. CAA may advise DCSOPS to be particularly careful in reviewing the rates for selected munitions because of a lack of confidence in the model inputs or the manner in which the munitions were employed.

After review, the rates for the current study can be applied directly to that theater. Changes in weapon system densities are handled independently of the expenditure rates. Since there is a substantial delay from the initiation of a study and its completion and some uncertainty because the study is for a predicted force structure for the last year of the POM, the estimate of the weapon densities may have already been revised for the theater being simulated before the ammo rates study is completed. Although large variances will invalidate the rates of current as well as outdated studies, the estimate of the force structure generally does not change too drastically year to year.

The directive provided by DCSOPS to CAA for the theater simulation is part of an illustrative scenario taken from the Defense Guidance. Ideally each of the theaters included in the illustrative scenario would be simulated to determine the appropriate rates. This is not possible, however, because the theater simulation process is very time consuming, and usually only one theater simulation can be completed in a year. Also, the Army must plan for deployments to other theaters even if they are not identified as areas of conflict in the illustrative scenario. Hence, there are many possible theaters and only the largest and most likely areas of conflict are ever simulated by CAA as part of the WARRAMP process. DAMO-FDL uses the rates from the current study and past studies to determine the total force WR resupply requirement that includes all theaters. All forces have a unique deployment associated with the illustrative scenario of the DG. This rules out the possibility of generating requirements for forces in more than one theater. This process is shown as the box labeled Total Force P-Rates in Fig. 1.

If older studies exist for other theaters, they will be reviewed for applicability to the current POM. Changes that may invalidate older study results are the introduction of new munitions and/or weapon systems, changes in the threat, or lack of confidence in the results because of outdated input data (e.g., pKs and tactics). If no study exists, or the most recent study is considered outdated, then the rates must be established based on an existing study for a different theater. The majority of the requirements are associated with the theaters that are simulated. The other theaters can be assigned rates based on similarities in terrain, threat, etc., to the theaters that are simulated.

In addition to determining the munition expenditure rates for each of the theaters, it is also necessary to determine the average authorized weapons densities for each of the time periods. The weapon densities are determined from the Structures and Composition System (SACS) developed by the USA Force Development Support Agency (MOFD-FAS), a field operating agency of DCSOPS. The Force Accounting System (FAS) contains the deployment times for all active and reserve forces and the initial issue quantity (IIQ) of equipment by line item number.[2] The logic leading to the SACS is shown in Fig. 1 as the boxes leading to and including the box labeled LOGSAC. From the SACS it is possible to calculate the average authorized weapons density for each time period and theater. The weapon system/equipment density multiplied by the appropriate expenditure rate gives the WR resupply requirement. The expenditure of a particular round is determined by summing over all weapon system/equipments that use that round. The round expenditures are summed over all theaters and expressed as a function of the time period (e.g., WR 0–15, WR 16–30, etc.).

AIIQ requirements are based on the number of rounds that are stored on board each weapon system/equipment and dedicated vehicles (referred to as the combat load). The munitions included in the AIIQ are determined based on inputs from the appropriate schools and the results of the rate studies. Examples of AIIQ are the munitions on board a tank or the munitions on board a self-propelled howitzer and its dedicated transport vehicle. Hence, the AIIQ requirement is a function of equipment design. Equipment is designed to accomplish a particular mission. So, just as the capacity of the fuel tank is determined in light of the mission to be accomplished, the number of rounds stored on board (or AIIQ) is determined to reflect the need to operate without munition resupply for some period of time.

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[2]The ammo rates are calculated by CAA for each weapon system/equipment (LIN) combination.

The AIIQ for each equipment is multiplied by the number of equipments and added to the munition requirement. The AIIQ requirement is calculated by time period and theater based on equipment deployment schedules given in the FAS. This is true whether the equipment is deployed as a replacement to an existing unit or as part of a new unit. Unlike the war reserve resupply rates, the AIIQ is constant and is counted only once for each equipment at its time of deployment. The AIIQ is usually summed over all theaters and time periods and expressed as a single requirement.

Any expenditures of munitions during the theater simulation are counted as part of the war reserve resupply requirements. Resupply for expended munitions is instantaneous, because the munition logistic system is considered completely unconstrained. In reality, resupply is not instantaneous. That is, a tank with an AIIQ of 40 rounds that expends 10 rounds and is then attrited may or may not have had time to resupply its munitions to the full AIIQ. The ten rounds expended, however, have already been counted as part of the resupply requirement. Hence, expenditures are counted whether or not the equipment would survive to require resupply. Because the AIIQ is counted up front, there is no need to add the rounds lost on board when the equipment is attrited (e.g., K-kill).

Each equipment should have a full combat load before deploying to engage the enemy, which is the reason for adding the AIIQ to the requirement. For example, consider 10 equipments that each expend 10 munitions per day. This suggests that an inventory of 500 rounds should last five days. But if each equipment has a AIIQ of 40 rounds, then 400 of the rounds are taken when the equipments initially deploy leaving only 100 rounds for resupply. The rate of expending 10 munitions per day was derived by a simulation that averaged over all the equipments of that type in the force structure. In reality, some equipments will expend their munitions at a rate faster than 10 per day and require resupply. Theoretically AIIQ could be returned, so the equipments that are expending at less than 10 rounds per day would have to return their unused rounds to insure that the inventory of 500 rounds lasted five days. Of course, this would result in a very inefficient logistical system and it would be impossible to predict which equipments would risk encountering the threat with less than a full AIIQ of munitions. Adding the AIIQ to the requirement is also related to the issue of maldistribution of stocks, which is not treated in the models (distribution and logistics are assumed perfect) used to derive the resupply requirement. In conclusion, the Army properly adds the AAIQ, in addition to expenditures, to the requirement.

Operational projects requirements provide munitions for projects that support special contingencies, operations, and war plans. An operational project may consist of requirements that are in addition to the AIIQ and resupply requirements. For example, a specific unit may be assigned the project of destroying a bridge. Then the particular charge or explosive to be used may be assigned as a special requirement separate from the total force requirement for that munition. That requirement would then be set aside and maintained by DESCOM for that particular unit apart from the overall stockpile to insure availability for the intended use. These requirements are only treated in an additive manner when specific contingency plans would require a large percentage of a munition's total stockpile. Common items (e.g., artillery rounds) are assumed available from the general stockpile, so additive OPS project requirements are limited to less commonly available munitions. The additive requirements for OPS projects account for less than 1 percent of the total requirement.

The mobilization training requirement shown in the equation above uses a methodology that is also used for peacetime training. Peacetime training is not part of the AAO, which represents the total WR requirement. It is accounted for in a category called peacetime losses (see Fig. 1), which also includes test requirements and damage to inventories.

The training directorate of DCSOPS (DAMO-TR) calculates both mobilization and peacetime training requirements, which are calculated based on readiness measures established by the Standards in Training Commission (STRAC). The STRAC prescribes the standards and training resources required to achieve different training readiness condition (TRC) levels (A, B, and C).

Peacetime training requirements are calculated by multiplying the resources required to maintain active duty troops at level A and reserve units at level C. Even given sufficient fiscal resources to purchase the training munitions it may not be possible to maintain active and reserve units at their appropriate TRC because of other constraints (e.g., range availability). Rather than lower the standards, the peacetime training requirement is further broken down into level 1 and level 2. Level 1 is based on historical usage patterns, which reflect constraints such as range availability, rotation frequency, etc. Level 2 is the difference between level 1 and the munition resources required to achieve the standard. If there are no other binding constraints, the level 2 requirement is zero and the level 1 requirement is equal to the munition resources required to achieve the standard.

Many training-unique rounds that are less expensive and/or safer to use than their WR counterparts have been developed. Because there are no WR stockpiles to draw off in case of higher than predicted consumption, these munitions have requirements referred to as Depot 1 and Depot 2 that are calculated as 55 percent of the level 1 and level 2 requirements respectively. Hence the Depot requirements for training-unique munitions represent a 200 day supply (200/366 = 0.55) and are the only stockpile available for those munitions because they are not part of the WR inventory.

There are mobilization training requirements for both training-unique and WR munitions. Mobilization training requirements are calculated as the quantity of munitions required to raise reserve and recruit units to level A training in accordance with STRAC standards or the highest level that could be obtained based on mobilization and deployment dates, whichever is less.

The total force requirement is the sum of the AAO and the peacetime losses.

The Army generates a global requirement by determining a force deployment schedule (where and when) for all the active and reserve units and multiplying the weapon densities by the appropriate munition expenditure rates. The force deployment schedule is based on the illustrative scenario of the DG. The munition expenditure rates are based on the theater simulation process described in the previous section. Added to the predicted expenditures are AIIQ, peacetime losses, etc. The final requirement represents an estimate of the inventory of munitions that would be required by the Army.

There is considerable statistical and real world uncertainty associated with the munition expenditure rates. The expenditure rates are represented in the resupply portion of the requirement. There is considerably less uncertainty, however, about the other components of the total force requirement (AIIQ, WRSA, mobilization training, peacetime training, and test).

There is also real world uncertainty about the force deployment schedule given in the FAS. The use of a global requirement (all the Army's active and reserve forces are engaged) results in a conservative, or "reasonable worst case," estimate of the inventory objective. The implicit assumption is that using a very demanding or "worst case" scenario implies that it is no longer necessary to account for uncertainty (because most other estimates of the requirement would be less demanding).

IV. PROCUREMENT

The previous sections provided an overview of how the unconstrained requirement for munitions are calculated, both the AAO and the expected peacetime losses. The discussion in this section will center on how the Army uses that information to decide what munitions to procure. The procurement process involves many individuals and agencies, and it is not well documented. Hence, the process is rather fluid depending on institutional memory and the viewpoints of those involved.

This Note has provided a description of how the unconstrained requirement for munitions is calculated. Similar methodologies exist to define the requirement for other items (weapon systems, combat support, personnel, etc.), the different categories of which will be referred to as programs. The requirement minus the current asset position (e.g., inventory of munitions) defines the shortfall for each program. The shortfalls of the programs are used along with information on Army priorities and overall funding limitations to allocate funds to each of the programs. This Note will not deal with how the overall funding level is determined for the munitions program. Instead, the discussion will proceed under the assumption that a funding level has been set for the munitions program. The dollar value of the shortfall in the munitions program has historically far exceeded the funds allocated. Hence, the process to be described is the allocation of funds among the different munitions.

Each munition falls under the management of a major subordinate command (MSC) of the Army Materiel Command (AMC) and a Program Executive Office (PEO). Missiles are managed by the PEO Missiles and the Missile Command (MICOM). Ammunition is managed by the PEO Ammo and by the Armament, Munitions, and Chemical Command (AMCCOM). HqDA provides the PEOs with the AAO for each item managed, the Total Obligation Authority (TOA)[1] for the group of items managed by the PEO,[2] and guidance or priorities on how the TOA is to be allocated among the items.

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[1]The AAO is the total war reserve requirement for an item and as such is expressed as a quantity. TOA refers to the planned level of funding for the group of items under the management of the MSC and is expressed in dollars.

[2]The priorities set by DA may be a suggested TOA for each item under the PEO's management. The PEO through the MSC, however, may have to alter the requested TOAs to reflect production constraints.

DA must include its priorities along with a statement of the requirement, because the dollar value of the shortfall far exceeds the available budget.

The MSCs make use of the current and projected asset position (stocks in or coming into inventory)[3] and expected peacetime losses (training, test, etc.) along with the AAO to determine the portion of the requirement that is unfunded. Beause it is not possible to fund the entire AAO of each item, it is necessary to allocate budget and production resources to satisfy the shortfall. The procurement plans are spread over the five years of the POM. The guidance provided by HqDA reflects HqDA's priorities on what items are to be funded subject to the budget and production constraints actually enforced by the MSC. As is usually the case, the resources are limited, and each MSC must make tradeoffs to arrive at a procurement program. Hence, at the MSC level, the procurement problem is one of allocating scarce production and funding resources to purchase the best mix of items under the MSC's management. Each subproblem solved at the MSC level then theoretically provides feedback to HqDA, which may result in a reallocation of resources among the MSCs.

The above process operates in a very dynamic environment. Total budgetary authority for the Army is under continual revision by Congress, which sends ripple effects through the system into each of the MSCs. Also, the information required to complete the decision process is not always available. For example, if there is a delay in developing the new rates, the AAO for munition items must be based on previously developed rates until the new ammo rates are ready. Each MSC may require a different amount of time to apply micro management to its items. As a result, the iterations between HqDA and the MSCs do not follow an orderly iterative process, and many processes actually operate concurrently. For example, the original demand for POM submission may be followed by updated demands or required responses even before the initial POM is ever completed.

The above two paragraphs provide a very brief overview of the environment that the MSCs operate under. To summarize, the MSCs are responsible for providing management for their items in the form of enforcement of production and budget constraints while taking into account HqDA priorities. HqDA provides priorities because the dollar value of the requirement far exceeds the available budget. The MSC

[3]The current asset position is generally computed by the MSC because they have more up-to-date estimates of production.

management should be carried out in a timely and responsive manner that will provide HqDA the feedback required to properly allocate funding resources.

The rest of this section will deal only with one particular MSC, the Armament, Munitions, and Chemical Command (AMCCOM), and how it manages conventional ammunition. HqDA provides the AAOs and guidance for conventional ammunition to AMCCOM[4] for enforcement of the budget and production constraints. AMCCOM first develops an unconstrained POM that on paper funds the entire AAO and yearly estimates of the peacetime losses, while taking into account the current inventories. This unconstrained plan is then adjusted to reflect budget and production constraints. The TOA (the available funding) is the most visible of the constraints because the unfunded requirement has historically been far in excess of the budget for ammunition.

AMCCOM is also responsible for scheduling production of selected conventional ammunition for the other services. AMCCOM receives the procurement quantities from the other services for the ammunition it manages. That is, the other services develop their AAOs and enforce their budget constraints, whereas for the Army, AMCCOM uses priorities provided by DA to enforce the budget constraint by determining what mix of munitions to produce.

AMCCOM must enforce a very complex set of production constraints. The production constraints include limited line capacities, the desire to balance plant staffing at government owned facilities, limited component availability, maintaining a warm production base, avoidance of wide swings in production, and observing Army inventory targets in light of the competing demands of the services. AMCCOM must often act as broker between the services to reach an agreement on how to share production resources for common items. HqDA lacks visibility of these detailed constraints occurring at the operational level, and there are invariably conflicts between the priorities set by HqDA for the Army buy and the production constraints.

Historically, the production required to satisfy the other services ammunition buys has been scheduled first. This means that resources are more constrained when the Army requirements are translated into procurement quantities. Also, since the Army buy represents over 50 percent of the total production, it has been used to a large degree to

[4]Under the reorganization, it appears that the total force ammunition requirements will be provided to the Program Executive Office for Ammunition (PEO-AMMO), which may then participate in formulating priorities before tasking AMCCOM to reflect those priorities in its POM development.

level out the work load among the different government owned plants. This leads to conflicting objectives between stable plant loading and the priorities stated by DA.

In the past, AMCCOM has used very labor intensive and time consuming methods to enforce the production and budget constraints. This resulted in considerable effort being expended during POM development and limited the "what if" analyses that could be done to provide feedback up the chain of command. AMCCOM is developing decision support and data management tools for use during POM development in an effort to correct the deficiencies mentioned above.

DA has made use of Force Packages (FPs) to convey its priorities to AMCCOM. The FPs act as a decision support tool by stratifying the unfunded requirements for each munition in a preemptive funding sequence. The packages consist of categories such as level 1 training, depot 1, OPS projects, AIIQ, and time periods of war reserve consumption. Many of the packages involve categories for which it is difficult to quantify tradeoffs (e.g. training versus war reserve). However, the concept of preemptive packages has also been employed to break up the war reserve requirements. As a result, the priorities set by DA on what constitutes the "best buy" of war reserve munitions have centered on maintaining balanced sustainability in the major munitions.

Sustainability has been measured by the DCSLOG in days of supply (DOS), which is calculated by dividing the quantity of a round in stock by the consumption rate in rounds per day. This can be related back to the CAA developed rates. For a given theater and time period, weapon system density times the munition expenditure rate in rounds/tube/day results in rounds/day. The munitions mix that this provides has been optimized for rounds modeled in COSAGE, which represent the bulk of the war reserve resupply requirement. That is, COSAGE chose the best pK direct fire round and the most lethal indirect round for the opportunities that occurred in the simulation for the unconstrained case. The optimality of the mix of munitions chosen by COSAGE does not necessarily hold for the constrained case, which includes budget, production, and logistic constraints.

Currently, the Army is trying to develop measures of sustainability that are more closely related to combat performance than DOS—for example, effectiveness against major threat systems and/or ability to perform critical missions. Such measures may then be issued as guidance to AMCCOM.

Any measure that is used to set the priorities of how to procure munitions must deal with the considerable uncertainty associated with a wartime environment. For example, the rates developed at CAA are only estimates. I believe there is considerable uncertainty associated with those rates. In that case, buying an equal supply in terms of DOS does not result in equal sustainability.

The POM developed by AMCCOM is reviewed by representatives of each of the services. This review may require considerable changes to the program because of the aforementioned conflicting objectives.

After the initial review, the POM is submitted to various Hq POM/Budget panels and eventually to OSD and Congress. During all of these reviews issues may be raised that require prompt response and possible reworking of the POM. Hence, it is necessary for AMCCOM to have a responsive methodology.

After the POM has been accepted, the first two years of the POM are prepared for budget submission. This involves updating costs and quantities and making sure the production schedule is executable.

The munition requirement is defined assuming no constraints on the munition logistic system. That is, when a weapon system expended munitions in COSAGE the munitions were assumed to be available. Munition expenditures that occur during engagements in CEM are based on force structure extrapolations of the COSAGE results. Hence, the availability of munitions is not constrained in CEM. When making procurement decisions, however, it is necessary to take into account the logistic constraints that actually exist in each theater. Currently, there is not a formal mechanism for including munition logistic constraints in the munition procurement decision process.

As well as deciding what to produce in the existing facilities, AMCCOM has the responsibility of maintaining and investing in the government owned portion of the ammunition production base and insuring that the national production base is adequate. This is accounted for by splitting the total TOA for ammunition between production of ammunition (for war reserve stockpiles and peacetime losses) and investment in the production base.

The requirements process is the primary source of information used in making procurement decisions. Listed below are several disconnects between the requirement and procurement processes.

- The projected consumption rates that are calculated in the requirements process do not consider the effects of real world constraints on ammunition logistic capacity, budget resources, and production capacities. These assumptions should be reviewed to insure that the inclusion of more realistic constraints during the calculation of the rates would not result in the procurement of a substantially different mix of munitions.

In the procurement process the assumptions above must be dropped and more realistic values used. For example, when one is deciding the quantity of a munition to buy, the cost and production capacity must be taken into account.

There are numerous examples of disconnects between planning and procurement because of the assumptions made above. For example, it may not be possible to increase the inventory of a munition that has been recently introduced, is expensive, or for which production capacity is limited. The unavailability of that munition could affect the projected consumption rates of munitions that defeated similar targets. The high and low tech runs made by CAA are an example of how the Army attempts to deal with this problem.

As another example, the assumption of unconstrained ammunition logistics may result in projected consumption rates that, because of high volume and/or weight, the ammunition logistic system is incapable of delivering.[5] In practice, the firepower that the Army could bring to bear on a threat in a timely manner could be considerably degraded because of the mix of munitions in the inventory compared with an inventory established in light of real world logistic constraints. The pertinent question in each of the above examples is whether changing the assumptions in the requirements process would improve ammunition planning and ultimately lead to better procurement decisions.[6]

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[5]Although the munition requirements process is used to promulgate logistic guidance, the support establishments must go through their own budgeting process and do not always reach the goals and objectives stated in their requirements.

[6]The requirements process is used for at least two different levels of budget decisions: first, to determine how much should be allocated to the munition program; second, given a budget for the munition program, how it should be allocated among munitions. The former dictates that the requirement should be calculated in an unconstrained fashion. Given the realities of the budget process, however, the latter can be of more importance.

- The methodologies used to procure munitions treat the point estimate provided by the requirements process as the de facto demand.

The current methodology for estimating the demand for ammunition makes use of a single worst case scenario and expected value estimates of the inputs required to describe ammunition consumption in that scenario. Although this makes the problem analytically tractable, the result is a single estimate[7] of the demand for ammunition (expected value with no variability information). By focusing on a single estimate, ammunition planners increase the risk of large differences between the projected ammunition consumption rates used for planning and procurement and the inventories desired in an actual contingency (possibly with catastrophic results).[8]

- The worst case scenario used by the Army to generate the requirement implies that it is not necessary to account for the uncertainty associated with the demand when making procurement decisions.

Some would argue that the global (worst case or conservative) nature of the scenario used in establishing requirements implies that no other scenarios need to be analyzed. However, the budget for the procurement of munitions falls well short of achieving inventories equal to the stated requirements. Using a global scenario to generate the requirement does not substitute for analyzing alternative scenarios (hence accounting for real world uncertainty) unless it is possible to fund the requirement associated with the global scenario (which still may not be the most economically efficient way to meet the demand). Also, it may be possible to devise scenarios of far less intensity than those used by the services that would result in more demanding requirements for some munitions.

- The final output of the Army's requirements methodology is a single point estimate of the demand for war reserve munitions.

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[7]That is, the result is a single expected value estimate of the demand rate for each weapon system/round/target/period combination.

[8]Munition inventories have an inherent robustness because commanders will adjust their tactics and doctrine to best match the munitions available. The question is: How much is combat effectiveness degraded by not having a better mix of munitions?

Burying whatever effect uncertainty has on the requirement in a point estimate (rather than explicitly identifying and analyzing the sources of uncertainty) has the unfortunate effect of making buying out the variability/uncertainty the only option (investing in larger inventories of munitions).

- The procurement process does not stress other investment options to respond to the variability and/or uncertainty associated with the requirements.

This is another effect of having the only information be a point estimate of the demand. As a result, it is not possible to evaluate other investment options, such as the robustness of the current inventories, delivery systems, or production base. This kind of analysis would require an estimate of more than one of the potential demands or some measure of the variability associated with the estimate provided. For example, whether to invest in production capacity or stockpile munitions will depend not only on the point estimate of the rate at which a munition will be expended, but also on the variability or uncertainty associated with the estimate.

In summary, the assumptions used to define the requirement result in a process that does not provide enough information to decisionmakers who must allocate resources to meet the the possible demands for munitions in light of real world constraints. Currently, the Army uses far too much effort and analytical resources to calculate a single estimate of the unconstrained munition requirement and too little to determine how to effectively allocate resources to meet the demands that may occur.

Even if the single estimate of the wartime demand for munitions output from the current requirements process were in fact the demand that occurred, it is not clear that the current process used to decide which munitions to produce would result in the most effective inventory. Hence, a new methodology is suggested for allocating funds to munitions. The methodology could be generalized to include any information output from the requirements process about the uncertainty in the demand for munitions (resulting in a more robust and combat effective mix of munitions).

The Army has used force packages (FPs) to stratify the requirement. Ordinal priorities are then assigned to the FPs to establish the funding. This is a very useful decision tool when dealing with categories that are hard to trade off (war reserve versus training). The single category of war reserve resupply has also been disaggregated into several FPs. AIIQ is accounted for in a separate FP. Several FPs are defined with respect to a given time period and represent the resupply requirement for that period. The structure of the war reserve FPs has been used to allow funding decisions to stress equal sustainability in the major munitions. Hence, the primary method of setting priorities for the Army's WR munitions buys has been days of supply (DOS). The criterion of equal DOS can be traced directly back to the rates as a function of time established during the theater simulation(s). Although other factors are used in determining what mix of munitions to procure, they are not well documented or formulated as a structured decision support system. Of course, the criterion of equal DOS is subject to the production constraints.

There are several benefits realized by using FPs and equal DOS as the primary criterion for establishing funding. It provides some structure to a seemingly intractable problem. With regard to WR resupply, the munition mix used was optimized with respect to effectiveness in COSAGE (see subsection on substitutions). Hence, maintaining equal sustainability can be argued to retain the most effective combined arms force (for a limited period). The above can be thought of as stressing the effectiveness of the forces during the critical early stages of a conflict.

There are two problems with DOS as a measure for establishing funding priorities. First, it does not provide a means of compensating for the assumption of unconstrained availability used to generate the requirement. That is, the resulting mix is optimal only under the assumption that there are no constraints on the available budget, munition logistics system, or production base. Second, there are so many sources of uncertainty in the simulations used to establish the rates that there will always be legitimate criticism of the predicted expenditure rate for a munition. Without a measure of that variability, the estimates of sustainability using the measure of DOS are questionable.

The above suggests that it may be possible to improve upon DOS as the primary criterion for funding decisions. The Army has recognized the limits of DOS (perhaps not for the reasons stated above) and is considering the use of criteria other than DOS for use in procurement. Such a measure should include the effectiveness of munitions against major threat weapon systems and/or toward the completion of necessary missions. One obvious source for such a measure is the theater simul ons used to determine the WR resupply requirement. Hence, it becomes important to increase the amount of analysis done when generating the requirements and the information provided to the procurement process. CAA has already done some development in this area.

Unfortunately, because of their preemptive nature, there are no formal mechanisms to establish tradeoffs between the different WR resupply FPs, although this is done currently on an informal basis. Hence, all WR resupply requirements, which represent the bulk of the Army's requirement, should be combined into a single category and organized as a function of discrete time periods (0–15, 16–30, 31–45, . . .). Then a discount factor could be used to stress the early stages of a conflict. The result can be thought of as FPs with cardinal rather than ordinal rankings. The cardinal ranking of a munition will be a function of the current inventory and whatever measure of effectiveness the Army finds suitable. That is, the sustainability of the current stockpile will determine the discount factor and the period for which the munition effectiveness should be evaluated. The cardinal weighting associated with procuring a munition for a given time period will allow tradeoffs between time periods.

If such a scheme were developed, the separation of management responsibilities (and funding) between MICOM and AMCCOM would make it difficult to establish the tradeoffs between munitions with essentially the same targets and/or missions. For example, consider the anti-armor mission area with TOW and HELLFIRE under the management of MICOM and 120 and 105 mm tank rounds managed by AMCCOM.

Existing nonpreferred munitions, although not considered in the requirements process, must be considered in the procurement process. For example, if a nonpreferred munition is determined to be 50 percent as effective as the preferred munition, using the FP structure and the measure of DOS, one would calculate an equivalent DOS (EDOS) as (quantity of preferred munition) + 0.5 × (quantity of nonpreferred munition) divided by the appropriate rate(s). That is, two of the nonpreferred munitions are judged equivalent in sustainability to one of the preferred munitions. This does not take into account the fact that the opportunity may not exist to deliver two rounds of the unpreferred munition (e.g., because of attrition or rate of fire). A decision to buy more of the preferred munition just increases the EDOS and does not take into account that the preferred munition would be used earlier in the conflict. By using a time discounting scheme, rather than a preemptive scheme, it would be possible to evaluate the difference in effectiveness between having greater numbers of the preferred munitions in the early stages of a conflict.

The development of a cardinal effectiveness measure for munitions would make it easier for the MSCs to evaluate how well they are translating DA priorities into production schedules. The obvious next step would be to use such a measure to find the "best" feasible (with respect to the production and budget constraints) mix of munitions.

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