Estimating Conventional Munitions Requirements

Toward Improved Processes

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The research described in this report was sponsored by the Assistant Secretary of Defense (Production and Logistics). The research was conducted in RAND's National Defense Research Institute, a federally funded research and development center supported by the Office of the Secretary of Defense and the Joint Staff, Contract No. MDA903-90-C-0004.

ISBN: 0-8330-1159-6

The RAND Publication Series: The Report is the principal publication documenting and transmitting RAND's major research findings and final research results. The RAND Note reports other outputs of sponsored research for general distribution. Publications of RAND do not necessarily reflect the opinions or policies of the sponsors of RAND research.

Published 1991 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

R-3872/1-P&L

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PREFACE

This is the final report of the project, "Review and Improvement of Munitions Acquisition Process." The research was aimed at improving DoD processes for establishing conventional munitions requirements. It provides an overview of the methods the Army, the Navy, the Air Force, and the Marine Corps use to estimate requirements, and it proposes some improvements. The results summarized here should be of interest to munitions planners in all the services, the Joint Staff, and the Office of the Secretary of Defense.

This project was sponsored by the Assistant Secretary of Defense for Production and Logistics. The research has been carried out in the Acquisition and Support Policy program of the National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and the Joint Staff.

SUMMARY

This study examines and critiques the models and criteria used by the military services to compute their requirements estimates. The research described here reports on two tasks. The first is a survey of the present estimation processes. The second is an assessment of the importance of problems observed in the existing requirements process.

CURRENT ESTIMATION PROCESSES

Most, but not all, munitions planners and models distinguish between "threat munitions" and "level-of-effort munitions" according to the constraint that limits munitions requirements. Threat munitions requirements are constrained by the number of enemy targets to be destroyed; when all estimated targets are destroyed, the requirement is satisfied. (Limits on the ability of U.S. forces to find the targets and deliver the munitions are not considered.) Level-of-effort munitions requirements are estimated on the assumption that the operable constraint is the number of tubes, barrels, shooters, or sorties that U.S. forces can generate. (Limited numbers of targets are not considered.) This distinction is arbitrary; it is used to simplify the calculations.

Nonetheless, the processes for preparing munitions requirements are lengthy. In general, inputs are collected and reviewed and models are refined each planning cycle. Initial results are then reviewed by various levels of service budgeters and policymakers. Most of these processes take close to a year to complete, some take longer. Moreover, munitions planners are continually modifying the processes.

MUNITIONS REQUIREMENTS MODELS CURRENTLY IN USE

The four armed services have recently used seven methodologies to establish their requirements for conventional munitions. The Navy and the Air Force each directly apply the distinction between threat and level-of-effort methodologies. The Marines make a similar distinction but refer to their models as "target-oriented level of effort" and "shooter-oriented level of effort." The Army employs only a theater simulation to make the requirements estimates for all their conventional munitions. Regardless of the format of the calculation, each methodology embraces a variety of submodels, pre- and post-processors, and logics. In general, the differences among the methodologies must be judged to be greater than the similarities.

Each model described in this report has a distinct character. The Air Force threat model, for example, has the advantage of simplicity. It uses an explicit confidence level and checks to insure that the Air Force can deliver the required munitions. The Navy threat model is more complex; to its credit it treats some statistical uncertainties and considers some aspects of the resupply chain. But both the Air Force and Navy threat models assume complete foreknowledge of the number of targets to be encountered and which specific U.S. weapon systems will meet them. There is no attempt to time phase the combat. All weapon firings are treated as if they will be statistically independent. Similar comments apply to the Marine Corps target-oriented level-of-effort calculation, although combat is time phased in this model.

The diversity among the level-of-effort models (including the Marine shooter-oriented level-of-effort model) is greater. The Air Force employs a sequence of four large models to arrive at level-of-effort munitions requirements; the Navy uses a family of 13 routines. Both contain a "least cost to kill" screen that affects the requirements for a subset of the munitions. Both processes insure that munitions requirements are consistent with other Air Force or Navy planning. Weaknesses of these methods include inappropriate application of the "least cost to kill" criterion, failure to consider many uncertainties, and highly variable results. The Marine "shooter-oriented" method includes a calculation of the "troop population," but ultimately it has little effect on the resulting requirement.

The Army theater simulation is a complex, detailed, and time-consuming process that must be repeated separately for each theater. As a two-sided simulation, the process does a good job of keeping track of both the number of targets to be destroyed and the Army's ability to bring munitions to bear on them. Time-dependent processes are modeled. The output of the process can be readily related to combat outcomes. However, the Army simulation uses many inputs, a large number of them uncertain. The process is so detailed that it takes at least a year to complete the estimate for a single theater.

VARIATIONS IN ANALYTICAL METHODS

The approaches described here vary significantly in six ways. One is the basic methods used. Three of the services make some sort of threat and levels-of-effort distinction. The Army uses a wholly different approach.

The second variation is the level of detail in the scenario used to depict combat. The Army employs a detailed scenario; the other models, particularly the threat routines, use only a rudimentary scenario representation.

A third distinction is between expected value results and higher confidence level estimates. The Army simulation, the Navy and Air Force level-of-effort methods, and the USMC shooter-oriented level of effort calculation all yield expected value requirements. The other processes all yield higher confidence level estimates.

A fourth variation was found in the treatment of resupply. Only the Navy threat calculation and the Marine target-oriented model consider resupply; and in those, resupply is assumed to be instantaneous.

The role of cost competition provides a fifth dimension of variation. It is present in the Navy and Air Force level-of-effort calculations but not elsewhere.

The last major variation is in the use of target values. The Air Force level-of-effort calculation routinely uses explicit assumed target values. The Army process values targets in low level calculations. All the other routines use only the numbers of targets, treating all as if of equal importance.

STRENGTHS AND WEAKNESSES

Each model has a distinct set of strengths and weaknesses. No across-the-board strengths were identified.

The inability of the models to reflect operational, weapon system, and logistics uncertainties was judged to be a considerable weakness, affecting the ability to examine the robustness of munitions stockpiles. Second, the failure of the models to examine munitions supply systems means that many relevant tradeoffs cannot be considered. This was judged to be a substantial omission. Finally, the use of one-sided analytical expedients (the threat and level-of-effort techniques) was judged to be a serious weakness.

VARIATIONS IN PLANNING FACTORS

The munitions requirements processes use a multitude of planning factors that differ among the services. In many cases these variations can be explained by differences in missions, equipment, tactics, and policies. But as joint and combined warfare is planned, it would be desirable to review and understand these differences. Are the services planning munitions requirements for fighting under the same weather conditions? Do all services make allowances for a maintenance pipeline for high tech munitions? Do the services make the same assumptions about losses to munitions enroute to the combat theater? Do their assumptions about losses on the ground in the theater appear consistent? The answer to all of these questions is No. Plans could be inconsistent and their inconsistencies difficult to detect.

IMPROVING THE MUNITIONS REQUIREMENTS PROCESS

Although some near-term improvements could be undertaken, such as streamlining the Army's process and achieving greater consistency of assumptions across the methodologies, more fundamental change is needed. The changes should deal with two widespread problems with the present approaches: They should treat the underlying uncertainties that are now largely ignored, and they should explicitly examine implicit constraints such as munitions resupply logistics that are now assumed away.

The approach to munitions requirements calculations suggested here is to divide total requirements into three constituent parts:

1. Combat consumption—the number of munitions needed for combat with enemy forces on future battlefields.
2. Munitions support pipeline—the number of munitions needed to maintain the flow of munitions to the forces on the future battlefield.
3. Safety stocks—the number of munitions to be provided as hedges against unexpected combat or logistics developments in future battles.

Combat consumption could be estimated as it is done today, although, in several cases, considerable streamlining of the present methodologies is both possible and desirable.

Although the modeling of the physical movement of munitions to the battlefield should be straightforward, the modeling of support policies will not be so easy. Hard thinking will be necessary to establish a measure of "robustness" for comparison of alternative support policies. Tradeoffs in the structure of the support system will have to be evaluated. The aim is to insure that requirements are set in the context of an effective, robust munitions logistics system.

Safety stocks are necessary because munitions planners face major uncertainties. Though the setting of safety stock levels can be informed by analysis, the final determination should be reserved for top-level service decisionmakers. Analysis can address the robustness of total munitions stocks, given alternative levels and mixes of safety stocks.

The conventional munitions requirements estimating process suggested here involves the explicit estimation and integration of combat consumption, munitions pipelines, and safety stocks. This integrated analysis should lead to a more rational, more effective munitions planning system.

ACKNOWLEDGMENTS

This project could not have been accomplished without the ready cooperation of the munitions planners in each of the services. Our project benefited at every stage from their knowledge and insights.

We are also indebted to Dr. Jay Mandelbaum, Director of Munitions and Sustainability in the Office of the Assistant Secretary of Defense (Production and Logistics). He monitored the work, opened doors, located relevant documents, and suggested research directions.

Finally, other RAND researchers, notably Irv Cohen, contributed to the formulation of the project and to the general thrust of the observations. We would like to thank them for helping to focus the summary and conclusions reached here.

FIGURES

I. INTRODUCTION

This report is concerned with the methods the services use to determine their requirements for conventional munitions. In the sense used here, requirements are point estimates of the quantities of munitions the services would buy to arm their planned forces if sufficient funds were available. Put another way, the requirements that result from the processes discussed here provide upper bounds to the demands of the services for conventional munitions. This review examines requirements for munitions to support wartime operations. Requirements for munitions for training and testing in peacetime are calculated by separate routines and respond to different factors, not examined here.

Requirements as calculated by the services do not translate automatically into actions to provide the munitions needed. Threats change and weapons technologies advance, but funds are rarely sufficient to buy out the requirement. Consequently, allocating limited funds among competing items becomes a crucial task for munitions planners in the services, the Joint Staff, and OSD. Moreover, when funded, programs do not translate automatically into the appropriately acquired munitions in the bins for potential use by combat forces.

The processes that the services use to calculate munitions requirements are lengthy. For example, the Navy uses 13 models to calculate its requirements for a family of munitions referred to as "level-of-effort weapons." The inputs to these models, as well as their results, are worked over first by a working-level group of representatives drawn from throughout the Navy, then by a one- and two-star group, and finally by the Non-Nuclear Ordinance Planning Board, a three-star group. This total process takes the Navy from 10–12 months. Other services go through similar processes. In short, staff efforts to estimate requirements absorb substantial amounts of real resources.[1]

[1]In some services, the Army in particular, requirements estimation is supplemented by capability estimation. The former assumes no resource limitations and asks what capability is needed; the latter assumes resources are limited to those on hand or procured and asks how much capability is provided. But resources are always limited. The logical way to determine munitions requirements (or demands) is to consider tradeoffs among the various resources that contribute to capabilities on the battlefield. Tradeoffs make sense only if resources are constrained. But in developing future capabilities and examining tradeoffs, planners need to consider the effects of marginal changes beyond those already on hand or procured.

The services put additional resources into extending and modifying their techniques to improve the quality of the resulting estimates. The rate of change varies from model to model and service to service, but model improvement efforts are underway in each service. The methodologies now used may therefore differ in some details from the models and techniques considered here.

BACKGROUND

The origin of this effort can be found in the efforts of the Defense Science Board (DSB) to improve the acquisition of conventional munitions. One study group critiqued the processes the services use to generate munitions inventory requirements, highlighting inconsistencies among the services, criticizing the methodologies, taking issue with the Defense Guidance and scenarios used, and questioning whether the measures estimated were meaningful. The DSB recommended that the OSD logistics staff should take the lead in recommending improvements in criteria, methodologies, and models used in setting conventional munitions requirements.

In response to DSB recomendations, in May 1986 RAND was asked to make a quick review of the munitions requirements models and methods used by the four services. RAND's review used six criteria to evaluate the processes used by the services.[2]

One was *the treatment of uncertainties* in warfare in calculating munitions requirements. The RAND review concluded that *the effects of uncertainties* in warfare are by and large ignored in the calculation of munition requirements.

Second, *the treatment of logistics* is weak. Logistics support for munitions is assumed rather than calculated in estimating munitions requirements.

Third, the kinds of measures used in setting munitions requirements had only the weakest *relationship to war outcomes.* The methods used were related in days of supply or percent of targets killed without any necessary connection to the expected course of the war.

Fourth, *coordination among the services* was seen to be loose, limited to the allocation of some targets across the services. The whole matter of joint and combined warfare is not treated in a coordinated fashion in the calculation of munitions requirements.

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[2]The six criteria summarized here are discussed in more detail in the appendix.

Fifth, the *treatment of costs* was found to be superficial. Costs of munitions are by and large ignored in the calculation of munitions requirements.

The final criterion was *responsiveness*. The processes that the services use are, in many cases, cumbersome ones that take a long time to complete.

In short, an ideal munitions requirements process would treat uncertainties explicitly, incorporate munitions logistics, relate munitions stocks to war outcomes, coordinate among the services, and incorporate cost considerations. It would also provide quick turnaround so "what if" questions could be answered. As suggested above, munitions requirements processes in use in 1986 fell short of this ideal in all dimensions.

OBJECTIVE

As a consequence of that quick review, OSD chartered the present work. RAND was asked to "undertake a detailed review of the processes and models used to develop requirements and programs for conventional munitions" and, after completing that, to provide "workable methods for improving the validity and responsiveness of conventional munitions planning for wartime sustainability." This report gives the results of the first two tasks laid out to complete this assignment.

The first task was to make an intensive survey of the present models and processes. Therefore, much of this report is concerned with what is in current munitions requirements estimation, not what ought to be. Second, RAND was asked to enumerate and assess the problems observed in the services requirements processes. Here, at least by implication, there is consideration of potential improvement, or what ought to be, in the munitions requirements process.

The project began by considering the six criteria used in the earlier RAND work:

Treatment of uncertainties.
Handling of logistics.
Relationship of measures to war outcomes.
Coordination among services.
Treatment of munitions costs.
Responsiveness to decision issues.

The approach used by the study team was to examine the logic of the methodologies and consider their strengths and weaknesses by these six standards. As will be seen, the results of this review did not find the six to be of equal importance across the various models and services. The study team was not tasked or funded to perform hands-on runs of the several models to test sensitivities and make independent estimates of munitions requirements. Consequently, the work summarized here does not try to assess the accuracy of the services' requirements estimates.

Work has been completed on the requirements processes for the four services and documented in reports covering each of the individual services.[3] This report summarizes that work and adds an overview.

OUTLINE

The balance of this report is organized into three sections. The next section provides a descriptive summary of the services' methods, drawing on the separate studies. The third section provides observations on the differences in the ways the four services approach munitions requirements estimation. The final section suggests improvements for OSD to consider. These improvements are divided into two categories. The first addresses near-term improvements that can be accomplished to repair recognized flaws in the current methods. The second set of improvements addresses more fundamental reforms, raising some complex issues that are obscured by the current munitions requirements processes.

Recent geopolitical changes in the Soviet Union and Eastern Europe are likely to result in considerable changes to U.S. military posture, missions, and forces. These will eventually affect munitions requirements and probably the methods and models used to estimate them. For example, the Conventional Forces in Europe (CFE I) agreement should result in a substantial reduction in Soviet tanks, armored vehicles, artillery, helicopters, and combat aircraft. There might also be some reduction in U.S. forces engaged in Europe. Both present methods and the suggested improvements should show an associated reduction in requirements for U.S. munitions for European scenarios.

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[3]These documents are: Gordon B. Crawford, *The Air Force's Munitions Requirements Process (NCAA)*, RAND, N-2821-P&L, March 1989; Kenneth Girardini, *The Army's Conventional Munitions Acquisition Process*, RAND, N-2864-P&L, July 1989; Gerald Sumner, *Conventional Munitions Requirements Estimation in the Navy*, RAND, N-2853-P&L, April 1989; Kenneth Girardini, *The Marines' Ground-Attack Conventional Munitions Requirements Process*, RAND, N-3076-P&L, January 1991.

At the same time, the independence movements in Eastern Europe and the dissolution of the Warsaw Pact are making the prospect of major conflict in Europe less likely. Military planners, and the munitions planners among them, may become more interested in various smaller contingencies. The present munitions requirements models are ill adapted to such cases. New methodologies may well be needed to examine munitions requirements for mid- and low-intensity conflict.

II. SUMMARY OF THE SERVICES' CURRENT METHODS

Many munitions planners and planning models distinguish between threat munitions and level-of-effort munitions. Basically, the distinction lies in the identification of the constraint that limits the munitions requirements. Threat munitions requirements are calculated to destroy a finite set of enemy targets, and when those enemy targets are destroyed, the requirement is considered to be satisfied. Level-of-effort munitions requirements are computed on the assumption that the constraint on munitions expenditure is the number of tubes, shooters, or sorties that U.S. forces can generate against plentiful numbers of enemy targets. The requirement is considered satisfied when all available U.S. tubes, shooters, and sorties can be loaded for the planned duration of the war. This distinction is an arbitrary one, but it permits simpler calculations. The separate analyses do not have to simultaneously consider enemy threat activities, U.S. force activities, and their interactions.

U.S. AIR FORCE THREAT MUNITIONS CALCULATIONS

About 30 percent of the USAF's munitions expenditures pay for threat munitions. These include spendings for air-to-air missiles, runway cutting ordnance such as Durandal and antimissile system weapons such as Harm and Tacit Rainbow. In Air Force parlance, these weapons are "earmarked" to attack specific targets.

Figure 1 outlines the process of calculating USAF threat munitions requirements. This process is carried out for each theater as if it were the only contingency. It begins with a definition of precise numbers of targets or threats to be destroyed and the USAF weapon systems available to counter them.

The Air Force first allocates the threat among the USAF weapons systems and uses the resulting weapon and target combinations as an input to the requirement calculation. To calculate the munitions requirements, the Air Force then needs to know the kill probabilities of each of the weapons against each of the target types and the number of targets to be destroyed. Moreover, the Air Force needs to select a level of confidence that it wishes to satisfy in setting munitions requirements. Generally, the Air Force uses a relatively high

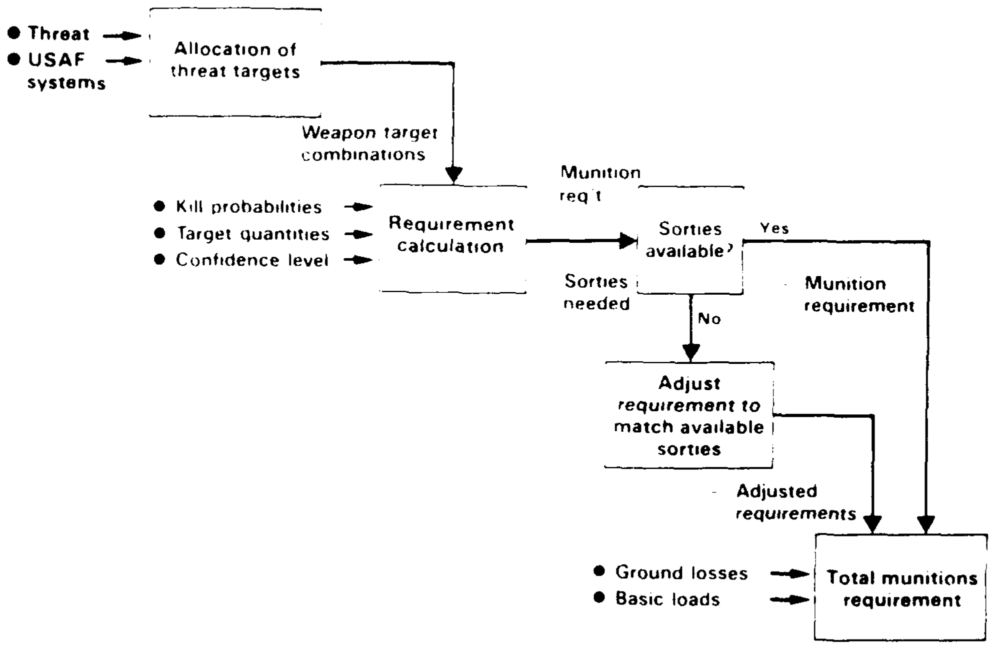

Fig. 1—USAF threat-oriented requirements calculation

confidence level in setting requirements for threat munitions. It then calculates a total requirement for threat-oriented munitions and derives the numbers of sorties required to destroy the targets.

For the more expensive of these munitions, the Air Force then asks whether the sorties required are, in fact, available. If the answer is no, the requirement is adjusted downward to match the available sorties. And if the answer is yes, the munition requirement is passed forward.

The final stage of the Air Force threat-oriented requirements calculation is to add a factor for losses of munitions in the pipeline to the theater, both at sea and on the ground. In addition, the Air Force estimates the weapons needed for "basic loads" for air-to-air warfare and self defense in air-to-air warfare.

The main strength of this USAF threat-oriented methodology is the simplicity of the calculation. It is the simplest of the seven methodologies considered here. There are other strengths as well. The calculation explicitly uses a fixed confidence level to arrive at the munitions requirement estimate. The choice of this level is a policy variable that Air Force leadership controls. There is also the explicit check of the sortie availability, which seems sensible. It is pointless to set requirements for munitions without the capability to expend them against the enemy.

This method has the drawback of assuming complete foreknowledge about the number of targets and the allocation of those targets among U.S. Air Force weapon systems. This is clearly a factor potential enemies can and will affect, creating an uncertainty this approach obscures. Moreover, on the basic statistical level, the calculations as done in the Air Force assume that dual shots are statistically independent of one another, a poor assumption for conditions of modern warfare. Finally, though requirements for basic loads and self-defense can amount to as much as half of the total requirement, they are not clearly spelled out in the Air Force documentation.

U.S. AIR FORCE LEVEL-OF-EFFORT METHODOLOGY

About 70 percent of the Air Force conventional munitions funding is applied to munitions identified as level of effort. For the most part, these are air-to-ground munitions that are considered to be, to some degree at least, interchangeable in attacking such targets as armored vehicles, fixed sites, troops in the field, bridges, and bunkers.

The sequence of four models the Air Forces uses to calculate requirements for these munitions is shown in Fig. 2. It begins with a model called SABER, which accepts weather data, aircraft data, information on the types of targets to be attacked, and data on the munitions; it calculates in detail the effectiveness or probability of kill for each munition against each target for all potential aircraft and weather combinations.

The output of the SABER model, a table of kill probabilities for all possible combinations, is passed on to the model called Selector, which adds attrition data, cost data, and information on delivery conditions (which control attrition). Selector then calculates a least-cost-to-kill set of weapons. Selector's output is a ranking of all weapons against all targets in all weather conditions on the basis of cost to kill, with the preferred least-cost-to-kill weapon at the top of the list but running down through all the weapons.

These preferred weapon lists are input to a third model, Heavy Attack, in which information from Operations Plans (OPLANs), estimated U.S. Air Force sorties, counts on the number of targets to be destroyed, and an arbitrary estimate of target value, along with weather are entered, in addition to the preferred weapon list. Heavy Attack uses the preferred weapons passed from the Selector model. It

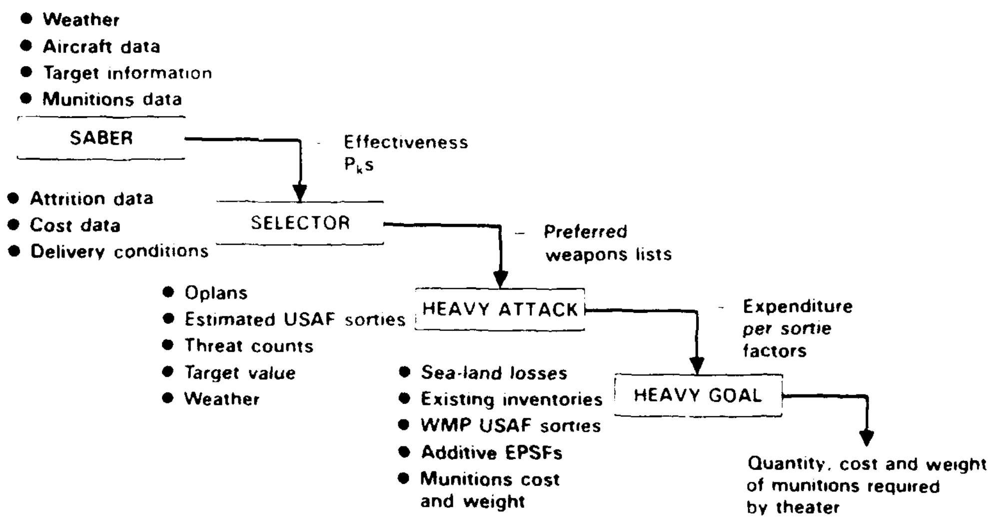

Fig. 2—USAF level-of-effort methodology

then optimizes the target value killed, given the estimated availability of U.S. Air Force sorties, the weather, and the counts and values of targets.

The results of this process are translated into expenditure per sortie factors, which are taken as an input to the final calculation, in a model called Heavy Goal. Information on losses in the logistics pipeline are added, as is the War and Mobilization Plan sortie availability and expenditure per sortie factors for other expendables referred to as "additives."

Heavy Goal uses these inputs to calculate the total requirement for Air Force level-of-effort munitions. Using information on the weight and cost of munitions, it yields not only a quantitative estimate of the number of munitions required but their cost and weight for each theater. By subtracting existing stocks, requirements for further procurement are identified.

The basic strength of this approach is that it is consistent with the other Air Force planning, such as that for spare parts, fuel, pilot training, and so forth. All this is tied together through the War and Mobilization Plan sortie rates. This approach benefits from careful calculation of *some* of the parameters. For example, the SABER routine is very detailed and thorough in its calculation of effectiveness. In addition, the first-day, first-pass attrition is painstakingly calculated to use as an input to this process. Sorties rates are carefully evaluated. Finally, in this process, a cost competition is attempted. This seems to be appropriate among munitions that are interchangeable—potentially competitive.

Some of the parameters in the model that importantly affect the results are not well calculated. Though first-pass attrition is carefully estimated, subsequent attrition is simply scaled against this value with scalers having little empirical justification for all the theaters in which they are used. Moreover, the attrition cost, as used in the least-cost-to-kill calculation, is certainly underestimated. It deals only with the flyaway costs of the aircraft, the operations and maintenance cost of the sortie, and the cost of the munition. It does not consider all the other costs such as pilot training and other pilot costs that go into generating a wartime sortie.

The Heavy Goal model does not properly weigh the opportunity "value" of sorties employed early in the war. This can be called a "limited concern with efficiency." It is limited because the model ignores the number of targets to be killed early in the war and minimizes cost rather than maximizing killing capability.

As in many of the other models, this Air Force routine yields highly variable results. Preferred munition mixes are sensitive to small changes in inputs. Finally, the model uses a target valuation scheme that is not analytically derived. This seems to be a device mainly to insure that the resulting munitions requirements match the operational plans of the commander-in-chief (CINC).[1]

NAVY THREAT MUNITIONS REQUIREMENTS

In calculating munitions requirements, the Navy makes a distinction between threat and level of effort, as does the Air Force. But the Navy's allocation of spending reverses the Air Force's allocation. Some 67 to 75 percent of Navy munitions expenditures are applied to weapons considered threat-oriented. These include most of the Navy's antisubmarine, antisurface ship, and antiair warfare weapons. Navy threat munitions are used against specifically detected targets, and expenditures of these munitions are limited by the availability of targets to be attacked.

The threat model in the Navy (Fig. 3) is run separately for each fleet in what might be called a "vestigial" scenario. The only elements of this scenario are the size of the U.S. fleet and the numbers of targets or

[1]This summary of Air Force conventional munitions estimation procedures is largely drawn from Crawford, 1989.

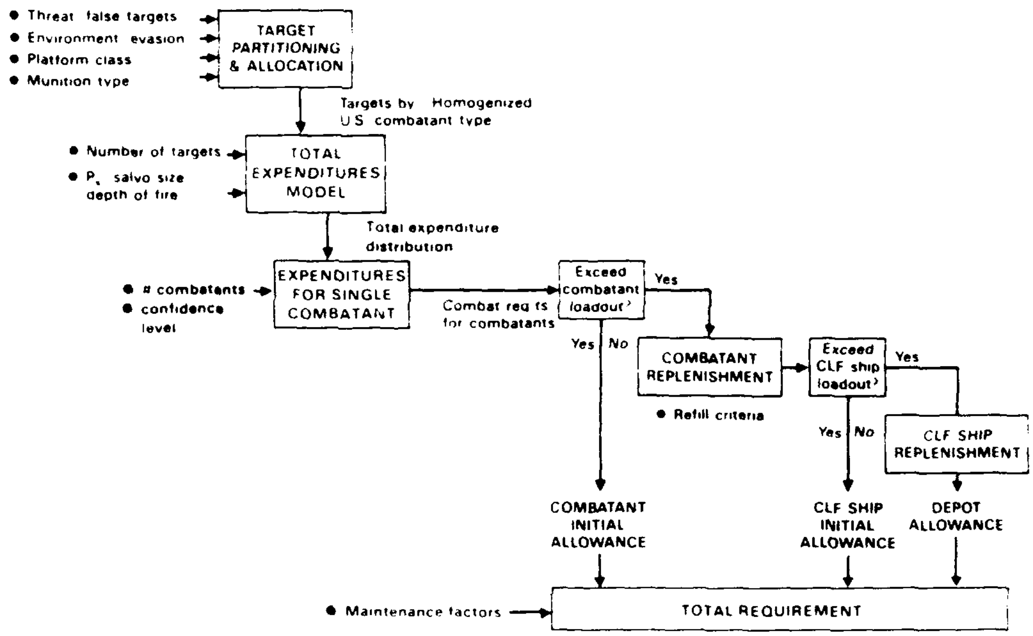

Fig. 3—Navy threat methodology

threats to be encountered in the enemy fleet. The Navy threat model begins with a partitioning or "splitting" of the targets among U.S. Navy platforms that have the capability to fire at them, considering the munitions types, environment, and evasive techniques that potential targets might employ. In addition, the Navy calculation introduces a category called "false targets," accounting for expenditures against phenomena that appear to be hostile but in fact are not.

In the first step of the Navy calculation, enemy targets are allocated among homogenized U.S. combatant types. For example, all U.S. Navy frigates or destroyers or SSN 688 class ships are considered to be identical; although there are, in some cases, differences in their weaponry and sensor suites. Given this allocation, the process uses several additional inputs: the number of targets and information on the tactical exchanges (e.g., kill probabilities that depend on salvo size and the depth of fire for the engagement). These inputs generate a distribution of the total number of munitions required to destroy the requisite number of enemy targets.

The Navy then takes a step that highlights the fact that all U.S. Navy combatants will not encounter an equal share of the threat. To allocate the threat over the available U.S. Navy combatants, the Naval munitions requirements estimators employ a technique or statistical distribution referred to as the Bose-Einstein model. This model, which reflects some limited historical data from the World War II and Vietnam eras, distributes total expenditures over U.S Navy combatants.

First, the Navy chooses a confidence level, meaning in this context the probability that a ship will run out of targets before it runs out of munitions. The Navy then asks if the requirements calculated as a result of the confidence level and the Bose-Einstein distribution exceed the combatants' potential loadout of munitions. If the answer is yes, then the combat loadout—initial shipfill, as the Navy calls it—becomes part of the requirement. If the answer is no—if the combatant is going to require fewer weapons than its potential loadout—the requirement per ship remains as calculated.

If the expenditures for a combatant exceed its loadout, the Navy calculation engages a combat replenishment module. This routine calculates the munitions stocks that must be on board combat logistics ships to satisfy the replenishment needs of the combatant ships. It incorporates predetermined refill criteria and a confidence level (as described above). The Navy analysis then asks whether the demands on the combatant logistics ships exceed their own stocks of munitions.

As a last step, the Navy calculates requirements for depot stocks, with the same confidence level used to determine requirements for combatants and replenishment forces. The sum of the shipfills and the combat logistics force ships' allowances, plus the depot requirements, yields a total requirement. This is then adjusted upward by an estimate of the required maintenance pipeline to keep Navy combatants armed with ready munitions.

One of the strengths of this process is the statistical treatment given to some of the uncertainties. The effectiveness of the individual combatants within the combatant type is treated as a stochastic variable. As noted, the distribution of targets is also treated statistically, employing the Bose-Einstein model. A fixed confidence level is employed to derive specific requirements from the statistical distributions.

Another strength of this Navy threat calculation is that it includes some explicit considerations of the resupply chain. Attention is given to acquiring sufficient munitions to keep the pipeline full so that combatant ships can draw munitions when they are needed.

This model employs a small amount of data and can be run rather quickly in response to changes in estimated parameters, threats, or any other of the inputs to the model.

But the Navy threat-oriented munitions requirement estimate has several defects. It ignores uncertainty about the number of targets and assumes that the allocation of targets among U.S. weapon/combatant types is knowable in advance and fixed for the expected duration of the war. (Even where the Navy process does consider uncertainty, the model responds only by buying stocks, rather than reflecting operations that would manage uncertainty as much as possible.)

Moreover, several questionable assumptions are employed to make this calculation work. There is no ability to time-phase U.S. combatants or potential threats into and out of combat. The threat calculation is done as if time did not matter. Another example is the assumption of independence among the combatants and independence between shots. Also, the sequential dependence of kills implicit in the Bose-Einstein model may no longer be justified given the changes in munitions, sensors, platforms, training, and command and control in the last 20 to 40 years. Finally, the model assumes that resupply is instantaneous. Therefore, the calculated confidence levels have very restricted meaning.

Finally, the category of false attacks (modeled as false combatants) raises problems. It is assumed that the number of false targets to be detected and attacked is known and is a fixed ratio to real targets. As a consequence, when there are no real targets there are no false targets.[2] Moreover, the requirements for munitions to attack potential targets that turn out to be false are not responsive to improvements in Navy sensors, training, or command and control.

NAVY LEVEL-OF-EFFORT METHODOLOGIES

The Navy level-of-effort munitions requirements methodology is used to calculate requirements for air-to-ground munitions for Navy and Marine Corps aircraft. The process accounts for a quarter to a third of Navy expenditures on conventional munitions. Figure 4 summarizes this methodology, really a family of models. As noted earlier, 13 models are employed to calculate requirements for all the Navy's level-of-effort munitions. Not shown, for example, is the Navy Surface Fire Support model, which is used to calculate requirements for

[2]The experience of the Royal Navy during the Falklands War puts this assumption into question. Many antisubmarine weapons were expended when, reportedly, no Argentinian submarines were present.

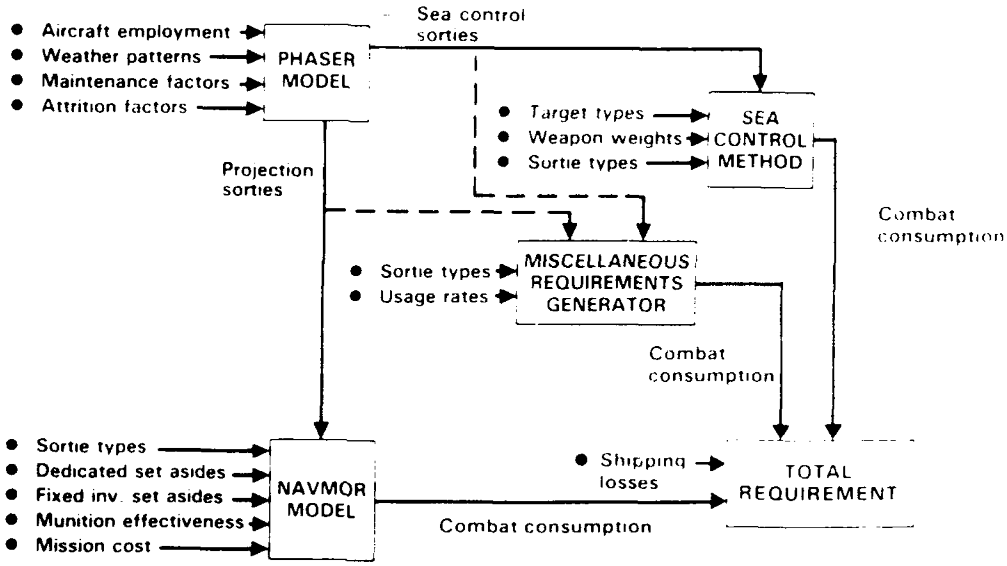

Fig. 4—Navy level-of-effort methodologies

naval gunfire in support of amphibious assault missions and to attack other targets ashore.

The air-to-ground munitions requirement calculation of the Navy begins with a model referred to as Phaser, which uses aircraft deployment plans, maintenance factors; weather patterns, and attrition factors to time-phase the availability of sorties over the duration of the planned war. The sorties the Phaser model calculates are then divided into sea control sorties, to attack enemy surface ship targets, and projection sorties, to attack enemy targets ashore.

The sea control mission gets preference in the Navy calculations. Sorties are allocated to it and requirements for munitions for use against sea control targets are calculated first. This process resembles a threat-oriented calculation in that the numbers of enemy surface ships to be destroyed limit the requirement. Weapon effectiveness parameters are input and the various kinds of sea control sorties (air defense suppression, standoff missile sorties, etc.) are entered. The model allocates targets to specific munition types and then uses linear programming techniques to pick a set of aircraft-munitions combinations that minimizes sorties across all targets.

The second main component of the level-of-effort calculation is referred to as the NAVMOR model and is used for many of the projection sorties. Additional separate routines calculate the effectiveness of weapons that are called "dedicated" and are set aside to attack specific sets of targets. Still another routine is used for allocating munitions that are in fixed inventory—no longer in procurement. Projection sorties for these munitions are then set aside from the total sorties available for calculation of projection munition requirements. NAVMOR calculations allow for estimated attrition of attack aircraft.

The remaining sorties are first classified into many separate groups. Within each group they are armed according to a cost competition in which munitions effectiveness and cost are compared and the least cost-to-kill munition is used to attack the targets. Combat consumption of this munition is passed forward as part of the level-of-effort requirement.

Several additional models are used to calculate requirements for other kinds of naval air-delivered ordnance. One is a separate method for projection Anti-Radiation Missiles (ARM). Another is a model for expendable countermeasures. Still another model is used for the sonobuoys employed by Navy antisubmarine warfare aircraft. The consumption of all of these latter items is estimated in a process known as the Miscellaneous Requirements Generator (MRG). The MRG applies munitions-specific consumption rates to appropriate sorties. The combat consumption of all weapons is entered into a last routine, which projects losses of weapons in shipping to the theater to generate the total requirement.

This methodology has the advantage that it relates tactical air sortie munitions planning to the general U.S. Navy force employment plans through the device of the Phaser model. It is desirable that the interchangeable munitions are subject to a cost competition as they are here. Finally, the level of effort process the Navy uses responds to some tactical and programming constraints such as fixed inventories, weather, and sortie rates.

Many uncertainties are not considered, however. It is assumed that sortie generation takes place according to plan under the prescribed conditions, that the sortie allocations between sea control and projection are not dynamic, and that the availability of certain munitions is never a constraint. Moreover, in calculating the costs of munitions expenditures, the NAVMOR cost competition understates the costs in that "opportunity value" considerations are ignored; further, aircraft attrition rates are scaled up or down to match the overall attrition premised in the Phaser model. Finally, the cost competition itself takes place for only a limited number of munitions and is quite fragmented. This partitioning of the calculations appears to favor special purpose munitions.[3]

ARMY MUNITIONS REQUIREMENTS CALCULATION

Almost all Army munitions—from small arms to artillery, from tank rounds to missiles—are calculated in a single methodology called a "theater simulation,"[4] which is exercised for each of three separate theaters, but in the context of the Defense Guidance scenario. In total, it is a very complex, detailed, and time-consuming process.[5] Figure 5 shows the basic characteristics of this process.

The first step of the Army requirements calculation is to generate combat samples for 24 hours of combat in a model called COSAGE (Combat Sample Generator), which takes notional opposing and U.S.

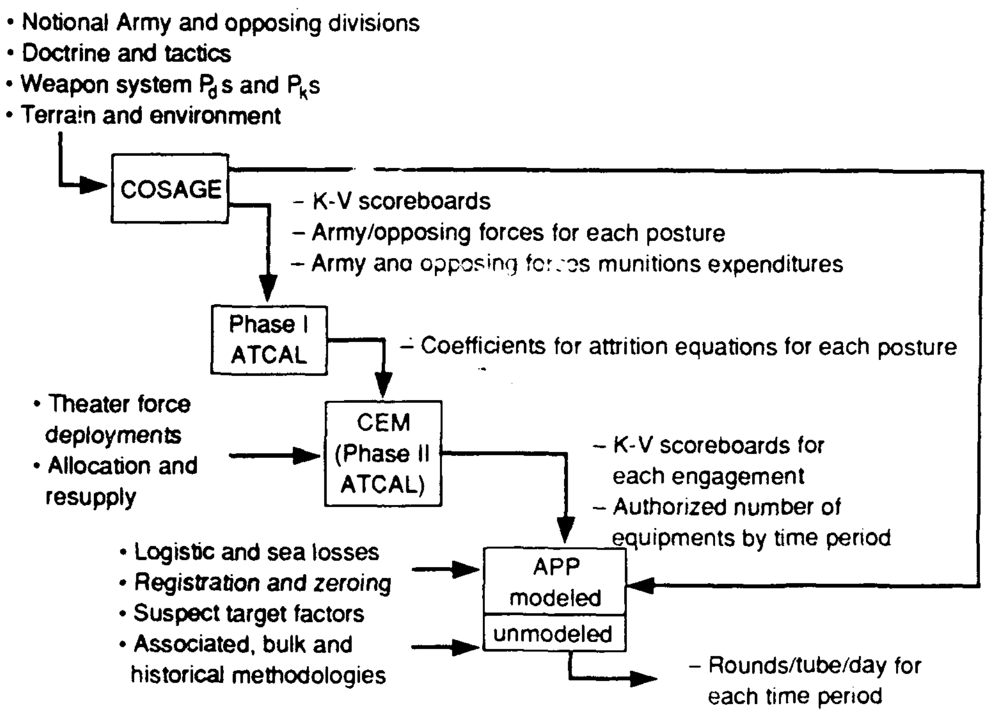

Fig. 5—Army theater simulation methodology

[3]The description of Navy methodologies draws upon Sumner, 1989.

[4]The main exceptions are the Patriot missile and a few other munitions. Requirements for these munitions are calculated outside the processes discussed here.

[5]This summary is based upon Girardini, 1989.

Army divisions, which are designed to include at least one of the weapons or shooters present in their force inventories. In addition, it takes inputs that include weapon system probabilities of detection and kill probabilities as well as information on the terrain and environment. Finally, COSAGE uses assumptions of doctrine and tactics to prescribe the activities of forces in four postures: attack, defense intense, defense light, and delay.

The results are reported in three main categories. First, killer-victim scoreboards show the expected number of Army targets killed by the enemy and the number of enemy targets killed by our forces. Second, COSAGE outputs the number of weapons systems of each type engaged by each side in each posture. A third output is the munitions expended by both sides in the 24-hour engagement modeled. Each 24-hour engagement is modeled stochastically 15 times and the results are then averaged.

The Army must plan munitions not for notional forces but for real forces. Therefore, it is necessary to extrapolate to the results of the actual division engagements based on the notional divisional engagements. This is done in a model called Attrition Calibration (ATCAL). The outputs of ATCAL are calibrated attrition equations for each posture. When provided with the number of weapon systems of each type for the two sides, the attrition equations can be used to calculate both attrition and munitions expenditures.

These calibrated attrition equations are entered into a theater simulation called the Concepts Evaluation Model (CEM), which takes the deployment of identified U.S. forces associated with specific OPLANS. It uses rules for allocating those forces among the various sectors for reinforcing when needed and for holding in reserve when not. The ATCAL equations are used as the combat outcome model for the engagements in each sector each day. CEM runs a simulated war in the theater for a period of days specified in the Defense Guidance. These runs assume that contributions from the USAF and all allied forces are limited to their existing munitions inventories.

The outputs of the CEM are killer-victim scoreboards and the authorized number of equipments in the theater by period of time. These results, along with the direct-fire shot list from COSAGE, are then entered into the Ammunition Post Processor (APP).

In the APP there are different treatments according to whether specific munitions have been modeled in COSAGE and CEM. These models consider about 45 percent of the numbers of munitions that the Army must buy. However, this 45 percent includes most of the high cost munitions that the Army employs—tank rounds, artillery ammunition, and missiles, accounting for over 90 percent of Army spending for munitions. The munitions not modeled in the COSAGE and CEM include some small arms munitions, grenades, line charges, bulk munitions, non-artillery delivered illumination rounds, and others of that nature. Requirements for some munitions that are not modeled are estimated by associating them with rounds that are modeled. Other methods include historical or bulk methodologies. These estimate requirements as a simple function of the number of men or equipments engaged in the theater.

The APP adjusts requirements upward to account for losses to enemy action on the ground in the theater and as munitions are shipped into the theater. Additional requirements are calculated for (1) registration and zeroing tubes as they enter the battlefield and (2) suppressive firing and firing at suspect targets, an analog to false targets in the Navy. The output is an estimate of the rounds per tube per day the Army will expend in the theater for each time period.

Combat consumption based on these rates is only one component of the total Army munitions requirement. The Army staff uses the rates of rounds per tube per day in conjunction with an estimate of the number of tubes to be available in the theater, to calculate the war reserve resupply requirements. This requirement counts for about 90 percent of the dollar cost of the *total Army ammunition objective*. The remaining 10 percent includes the Ammunitions Initial Issue Quantity (AIIQ) (the initial outfitting load for Army equipments), requirements for mobilization training, war reserve stocks for allies and special activities called "Operational Projects." Actual Army procurement spending, however, allocates about 60 percent for war reserves and 40 percent for peacetime training, AIIQ, etc.

This approach has several strengths. The first is that it is a two-sided combat simulation, simultaneously keeping track of the availability of targets to be destroyed and the ability of the U.S. Army to bring munitions to bear on those targets. This two-sided simulation models time-dependent processes. U.S. and opposing forces are introduced according to their ability to get to the battle areas. Attrition of both forces is explicitly modeled. Finally, the output of the theater simulation can be more easily related to the outcome of theater-level combat than the estimates of days of supply in the level-of-effort calculations or the percent of enemy targets killed from the threat models.

The model has some serious weaknesses. It fails to consider the effect of numerous uncertainties about enemy operations, U.S. operations, and resupply. The CEM model and the APP, used to calculate the requirements, are expected-value models. The results of COSAGE, which is a stochastic model, are averaged before they are used in CEM.

The greatest difficulty with the Army's current simulation is that the level of detail involved in making the calculations is so great that the model takes more than a year to complete for a single theater. The Army process is therefore not very responsive to changes in Army forces or the kinds of "what if" questions that routinely arise in DoD planning and programming.

Given that the process takes so long and is done so carefully, its output is sparse, limited to the rounds per tube per day estimates. The analysis passes on no information about the relative effectiveness of weapons on the battlefield, nor does it give any information about the variation that might be expected in combat consumption. The limited samples run in COSAGE are averaged so that information about the variability of consumption is washed out.

Nowhere does this Army simulation consider the costs of munitions in calculating requirements. And, as in most of the other routines, the Army calculation of munitions requirements assumes resupply.

USMC LEVEL-OF-EFFORT SHOOTER-ORIENTED

The Marines use several models to develop their requirements for ground-launched munitions.[6] Two of these models will be discussed here: first the "level-of-effort shooter-oriented" then the "level-of effort target-oriented." Together these two models estimate requirements that account for about three-quarters of Marine Corps spending on ground-launched munitions. Though both are labeled "level-of-effort" (LOE) models, differences between them are substantial. In particular, the "target-oriented" model includes steps found in other models categorized as "threat" methods.

Both of these models use results derived from a third model, called the Troop Population Model (TPM), which keeps track of the number of "combat active" Marine Corps personnel involved in the scenario used for calculating conventional munitions requirements. The scenario normally envisions 180 days of fighting by a single reinforced Marine Expeditionary Force (MEF) in a series of postures, the "posture profile." The rate of USMC troop losses is estimated for each posture. As losses accumulate, troop levels decline; at a particular "reconstitution level," replacements are assumed to bring "combat active" Marine strength back up to full strength. Thus, the model estimates both the number of Marine Corps casualties and the number active in the fighting.

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[6]This section summarizes work on the Marine Corps as reported in Girardini, 1989. Marine Corps requirements for air launched conventional munitions are included in the Navy level-of-effort calculation (see Sumner, 1989).

The Marines' level-of-effort (LOE) shooter-oriented methodology combines the number of combat active Marines (from the TPM) with estimates of the number of rounds expended each hour by active Marines in each posture (Fig. 6). The latter estimates are derived from Marine professional judgments. Combat consumption of munitions is simply the product of the number of shooters times the expenditure rates (in rounds per hour per day) summed over the posture profile. The total requirement for munitions calculated by the LOE shooter-oriented methodology also includes a "basic load" for each deployed weapon system (and replacements) as well as allowances for zeroing weapon systems in the field. Total munitions expenditures are then divided into six 30-day periods and increased by a factor that allows for "logistic losses." The expenditure rates are found by dividing the total expenditures by the number of initially deployed shooters. Total stockpile requirements are calculated by multiplying the rates by the number of tubes planned for the USMC force structure.

This is a fairly simple, direct way of calculating munitions requirements for those conditions when a "target rich" environment is appropriate. Shooter *attrition is explicitly* modeled. The main factors in this calculation are (1) the size of the Marine force, (2) the assumed

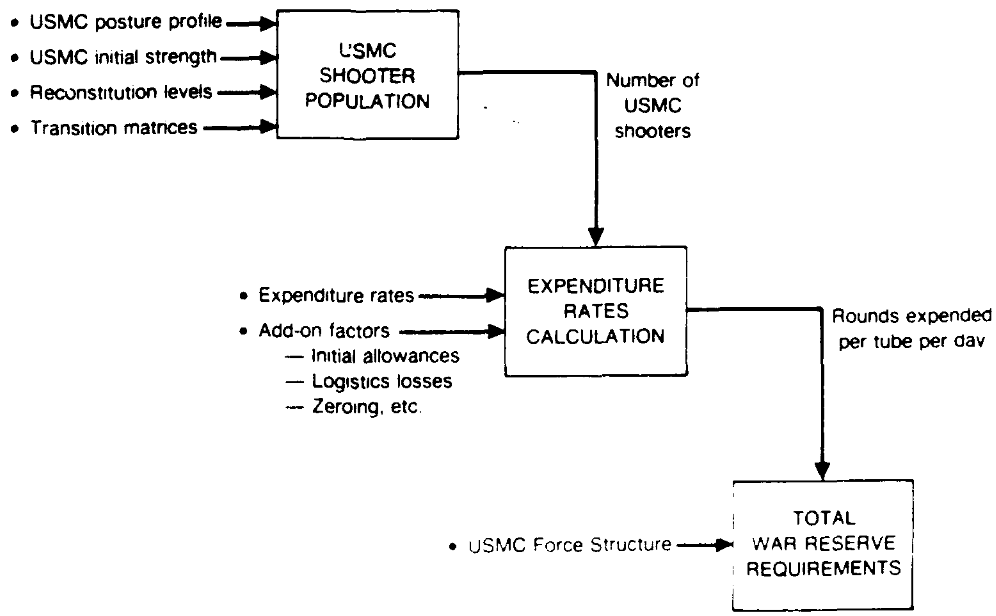

Fig. 6—USMC LOE shooter-oriented methodology

mix of combat postures, (3) the casualty rates for each posture, (4) the reconstitution level, (5) the expenditure rates for each posture, (6) the size of the basic load, and (7) logistic loss rates. Force size, reconstitution levels, and basic loads are reasonably certain because the Corps controls them. This process does not appear to match the resources available to meet reconstitution demands with the demands estimated in the LOE shooter-oriented methodology.

However, there is considerable uncertainty about the mix of combat postures, casualty and expenditure rates, and logistic losses. Some actions to improve this process should be considered. First, it is appropriate to reexamine the validity of the point estimates employed. Why, for example, are USMC casualty rates so much lower than the rates the Army uses? Second, and more important, methods for incorporating the effects of uncertainty directly into the requirements estimation process should be considered. Only point estimates are given; the potential variance of demand is not considered. The ability of the resulting Marine Corps munitions stocks to meet multiple demands is not tested. Though the TPM is relatively simple, an even simpler approach would be just as good, permitting the Marines to direct more attention to the effects of uncertainty on munitions requirements. Finally, it might be possible to introduce cost considerations into the choice of munitions and the determination of munitions requirements.

USMC LEVEL-OF-EFFORT TARGET-ORIENTED

The LOE target-oriented methodology is considerably more complex than the LOE shooter-oriented calculation. The several steps in the methodology are outlined in Fig. 7.

The first step is to size the target pool—the threat to be defeated—by analyzing four factors: (1) Marine troop losses from the TPM, (2) force exchange ratios, (3) force ratios, and (4) "equivalent threat divisions" (ETD).

First, the Marines define a threat division to be encountered. This assumed division is equivalent (by a measure of effectiveness) to the capabilities of a USMC division. Assumed force ratios then yield the proportion of this "equivalent threat division" that will be encountered in the various scenario combat postures. This gives the total number of targets to be faced. Next, targets to be taken under fire by related weapons systems (such as Marine and Navy air) are removed to leave the pool that will be attacked by USMC ground forces. The Marines do not plan munitions requirements to destroy all these potential targets. Rather, they calculate the proportion of the "target

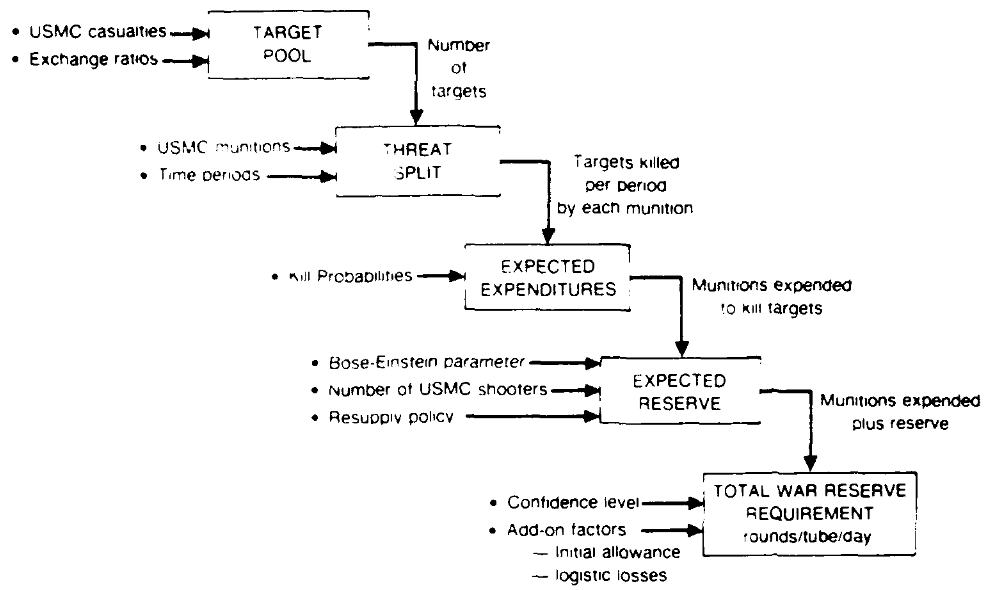

Fig. 7—USMC LOE target-oriented methodology

pool" to be defeated. This is done by relating the number of enemy targets to be destroyed to estimated Marine Corps personnel casualties (from the TPM).

The next step is to divide the total target pool among several time periods for the scenario. The division among time periods is implied by the sequence of postures. The target pool must also be divided among the various Marine Corps munitions that could be used to destroy them. The split of the threat among USMC munitions is largely determined by Marine Corps professional judgment, informed by and addressed to the results of Army COSAGE analyses. An "overlap" factor allows more targets to be engaged than the estimated target pool contains.

Given the allocation of Marine munitions to enemy targets, kill probabilities are used to derive the numbers of "rounds to kill" the targets. Given the total number of targets in the pool, the expected total expenditures are estimated. For direct fire munitions, an allowance is made for firing at suspect or false targets.

The Marines then employ a separate calculation to estimate the requirements for munitions reserves. This calculation assumes that enemy targets are not evenly distributed among identical USMC shooters. The distibution of the targets is modeled as a Bose-Einstein distribution. Using this distribution, some "shooters" see far more targets than they can take under fire with their initial allowance of munitions, implying the need for munitions reserves to replenish these shooters' allowances. It is assumed that resupply is furnished when half of the initial allowance has been expended.

The final step derives the total Marine Corps requirement for LOE target-oriented munitions. A level of confidence that shooters will not run out of munitions when faced with live targets is given. This determines the level of reserve munitions requirements. Then, separate factors are used to provide for the initial allowances for USMC weapon systems and for logistics losses enroute to the battle. These requirements, expressed as rounds per tube per day, can then be multiplied by the number of tubes in the Marine force structure to yield the total USMC requirement for LOE target-oriented munitions.

This is a rather involved process. To its credit, the process treats some uncertainties and accounts for attrition of the Marine Corps weapon systems. A "confidence level" is explicit. The process attempts to time phase the appearance of targets. Moreover, the Marines do not attempt to calculate the requirements to kill 100 percent of the potential target pool. However, as a consequence of the reconstitution of Marine units, the proportion of the target pool killed can, in fact, exceed 100 percent. Also, munitions resupply is treated in the context of establishing the requirements for munitions "reserves."

This approach also has several problems. The complexity of the calculation means that the process is not transparent, and much of this complexity appears unnecessary. Like the Air Force and Navy threat methodologies, the "LOE target-oriented" approach ignores uncertainty about the total number of targets. (Target "overlap" in the calculation simply inflates a single point estimate of requirements.) The split of the targets among USMC munitions is essentially arbitrary, though reflecting Marine Corps professional judgment. Finally, the Bose-Einstein parameter has not been validated with data from the history of ground combat.

III. OBSERVATIONS

VARIATIONS IN ANALYTICAL METHODS

Clearly, the services have major variations among the methodologies used to calculate their requirements for conventional munitions. Six important dimensions of these differences will be highlighted.

The first is in *the basic method* used to calculate requirements. The contrast here is between the combat simulation the Army uses to calculate requirements for all its munitions and the separate threat and level-of-effort calculations the other services use.

Outside of convenience in calculation, the logic for the distinction between threat and LOE munitions is hard to understand. The distinction cannot be found in the nature of the munitions themselves. For example, the Air Force treats runway cutting munitions as a threat munition, but the Navy and Marine Corps consider them as level-of-effort munitions. The convenience in calculation is purchased at the price of omitting potentially pertinent variables. The issue is whether munitions requirements should be set without regard to the capability to expend them, as is the case for threat munitions,[1] or without regard for the detection of enemy targets, as is the case in LOE munitions. On the face of it, either seems a questionable way to go about planning munitions requirements.

The second major variation concerns *the level of detail in the scenario* used to depict the combat for which munitions requirements are being generated. In the Army simulation, the scenario is highly refined, and the military plans that are entered into it are detailed and time-phased not only for U.S. forces but for opposing forces. Terrain is considered, the precise threat estimate for the point in time for which requirements are being calculated is considered, and, in general, attention is paid to all of the factors that are normally considered in any evaluation of future combat forces.

Other methodologies, particularly the threat-oriented models, contain only the most rudimentary elements of the scenario. It would not be much of an exaggeration to say that there is none at all. The "scenarios" in these threat-oriented requirements are limited to statements of the number of targets to be encountered and the types of U.S. forces to engage them. There are no geographic or time

[1]Recall that only the Air Force checks to determine whether it can deliver the required numbers of threat munitions.

considerations. In contrast, planning and most analyses for military weapon systems and force structure are routinely carried out in the context of well-defined scenarios. It seems reasonable to consider, for example, why air-to-air munitions requirements should not be justified in the same context that is used to justify the fighter aircraft themselves.

The third major distinction among the various requirements estimating approaches is between *expected value requirements and higher confidence level estimates*. Expected value requirements are yielded by the Army simulation, the Navy and Air Force level of effort calculations, and the USMC LOE shooter-oriented. These imply a probability of 50 percent that actual combat consumption will exceed the estimated requirement. But the Navy and Air Force threat calculations, and the Marine Corps LOE target-oriented methodology, explicitly use higher confidence levels. However, the confidence levels chosen differ. Equally important, the proper interpretation of the meaning of the confidence level also differs among the three services.

A fourth major variation among the models is *the treatment of resupply*. Only the Navy threat and the Marine Corps LOE target-oriented models consider resupply, and they assumed it to be instantaneous. All the other methodologies for calculating munitions requirements assume that the shooter or sortie can be armed immediately with the preferred weapon. By and large, logistics considerations are completely omitted from the requirements calculations. As will be discussed below, this is both unnecessary and inadequate.

A fifth major variation among the approaches is *the role of cost competition*. As has been seen, there is cost competition in the Air Force level-of-effort munition calculation and among some of the Navy and Marine Corps air-delivered level-of-effort munitions. The other approaches to estimating munitions requirements have no explicit cost competition anywhere in the requirements calculation. However, in many cases, the individual munitions programs are subject to cost competition and cost-effectiveness calculations that are made before the munition enters into the requirements calculation process. Although that may be the case, there is no assurance that the conditions for which the cost-effectiveness calculations were done and the conditions for which the requirements calculation are being made bear any resemblance to one another.

Finally, there is the question of *the use of target values* in contrast to simply counting the *numbers* of targets. Only the Air Force level-of-effort methodology uses a target value routine for calculating munitions requirements, though there is a tactical target evaluation scheme in COSAGE.[2] All the other routines for calculating weapons requirements deal only with the numbers of targets and do not consider the importance of killing one kind of target relative to another on the battlefield or in the air warfare.

VARIATIONS IN PLANNING FACTORS

This review of the several methodologies for estimating conventional munitions requirements has identified several planning factors that, at least in principle, any of the techniques might use. For example, where appropriate, the services should allow for "maintenance pipelines" for high-tech munitions. Each of the services is to some degree concerned with making provisions for weapons that may be lost to enemy action as they are being shipped to the combatants. The effectiveness parameters of weapons used in all of the services are affected by weather. Does the planning for munitions in the different services consider the same weather conditions?

That these factors are not considered in all approaches raises some questions. Should not all services account for the fact that some proportion of their modern munitions will require maintenance before they can be used? Should munitions planning for joint and combined warfare proceed on the basis of different assumptions about terrain, weather, false targets, etc?

Many planning factors can at least in principle be compared among the services. In some cases there are clear and compelling reasons for the observed differences; in others the differences are not so easily explained.

In modeling combat consumption of conventional munitions, the services must make allowances for firings at false and suspected targets in addition to shots at real targets. There is considerable variation in their methods. The Army increases its requirements to allow for expenditures against suspected targets. The Marines make a similar allowance in their target-oriented methodology but nothing explicit in their shooter-oriented calculations. Neither the Air Force nor the Navy allows for false targets in air-to-air warfare. For antisubmarine and antisurface warfare the Navy sensibly allows for attacks on false targets.

Each service also provides for losses to munitions on the ground in the theater. (Such losses are not considered in the Navy methodology,

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[2]In running the NAVMOR model, the Navy first specifies the proportions of total sorties to be deployed against 23 types of targets. This process implicitly reflects target valuation.

which calculates requirements that are considered to be independent of losses.) In large-scale, long duration scenarios, Army and Air Force munitions would move through a common ground logistic system until delivery to the user, implying that expected loss rates would be the same. Yet the differences in techniques used for estimating requirements prevent direct comparisons. In general, higher loss rates apply to small arms and older general purpose bombs and rockets. Loss rates for the more expensive modern air-to-ground munitions are lower, perhaps reflecting better, harder storage facilities.

In any large-scale conflict, each of the services would expect munitions to be shipped to the theater from the United States. Enemy action might be expected to cause some losses to such shipping. The Navy and the Air Force use the same framework in estimating these losses for level-of-effort munitions. The loss rates are applied when munitions are shipped. The Navy and the Air Force agree on loss rates for shipping to the European theater but differ for other theaters. The Navy assumes lower at-sea losses of LOE munitions en route than the Air Force. Marine Corps calculations of weapon requirements appear to assume that no munitions will be lost in shipping to any theater.

In the Army's calculations, loss rates are applied when the munitions are used in combat rather than when they are shipped. There is, as well, considerably greater refinement of these factors, both by time period and by area.

Another variation in planning munitions requirements is arming weapons systems as they are fielded. In the Army, the initial outfitting of the system is referred to as the Ammunition Initial Issue Quantity (AIIQ), in the Navy it is referred to as the shipfill, and in the Air Force it is called the basic load.

The size of this requirement varies from a high of nearly 40 percent of the total requirement down to none for some small arms. The proportion of the inventory objective that is taken up by these initial outfittings depends on the munition and the theater, and it is different for missiles, artillery rounds, and small arms.

The services give several reasons for the requirement to arm weapon systems in addition to providing for combat consumption. One is that these allowances account for on-board losses. Certainly, some munitions are going to be lost when tanks are destroyed and aircraft shot down. Munitions requirements must account for these losses even though the weapons do not go to kill enemy targets.

Another rationale is that these initial outfittings provide an "end of war" capability. If things were to go entirely according to plan, at the end of a war the services would end up with sufficient ammunition to outload all their remaining weapon systems for any subsequent action required.

Additional rationales for these outfitting requirements are sometimes given. One is to provide munition stocks to hedge against unforeseen events. Therefore, munitions requirements are increased to include these basic loads so that there is some flexibility in dealing with untoward events such as greater than expected losses during battle, lower probabilities of kill, and so on. Another rationale is to maintain a logistics pipeline to the battlefield, though no attempt is made to relate these allowances to logistics requirements.

Analysis of requirements for a weapon system used by both the Navy and the Air Force showed that weapons designed to shoot at enemy targets account for only a third of their total planning objectives. Self defense accounts for another one-third of the requirement.

The Navy did not use a basic load in estimating requirements for this weapon. Instead, it had the "distribution" requirement that results from the Bose-Einstein calculation described above. But the Navy added weapons to be carried in the pipeline so that Navy forces can be armed with up and ready weapons when the need arises.

In the Air Force, basic loads account for a quarter of the requirement for this weapon, and expected ground losses account for another 3 percent. There is no explicit allowance for a maintenance pipeline.

COMMON CONSIDERATIONS

In spite of the many differences, several considerations cut across all methods in all services.

First, whatever the estimating method, events and targets must be allocated over theaters, services, and U.S. weapon systems. Since this is not something that is fully under the control of U.S military planners, it is a source of uncertainty.

Second, as in all such military analysis of future combat, the services must use many "soft" inputs about enemy plans and about U.S. capabilities. Generally, point estimates of these uncertain factors are used.

Third, all the services, whatever methods they use, must estimate losses on the ground or losses at sea as inputs to their requirements calculations. These are uncertain because they are determined in part by the choices the enemy makes about the amount of his resources to devote to attacking our logistics.

These latter planning factors are examples of assumptions that can—at least in principle—be compared across the services. Other such parameters include the weather conditions under which combat expenditures are planned, maintenance pipeline factors for high-tech munitions, false or suspect target expectations, requirements for self-defense weapons, aircraft attrition, initial outfitting quantities, and so on. In some cases there are sufficient reasons for the observed differences; in others the differences are not so easily explained.

Finally, requirements and other results of the models generally display "instability." Requirements can shift drastically throughout whole families of munitions plans when a single parameter for one of them is changed a little. As a result, policymakers can lose confidence in the entire requirements estimation process. Since dramatically changing results cannot be simply explained, the processes are considered "opaque." The results that raise these problems are a consequence of both the basic methodologies and the various models used to implement them.

STRENGTHS AND WEAKNESSES

The strengths and weaknesses of the various munitions requirements models were reviewed briefly in Sec. II. Each model has a distinct set of attributes related to the six initial criteria. Judgments of strengths and weaknesses generaly reflect how well existing models satisfy those criteria.

Treatment of Uncertainties

Defense Guidance from OSD focuses the services' efforts on specified scenarios and constrains their ability to consider scenario uncertainties. But service munitions planners could reflect operational, weapons system, and logistical uncertainties.

Threat and target-oriented models do give some attention to operational and weapon system uncertainties. They permit the users to set the confidence level desired and they handle some statistical uncertainies. But these methods also require their users to assume away many of the major sources of uncertainty. For example, they assume complete foreknowledge of the number of targets to be met and which specific U.S. weapons systems will meet them. They also eliminate the time dimension of combat. None of the methodologies treats logistics uncertainties.

On the whole, failure to deal adequately with these types of uncertainties must be judged a considerable weakness. To the extent that requirements affect weapon stockpiles, this deficiency raises questions about stockpile robustness.

Treatment of Logistics

For the most part logistic systems to produce and deliver munitions are not considered. That is, requirements estimates implicitly assume that logistic systems work perfectly in supplying munitions wherever and whenever they are needed. Even when logistics is considered, as in the Navy threat model and the USMC target-oriented model, resupply is assumed to take place instantaneously. In short, the models are not set up to examine some of the important tradeoffs that ought to be considered in setting munitions stockpile requirements. This is a second weakness cutting across all requirements models reviewed here.

Relationship to War Outcomes

Only the Army process estimates requirements in a way that permits a meaningful assessment of the net results if all the required munitions are provided. The Army simulation examines two-sided, theater-level combat and shows the position of the battle line as one of several results. Threat and level-of-effort methods each deal with half the problem of assessing the net effects of munitions on combat outcomes; they are one-sided analytical expedients, which must be judged as a serious weakness. To the extent that munitions stocks are also evaluated in two-sided capabilities analyses, the effects of this weakness in the requirements models are mitigated.

Coordination Among the Services

This review has not highlighted issues of coordination among the services as either a strength or weakness. The major formal effort at coordination is the allocation by the Joint Chiefs of Staff of threats or targets among the services and the U.S. allies. Service munitions planners often arrange other, informal forms of coordination.

Treatment of Costs

Only the LOE methods of the Air Force and Navy explicitly treat costs in setting munitions requirements, and those methods were found wanting in the way they have been conceptualized and implemented. The effect of this limitation is tempered, to some degree, since individual munitions are often screened for cost-effectiveness before they are entered into stockpile requirements calculations.

Responsiveness

This review could not directly estimate the responsiveness of the models. The Navy and Air Force threat models were described as having fairly simple calculations and databases, implying they can be responsive to policymakers' "what if" questions. At the other extreme, the complexity and detail of the Army models prohibit using them to examine such issues. The various LOE models lie somewhere in between in complexity and size of database. Their responsiveness is as much a matter of staff agility and ability as of inherent model design. The complexity of the methodologies, apart from that of the Army, did not appear to limit responsiveness to "what if" questions about sensitivities.

Other Considerations

Other criteria might be used to compare the services' munitions requirements estimation processes. Cost is one. This review has concentrated on the workings of the analytical models. Threat models appear to be simpler and less costly to employ. But except for the Army, each of the services uses both a threat model and a level-of-effort model. Moreover, for either type of model, the collection, review, and preparation of input data require greater effort than the running of the models once the data are ready.

The proxy for total cost examined was the time each service took to complete a set of estimated requirements for all forces and theaters. The Air Force, Navy, and Marine Corps accomplish this task in about a year with roughly equal efforts. The Army required more than a year to complete its estimates for a single theater and used a somewhat larger staff. In all, then, it appears to take the Army at least three times as long as it takes the other services to complete a full set of munitions.

For all services, the total cost of preparing the estimates is very small relative to the costs of the resulting munitions programs. Thus, the cost criterion does not discriminate among the several processes.

The credibility of the services' requirements estimates could provide another standard for comparison. All of the services use many of the results of the processes described earlier as their munitions requirements. Resources are allocated toward meeting the requirements. These uses suggest that the munitions requirements have sufficient credibility within each of the services that they can be reliably used.

Outsiders often find grounds to question the utility of the services' estimates. The Defense Science Board November 1986 report broadly questioned the credibility of munitions requirements. Those who are not involved in the processes tend to view the services' processes as esoteric and mysterious. However, this sort of evidence does not discriminate among the services, much less among the individual models. Given the various weaknesses highlighted above, the models reviewed fall considerably short of the ideal.

IV. IMPROVING THE MUNITIONS REQUIREMENTS PROCESS

Munitions planners face formidable tasks. Adequate munitions stocks are critical to warfighting capabilities, yet munitions planners must deal with substantial uncertainties that obscure just what "adequate" means. The important data they use are, and always will be, very soft. The requirements they estimate are seldom fully funded. And their processes are criticized as cumbersome and opaque. The temptation to elaborate and refine the existing methodologies to deal with these problems is strong, but the fact of the matter is that high confidence, future-oriented, munitions requirements estimates are unachievable. So efforts to achieve such estimates, whether through research, analysis, investment, or testing, are bound to result in disappointment.

What, then, would make a better approach to the methods for estimating munitions requirements? What directions should improvements take? The fundamental answer given here is to seek broader, more flexible methods that remedy the main weaknesses in the current models. That means explicitly addressing uncertainties, incorporating munitions logistics, using higher level measures of outcome, and simplifying the processes.

The first step in a better approach would be a careful definition of the problem. Improvements in the models used to set munitions objectives can be designed and judged only in terms of a clearly defined goal. Certainly, requirements must have a "sustainability" dimension, but that alone is insufficient, for combat can be sustained while falling back as well as when holding or advancing. Munitions requirements need to be related to planned military operations, and sustainability implies that supply capabilities need to be considered as well as combat consumption. One way to state the goal might be:

> To acquire sufficient conventional munitions supply and delivery capabilities that theater commanders can have high confidence of carrying out preferred military operations with programmed forces long enough to deny the enemy success.

This statement includes both supply capabilities (stockpiles and production base) and delivery capabilities, and it ties munitions requirements to the operational plans of theater commanders; but it is open on the meaning of "high confidence" and "long enough." These should be defined by responsible DoD policymakers. And "deny the enemy success" could be replaced with "win" or any other high-level goal. Needless to say, programs to meet munitions requirements should be economically efficient.

This definition calls attention to the need to integrate munitions planning matters that are now largely considered separately. If munitions requirements are to be set to meet this or some similar goal, it will be necessary to jointly consider warfighting plans, stockpile plans, transportation and distribution capabilities, and production base issues. Such a coordinated approach should yield a more robust munitions posture than the present less integrated processes.

Basically, then, a fundamental change is needed—to treat underlying uncertainties expressly and provide a robust munitions support system. But some near-term changes can make current estimates less cumbersome, easier to compute, and more readily understandable. Eventually, current estimating techniques must be replaced by methodologies that permit consideration of the effects of uncertainties in consumption and logistics. Both near-term and long-term improvements would contribute to better statements of munitions requirements.

NEAR-TERM IMPROVEMENTS

The first near-term improvement is to shorten the time it takes to complete requirements estimates. The processes can be made less cumbersome. For example, consider the Army combat consumption model. In recent years it has taken the Army 18 months to estimate requirements for a single theater. The critical path through this extended calculation should be examined carefully and the model streamlined. The aim is to generate estimates of Army combat consumption in a shorter time.[1] A goal of six months would not be unreasonable. Though the processes of the other services are considerably quicker, they each take about a year to generate a set of estimates. Streamlining across the board would create more responsive processes.

Streamlining would contribute in another way. The processes would become more capable of answering the various "what if" questions that are often asked. Iteration between the policymakers and the requirements planners would be enhanced, and requirements

[1]In 1988 the Army considered a much simpler approach to requirements estimation, one using a "threat" model. Other simplified simulation processes have also been discussed.

estimators would improve their ability to match their requirements to the thinking of the policymakers.

As a second near-term improvement, it is desirable to achieve greater consistency of methodology and assumptions across the services. The aim is to achieve measures for munitions programs that facilitate meaningful comparisons among different services, theaters, and munitions. Consistency over time is required so that trends in munitions programs can be measured. Losses of munitions in transit from the continental United States to the combatant forces in the theater (both land and sea losses) and such factors as maintenance pipeline allowances for modern munitions are obvious candidates for consistency checks. Of course, many factors will remain unique to a single service's calculations, for tactics, procedures, equipment, and missions are often different. Consistency is especially desirable if it is carried on from year to year as well as across the services. Consistency, of course, is not an end in itself.

The final near-term improvement is to correct the implementation of "least cost to kill." The Navy level-of-effort model and the Air Force Selector model employ a cost-effectiveness competition among munitions using least cost to kill as the criterion. The application of that criterion in the present models suffers from two deficiencies. The measure of cost is incomplete; the measure of effectiveness is inappropriate.[2] Basically, this approach would improve the selection of preferred munitions by incorporating the "oppportunity value of lost sorties" that is incurred when cheap but inefficient munitions are employed. The Air Force and the Navy should examine this approach and assess the benefits from instituting the logic suggested by Crawford in their present models.

LONG-TERM INITIATIVES

Unfortunately, such achievable near-term improvements do not address the fundamental problems in the services' conventional munitions requirements estimation processes. Three basic improvements are imperative, but they are more difficult to implement. The first would be to recognize explicitly a variety of uncertainties about U.S. force operations, enemy operations, logistics performance, weapon performance, and so on. The second is explicit consideration of munitions logistics support in the requirements setting process. The third would consider how the services might relate munitions requirements

[2]An approach to overcoming the problems in these current processes is detailed in Crawford, 1989.

to measures of effectiveness (MOEs) that are more easily related to the outcome of the combat and more readily compared across the services. These fundamental changes should be jointly examined by OSD and the services.

Handling Uncertainties

The first fundamental change to consider is to recognize the importance of scenario uncertainties in setting munitions requirements. Munitions planners need to make plans that reflect the manifold uncertainties of future combat. Munitions requirements look five to eight years into the future. Many uncertainties must be addressed—about the operations of U.S. and enemy forces on the battlefield, about the performance of weapons systems (some of which have not yet entered into operational testing), and about the performance of munitions logistics pipelines.

Existing munitions requirements processes treat as known much that is, in fact, unknowable. These "scenario" uncertainties include enemy objectives and operations, U.S. operational plans and priorities, the outcomes of measure and countermeasure interactions on the battlefield, and so on. An improved process would recognize these uncertainties and that wartime planners will seek to mitigate their effects.

Munitions Logistics

A second essential basic change to the calculations of conventional munitions requirements is explicit consideration of the munitions logistics pipeline. However careful the calculation of combat consumption of munitions, additional munitions must clearly be provided to maintain the flow of munitions to the combat forces. Existing processes assume that the munitions support system works perfectly so that forces can always get the munition they want, when and where they need it, but real world munitions logistics systems cannot meet this standard. The requirements of the munitions logistics system should be considered just as carefully as the requirements for combat consumption. Such analyses will help insure that the logistics system is configured to match the stocks and to yield the maximum combat effectiveness from given stocks of munitions.

Warfighting MOEs

A third fundamental improvement would be to relate munitions requirements to warfighting measures and objectives such as the ability to defeat the enemy or to sustain warfare under certain conditions. A better statement of requirements would also have a standardized treatment of time and would enable policymakers to see requirements for all munitions as a function of duration of the combat and its location. These are not possible in current threat-oriented models.

Alternative Treatments of Uncertainty

One way to deal with uncertainty in planning munitions requirements is the approach used in the processes the services now employ. Though some of these processes treat a few uncertainties statistically, for the most part the current approach is to build various "hedges" into the estimated requirement. These hedges take several forms. All adapt or "fudge" planning factors so that estimated requirements are increased. For example, kill probabilities are reduced to allow for a variety of potential contingencies. Increasing activity rates beyond expected levels is another hedging technique. "Overallocation" or "overlap" of the threat is a third. The gist of this approach is that large enough inventories will permit unexpected events to be handled. This can be called "buying out"—providing sufficient stocks to cope with the effects of uncertainties. Unfortunately, funds are seldom sufficient to buy out the total requirement. Hedges built into requirements then may not be hedges at all.

A second approach to uncertainty seeks greater understanding of the determinants of variation in munitions consumption so that they can be allowed for in setting requirements. The premise of this approach is that further operational tests and field exercises, more information, and better modeling will lead to sufficient understanding of variability so that its effects will ultimately be mitigated. If events can be predicted, then "true" requirements can be determined. Improved requirements analysis is the core of this approach. But munitions stocks would still be bought to cope with the remaining, presumably smaller, uncertainties.

A third way to deal with uncertainty recognizes the extreme difficulty, perhaps impossibility, of handling the manifold uncertainties of future combat scenarios in setting munitions requirements. Since the factors that would determine munitions consumption are unknowable, the search for "true" requirements is futile. Recognizing this, the third approach rejects detailed analysis. Instead, it drastically simplifies the statement of requirements, making them a simple linear function of force levels. Thus, a fixed number of weapons would be provided for each tank, artillery piece, aircraft, and ship. For example, the requirements for weapons for nuclear submarines could be set at a "shipfill and a half." In itself, this approach says nothing about the adequacy of the resulting munitions stocks. That depends on how the planning factor or weapons ratios are determined.

A fourth approach to dealing with uncertainty requires a broader perspective. Like the third approach, it considers uncertainties about future combat munitions requirements as dependent on processes that cannot be tested, so "true" requirements are essentially unknowable. Given this premise, the analysis broadens to address munitions stockpile requirements and support system techniques. A tradeoff between stocks and distribution system capabilities is considered. Flexibility for operational logistics managers to meet unfolding needs is emphasized. Improved management of munitions logistics is the core of this approach. The focus is on finding the combination of stocks and supply systems that deals most effectively with a range of potential demands for munitions. But this "robustness" is not costless. Robust stocks will not yield as much effectiveness in a particular scenario as stocks that have been "optimized" for that contingency.

Suggested Approach

There is some merit in each of these approaches. Some elements of each are incorporated into the recommendations made below. The approach to war reserve munitions requirements suggested here is to separate total requirements into three constituent parts:[3]

1. *Combat consumption*—estimates of the number of munitions needed for combat with enemy forces on future battlefields.
2. *Munitions support pipeline*—estimates of the number of munitions needed to maintain the flow of munitions to the forces on future battlefields.
3. *Safety stocks*—estimates of the number of munitions to be provided as hedges against unexpected combat or logistics developments.

[3]Requirements for munitions for training and testing in peacetime are now determined by separate calculations. There is no reason this practice could not be continued.

Combat Consumption. Combat consumption could be estimated as it is done today, although, in several cases, considerable streamlining of the calculation is possible and desirable. However, the streamlining should not be allowed to obscure the real uncertainties affecting the combat consumption of munitions. Indeed, the streamlined models should be constructed so as to allow exploration to the effects of state-of-the-world uncertainties as well as variability of munitions consumption in a given combat situation. An appreciation of the effects of these uncertainties is essential to setting safety stock levels.

Uncertainties in setting munitions requirements arise from many sources. Within a given combat situation, the so-called "fog and friction" of war are a recognized source of variation in munitions usage. Munitions planners must also be concerned with uncertainty about the many scenarios that may arise. In fact, munitions planners should consider several potential scenarios to deal with this source of uncertainty. This raises the question of how to integrate the combat consumption needs of several scenarios into a single combat consumption requirement. Although there are several mathematical techniques for accomplishing this integration, none is fully satisfactory from a policy point of view.

Whatever the methodology used to estimate the combat consumption requirement, there is no reason that the resulting requirements could not subsequently be translated into a simplified planning factor such as a fixed number of a given missile for each aircraft that could fire it or a "shipfill and a half" for ship-launched weapons. Suppose, for example, using the threat model described above, the Navy comes to a requirement for 4400 of a given submarine-launched torpedo to destroy 220 targets. If the Navy has 100 submarines, each capable of carrying 22 each, then why not state the requirements as two shipfills per submarine? Alternatively, the requirement could be stated as 20 per target. Such planning factors could, in general, be assumed to be stable. Unless there are dramatic changes in opposing submarine forces, in other antisubmarine warfare capabilities, or in missions for U.S. submarines, there would be little reason to reassess the requirement annually or biannually.

Munitions Support System. As has been noted, current munitions requirements do not consider questions of munitions distribution. Rather, they assume that the shooters can get the required munitions when and where needed. Sustainability estimates, usually stated in terms of "days of supply," also assume that the available stocks of munitions can be efficiently distributed among the combat forces. These assumptions should be examined. Munitions requirements planning should be broadened to give explicit attention to the transportation, storage, and command and control arrangements needed to make the best use of limited munitions stocks during military operations.

The complex of production, movement, storage, and control systems for managing munitions stocks and flows can be called the "munitions support system," which comprises the munitions production base, movement and storage facilities in the continental United States, intertheater movement capabilities, and theater munitions storage and movement systems. Clearly, there are important tradeoffs in the design of these components that ought to be considered in setting munitions requirements. For example, a substantial, quick-reacting production base can decrease the requirement for munitions to be produced and stored in peacetime.

Munitions support pipeline requirements per se do not appear to raise insuperable estimation or calculation difficulties. Compared with the analyses of combat consumption, the modeling of the physical movement of munitions through the pipeline should be straightforward. Some policy questions will be raised—push vs. pull systems for example—but such considerations are precisely what is lacking in any of the current approaches to estimating conventional munitions requirements. However, in modeling the munitions support pipeline, potential vulnerabilities must be considered. As with combat consumption, these vulnerability or logistics loss factors can result from highly sophisticated operations analyses. However, setting requirements for the munitions in the pipeline can use simple and stable planning factors for losses.

Modeling of munitions support policies and options will not necessarily be so easy. Nonetheless, there should be substantial benefits from modeling the means of improved munitions management. The aim would be to help insure that munitions stocks are put to their best use. Tradeoffs in the scale and scope of munitions storage and transportation activities need to be assessed. Flexibility in the use of munitions logistics resources (lateral distribution, responsive production base, etc.) should be explored. Hard thinking will be needed to establish the appropriate measure of "robustness" for comparison among alternative munitions stocks and logistics pipelines. The aim of considering the munitions support system is to insure that stockpile requirements are set in the context of an effective, robust munitions logistic capability

Safety Stocks of Munitions. The estimates of combat consumption and munitions support pipeline requirements should be enhanced by efforts to improve the planning factors used. Field tests and operational exercises can sometimes provide useful information. But munitions planners will necessarily be confronted with major uncertainties that no amount of testing or intelligence gathering will overcome. Such uncertainties include scenarios, the strategies and tactics of potential enemies, the operational responses of U.S. commanders, and the net result of measure/countermeasure interactions as well as the usual statistical uncertainties of weapons delivery in combat. It is important to realize that uncertainties can lead to unexpectedly favorable outcomes as well as less welcome surprises. The munitions support system should be configured to enable logisticians to realize the benefits of favorable developments and to limit the effects of unfavorable ones.

Given these major uncertainties, some hedging or insurance against unfavorable developments may be desirable. Certainly, current estimates contain adjustments or hedges providing "extra" stocks to protect against unfavorable developments, but these are usually hidden deep in the estimation methodology. As a consequence, policymakers cannot see the size of the implicit safety stocks. They cannot tell how much they are spending for hedges, nor can they understand the amount of insurance they are getting. This ought to be corrected.

The determination of safety stock levels should be reserved as a top level decision by the services. The setting of these levels can be informed by analyses, simple or sophisticated, that should address the size and costs of varying safety stock levels. The kinds of contingencies to be hedged against and the degree of protection sought should be made explicit. Given best estimates of combat consumption and munitions support system requirements, analysis can address the robustness of total munitions stocks given alternative levels and mixes of safety stocks.

There is the danger that such safety stock levels would become a variable, depending largely on available funding. Therefore, once determined, any changes in safety stock levels should be considered in light of changes in threats, munitions technologies, logistics capabilities, and other substantive factors. Conventional munitions requirements statements should not become a function of the expected level of service budgets.

Measure of Effectiveness. The approach described here implies different measures of effectiveness than those used for munitions in the past. The measures should be broad enough to reflect the tradeoffs between stocks and the munitions support system. They should reflect the benefits of safety stocks and permit tests of the "robustness" of the total munitions posture. Finally, the measures used in assessing the munitions posture should be meaningful to DoD decisionmakers.

Measures now used for munitions programs fall short of these standards. The fundamental purpose of requirements estimation is to plan the procurement of the munitions stocks needed by the combat forces. This has been taken to mean the provision of sufficient stocks to sustain the forces in combat for a period of time. As a consequence, the MOE employed, particularly for those munitions designated as "level of effort," has been taken to be the number of days of fighting that the stocks could support—days of supply. For threat munitions, the usual MOE is the proportion of the intended targets that can be destroyed with the stock of threat munitions.

Unfortunately, neither of these measures bears any close relation to the success of combat forces nor any particular relevance to the allocation of scarce DoD resources. Over the range of interest to DoD decisionmakers, neither do they bear any necessary relation to each other or to such basic measures as the movement of the forward edge of the battle area (FEBA) in air-land battle.[4] When aggregated, these measures tend to obscure potentially critical shortages. Moreover, they do not consider the performance of the munitions support system.

The criteria for the MOE suggest a scenario analysis. Clearly, it is appropriate to develop munitions requirements in the same scenarios used to set the requirements for the aircraft, ships, and weapons systems that will expend the munitions. Force planning scenarios normally specify the opposing forces, levels of activity, and time dimensions as well as some geographic considerations. Scenario analyses, then, reflect the interactions of opposing forces, including attacks on munitions stocks and munitions support systems.

The MOEs used in munitions requirements calculations in these scenarios should be high-level ones. They should reflect the effects of tradeoffs among the various munitions programs as well as between munitions stocks and logistics capabilities. The movement of the FEBA is one such higher level measure, though the ratio of surviving forces may serve as well. Such a measure can be calculated to incorporate the effects of air support as well as those of ground forces. For air superiority and sea control, the ratios of surviving forces can be used as a proxy.

Although it is easy to suggest the benefits of using such high-level MOEs, estimating them raises real difficulties. First, these measures require modeling that is different in kind from most logistics

[4]Of course, if stocks of level-of-effort munitions can support only a few days of fighting (and the enemy is expected to support a much longer war) or if threat munitions can defeat only a very small percent of the threat, then the result of the combat will be clear, even by crude measures of sustainability.

analyses, necessarily involving concepts and operations that go well beyond logistics considerations—e.g., threat estimates and operational plans. Such factors are inherently sources of additional uncertainty. The estimation of high-level measures of effectiveness also involves great simplifications about how the war might go, and this introduces additional uncertainties. In short, to estimate high-level measures requires more modeling and more soft data. A case might be made that simpler, more transparent modeling and measures could be used to convey the appropriate notion of munitions contributions to force effectiveness without sacrificing the appreciation of uncertainty.

Using such measures as FEBA movement will add to the complexity of the calculations, but there is a real benefit. Such measures would help munitions planners address difficult but appropriate issues. They would also help top level decisionmakers to better understand the broad implications of increases or decreases in munitions program funding.

Implications of This Approach. The suggested approach may well lead to higher estimates of munitions requirements. Current processes assume instantaneous or perfect munitions logistics. Consideration of a more realistic (and therefore less than perfect) munitions support system is bound to increase requirements. Since munitions requirements are seldom fully funded, what is the point of increasing the upper bound for the services' appetites for munitions? A higher upper bound will have little or no effect on actual munitions programs. So why bother?

First, whatever requirements may be, wars will be fought with the stocks on hand at the outset plus whatever munitions can be provided from the production base as fighting goes on. Attention to the munitions support system will help insure that, whatever the size of these stocks, they can be put to the best use the warfighters envision. This alone would be an improvement in munitions planning.

Second, by raising considerations of production base contributions, intertheater shipping, and theater distribution, some tradeoffs may result that reduce munitions stockpiles and increase such capabilities. For example, a highly responsive production base, coupled with a reliable munitions support system, could reduce stockpile requirements. This kind of tradeoff should be considered but is not encouraged by present DoD procedures. Current munitions requirements methodologies do not permit examination of this sort of tradeoff.

Third, adding consideration of the munitions support system is only part of the suggested improvement. Making the allowance for safety stocks explicit could also lead to higher requirements. But it could also lower them. For the weapon discussed on page 28, the proportion of the requirement that can be traced to shots at the enemy is about one-third. This proportion arises from a threat that is already inflated ("overlapped") to allow for variability in where the enemy targets would actually appear. It appears that two-thirds of these munitions are required for logistics purposes, hedging, and self-defense. By making the requirements for both the munitions support pipeline and safety stocks explicit, total requirements could be lowered.

That result, of course, awaits the results of explicit, quantitative analyses to inform the judgments of top-level decisionmakers. Whatever the result, the integrated analysis recommended here should lead to a more complete, more effective munitions planning and operational system.

COORDINATION OF BASIC APPROACHES

This report has described seven different methodologies now in use among the services. Each methodology employs many unique steps and calculations. It is appropriate to conclude by stressing the desirability of coordinated modeling approaches across the services. Each service need not use the same model as the others because they all deal with very different kinds of threats and combat situations, but all services could use the same fundamental methods for calculating their requirements. The services should be required to explain differences from common scenarios, data, and modeling assumptions. A general framework for calculating munitions requirements, consistent across the services, would be a step toward more meaningful comparisons among the services for readiness and sustainability. Two matters deserve special attention.

An explicit cost competition should be required among all munitions. It could be accomplished within the service and within mission areas as is now done in the Navy and Air Force LOE calculations.[5]

OSD should establish guidance on confidence levels. Such a step would make even more sense if the services used a common modeling approach so that the interpretation of the confidence level would be consistent among them. A decision to set confidence levels could have a major effect on the level of stated requirements. As it is now, in

[5]Most, if not all, munitions have already been subjected to some kind of cost competition earlier in the acquisition process. Thus, the munitions that are entered into requirements calculations have already passed one cost-effectiveness test. However, those analyses deal with only a handful of competing munitions. Moreover, the context (or scenario) is generally different from that of the requirements calculations.

threat munitions calculations, explicit confidence levels greater than expected values are employed in some calculations by the Air Force, the Marines, and the Navy. Other methodologies used by the the same services calculate munitions requirements on an expected value basis—at a confidence level of 50 percent.

The Office of the Secretary of Defense is responsible for assessing and coordinating munitions requirements across all components of the Department of Defense. That is a difficult task given all the unavoidable uncertainties of scenarios, threats, operational plans, munitions effectiveness, and munitions logistics. Unnecessary variations in techniques and assumptions should not be allowed to further cloud the vital comparisons across the services that are necessary to assess the feasibility of plans for joint and combined military operations.

Appendix

CRITERIA FOR JUDGING MUNITIONS PLANNING

What criteria should be applied to judge whether a munitions acquisition planning and programming process is a good one? Six criteria used in this report are described here.

First, does the process deal with contingencies or uncertainties implicit in the complex problem of developing munitions stockpiles?

A good process would consider several sources of uncertainty. One is uncertainty about scenario. Where are the forces going to fight, who will the opponent be, and when is the combat expected? While the Defense Guidance scenario imposes answers to these questions, it does not eliminate the need to develop capabilities to meet other more or less likely conflicts.

Another source of uncertainty is variation in enemy and U.S. force operations. How will enemy forces attack in the early stages of the war? How will enemy commanders employ their forces to try to erode defenses, achieve breakthroughs, gain air superiority, break the sea lines of communication, etc? No single answer is appropriate. And how would U.S. commanders respond to the varying threats? What are their own operational plans for offensive activities? Will U.S. forces need to supply munitions to allied forces? Variations in these plans can affect munitions needs and therefore should be examined when munitions requirements are being developed.

A third source of uncertainty is weapon performance under combat conditions. Some estimates of weapon effectiveness against targets are based on historical experience, some are based on field tests, and some are mere "guesstimates" of effects on enemy targets about which we know all too little. The estimates may be low or high, but the munitions requirements processes should deal with this uncertainty.

Still another uncertainty in estimating munitions requirements is variations in the logistics systems' delivery capability, which should include a pipeline to feed the ordnance to the hands of the shooters. Logistic uncertainties can arise because of varying performance by logistics forces and because of enemy action against logistic networks.

Second, does the process impose sensible constraints?

One constraint to consider in setting munitions acquisition programs is the capability of the system to transport munitions and to store them.

Consideration of such constraints is essential if the services are to have balanced programs to execute their warfighting strategies. A second constraint that needs to be considered is the production base. By using higher level MOEs one ought to be able to examine how production base capabilities can relate to warfighting. Budget constraints are also appropriate. The services must plan their acquisition programs within constrained procurement and operating budgets. In doing so, they need to be sure that the munitions programs they are choosing maximize the capability of the service to meet its goals.

Third, does the process relate munitions programs to warfighting using higher level MOEs?

Such measures as the movement of the FEBA, the outcome in the contest for sea control, or the trend in the battle for air superiority all should be related to munitions plans. The use of such measures would add complexity to the calculations, but it would also help munitions planners to address difficult but appropriate issues. For example, what are the relative contributions of the different families of munitions—antiarmor, antipersonnel, antiair, and so on—to success in battle? Where, among such families, should programs be increased or decreased? Understanding of how higher or lower munitions stockpiles affect warfighting measures would also be useful to high-level decisionmakers in allocating resources to munitions programs.

Fourth, does the process coordinate munitions supply and expenditure among the four services?

Allocation of targets among the services is an important element of this process, but the process should also coordinate on joint operations so that the munitions requirements reflect joint plans for force employment. The supply of common munitions should also be considered in calculations of pipeline requirements. Among the 60 separate munitions cited as critical, more than half are common to two services. The predominant pairs are the Army and Marine Corps for ground munitions and the Air Force and the Navy for air-to-ground munitions. Even when one looks only at the newer "high-tech" munitions on the munitions critical items list, the proportion of commonality is greater than 25 percent.

Fifth, does the process deal with economic efficiency and treat substitutions that would move munitions programs in the direction of efficient use of resources?

Several tradeoffs should be examined in munitions acquisition. Substitutions among the various munitions that go to make up the total DoD stockpile should be examined. Such a tradeoff would help insure that the munitions DoD is buying are the most cost-effective for defeating the threat. Another substitution to be considered is between munitions stocks and the logistics system for delivering weapons into the hands of the forces. A faster or more survivable munitions logistics system ought to reduce our requirements for ammunitions stocks. A third tradeoff is between the stockpile and the production base for manufacturing munitions. The ability of the production base to surge deliveries under mobilization conditions is an important dimension of the sustainability problem that should be treated in setting munitions acquisition plans.

Sixth, does the process respond to issues raised by decisionmakers? The munitions requirements process needs to be responsive to issues about scenarios, contingencies, weapon system performance, and funding. Issues about munitions arise from several sources—from the research and development communities advancing weapon technologies, from service leaders assessing alternative programs, from the interaction between the services and OSD, and from the Congressional review of munitions programs and budgets. No single model or tool can be expected to address the great variety of questions that inevitably arise. But, equally clearly, the munitions planning and requirements processes must be able to systematically assess broad issues of munitions funding, distribution, and employment.

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