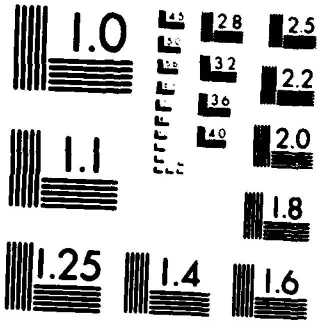
AD-A091 682 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA PROGRAM --ETC F/G 15/3 1/3

REPORT OF COMBAT CONSUMPTION MODELING IMPROVEMENT PANEL.(U)

JUL 80 J BRACKEN, J R BODE, S BONDER MDA903-79-C-0320

UNCLASSIFIED IDA-P-1455 IDA/HQ-79-21815 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

AD-E500 219

Copy 14 of 140 copies

(12) LEVEL III

AD A091882

IDA PAPER P-1455

REPORT OF COMBAT CONSUMPTION MODELING IMPROVEMENT PANEL

Jerome Bracken, *Chairman*, Institute for Defense Analyses
John R. Bode, The BDM Corporation
Seth Bonder, Vector Research, Inc.
Hugh M. Cole, Independent Consultant
David B. Kassing, Center for Naval Analyses
Milton G. Weiner, The RAND Corporation

with an Appendix by
Lowell Bruce Anderson, Institute for Defense Analyses

July 1980

Prepared for

Office of the Assistant Secretary of Defense
(Manpower, Reserve Affairs and Logistics)

INSTITUTE FOR DEFENSE ANALYSES
PROGRAM ANALYSIS DIVISION

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Report of Combat Consumption Modeling Improvement Panel	5. TYPE OF REPORT & PERIOD COVERED Final
	6. PERFORMING ORG. REPORT NUMBER IDA Paper P-1455
7. AUTHOR(s) Jerome Bracken, John R. Bode, Seth Bonder, Hugh M. Cole, David B. Kassing, Milton G. Weiner, Lowell Bruce Anderson	8. CONTRACT OR GRANT NUMBER(s) MDA903 79 C 0320
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Defense Analyses 400 Army Navy Drive Arlington, VA 22202	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task 79-IV-1
11. CONTROLLING OFFICE NAME AND ADDRESS Asst. Secretary of Defense Manpower, Reserve Affairs and Logistics The Pentagon, Washington, DC 20301	12. REPORT DATE July 1980
	13. NUMBER OF PAGES 210
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE n/a

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sustainability, Munitions, War Reserve Equipment, Combat Consumption Modeling, Planning, Ground-Air Warfare, Naval Warfare, Ground Forces, Tactical Air Forces, Naval Forces.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report recommends improvements to the process of planning for sustainability of ground, air and naval forces. The methodologies used by the Services for analyzing warfare and deriving requirements for munitions and war reserve equipment are reviewed, and improvements are suggested in many areas. The report includes an appendix which treats selected modeling issues in detail.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

IDA PAPER P-1455

REPORT OF COMBAT CONSUMPTION MODELING IMPROVEMENT PANEL

Jerome Bracken, *Chairman*, Institute for Defense Analyses
John R. Bode, The BDM Corporation
Seth Bonder, Vector Research, Inc.
Hugh M. Cole, Independent Consultant
David B. Kassing, Center for Naval Analyses
Milton G. Weiner, The RAND Corporation

with an Appendix by
Lowell Bruce Anderson, Institute for Defense Analyses

July 1980

INSTITUTE FOR DEFENSE ANALYSES
PROGRAM ANALYSIS DIVISION
400 Army-Navy Drive, Arlington, Virginia 22202

Contract No. MDA903 79 C 0320
Task 79-IV-1

SUMMARY

The Combat Consumption Modeling Improvement Panel was convened by invitation of the Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics). It was established in response to recommendations in the DoD Sustainability Study, published and distributed in October 1979. One recommendation of that study was:

> OSD should develop a framework and long-range plan under which the Services would undertake to improve their methodologies for simulating combat and estimating combat materiel and manpower demands.

The Institute for Defense Analyses was tasked, in June 1979, to organize a panel of experts in combat analysis and modeling, with the following objective: "To recommend mid-term and long-term improvements to analytical techniques for prediction of wartime consumption." The members of the panel are the authors of this report. Their names and affiliations are as follows:

Jerome Bracken (Chairman), Institute for Defense Analyses
John R. Bode, The BDM Corporation
Seth Bonder, Vector Research, Inc.
Hugh M. Cole, Independent Consultant
David B. Kassing, Center for Naval Analyses
Milton G. Weiner, The RAND Corporation

Consultation to the panel was provided by Lowell Bruce Anderson of IDA.

The panel held a three-day meeting in September 1979 in which representatives from OSD and the Services presented the existing methodologies for projecting demands for combat con-consumption. The members reviewed the DoD Sustainability Study and reviewed selected Service planning documents. The panel met on several occasions for discussions in connection with the present report. This report embodies the panel's findings.

The questions addressed in the DoD Sustainability Study are vast in scope, and the resources of the panel have been small. Thus, it has been necessary for the most part to consider planning for sustainability from a highly-aggregated, top-down point

of view, and to investigate only a few issues, identified by the panel to be important, in detail. In many areas, the panel believes that the caveats and recommendations for future work presented in the DoD Sustainability Study are helpful in identifying areas for methodological improvement.

Summaries of key recommendations follow:

Analysis of Ground-Air Warfare. Army and Air Force materiel and manpower demands for conflict in the critical NATO central Region would occur in a common underlying ground-air war; however, neither Services' present methodologies contain comprehensive, explicit, analytical representation of such a conflict. The Army and Air Force, either jointly or separately, should project the outcomes of ground-air warfare over time for various sets of planning assumptions. All key combat interactions should be explicitly addressed (fourteen key interactions are specified on pages 23 and 24 of this report).

"Level-of-Effort" Versus "Threat-Oriented" Approaches. We prefer two-sided, dynamic level-of-effort approaches over one-sided, static threat-oriented approaches because we believe that most of the combat processes being treated cannot be abstracted in the form of a threat-oriented model and still be analyzed in a credible manner. Level-of-effort models neither should be nor need be so complex and detailed as to make their understanding difficult and their use cumbersome.

Naval Combat Demands. The present Navy threat-oriented procedure for determining ordnance demands for other than air-to-surface munitions is so inadequate that it should be discarded. The principal reason is that the process models attacks on friendly forces by enemy weapons as random events rather than as purposeful military operations with the intention of destroying the targets. We believe the Navy should base their analyses of these ordnance requirements on simulation models of warfare. The present Navy/Marine Corps one-sided, dynamic level-of-effort air-to-surface munitions methodology is adequate, except the scenarios should be explicitly coordinated with the scenarios of the other Services.

Air Force Air-to-Ground Methodology. This one-sided, dynamic level-of-effort model does not emanate from any underlying ground-air war. The Air Force operates in close harmony with the Army in the primary ground-air warfare planning scenarios (unlike the Navy, which is designed to be used more flexibly in air-to-ground roles and for which the methodology is judged to be adequate). The defects in scope of the Air Force air-to-ground methodology are major and need correction; this would be accomplished by the integrated ground-air analysis recommended above.

OSD Role. The OSD staff should monitor the study process regularly and systematically. It should establish or endorse the basic planning scenarios. It should understand the models, data, and assumptions. Where the models are too complicated to be monitored, simpler processes should be developed and applied. OSD may need to devote more resources to the monitoring function.

Treatment of Risks. Some but not all Service methodologies include factors for statistical risks. We believe, however, that scenario risks are far more important than statistical risks. The basic planning scenarios should explicitly treat these risks so that the impact on combat demand can be made visible and appropriate hedges incorporated in the planning process.

Theater Logistics. Logistics resources and their combat attrition appear to be largely ignored in existing warfare simulation methodologies. Because history strongly suggests that military capabilities degrade due to logistical failures, analysis of logistical constraints and attrition should be explicitly included in planning for sustainability.

Definition of Sustainability. Recognizing the problems with the accepted definition of sustainability (namely, days of supply), the DoD Sustainability Study proposed a new definition (namely, percent demand that can be satisfied over time). We believe this new definition suffers from at least as many drawbacks as the old one. (The principal drawback is that if demands were only partially satisfied at a particular time, subsequent demands would be affected.) The panel proposes no alternative; we simply note that a satisfactory definition of sustainability is still to be found.

Specific Recommendations for Marginal Improvements to Service Models. These are covered beginning on page 26. Also, Appendix A treats specific problems of Service models.

The report consists of the main body, a long appendix on selected aspects of combat consumption modeling treating both general topics and quite specific technical problems, and four appendixes which are informal comments of panel members dealing with topics identified by them as being important.

MAIN REPORT

CONTENTS

APPENDIXES

I. INTRODUCTION

A. BACKGROUND, OBJECTIVE AND SCOPE

The Combat Consumption Modeling Improvement Panel was convened by invitation of the Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics). It was established in response to recommendations in the DoD Sustainability Study, published and distributed in October 1979. One recommendation of that study was:

> OSD should develop a framework and long-range plan under which the Services would undertake to improve their methodologies for simulating combat and estimating combat materiel and manpower demands.

The Institute for Defense Analyses was tasked, in June 1979, to organize a panel of experts in combat analysis and modeling, with the following objective: "To recommend mid-term and long-term improvement to analytical techniques for prediction of wartime consumption." The members of the panel are the authors of this report. Their names and affiliations are as follows:

Jerome Bracken (Chairman), Institute for Defense Analyses
John R. Bode, The BDM Corporation
Seth Bonder, Vector Research, Inc.
Hugh M. Cole, Independent Consultant
David B. Kassing, Center for Naval Analyses
Milton G. Weiner, The RAND Corporation

Consultation to the panel was provided by Lowell Bruce Anderson of IDA.

The panel held a three-day meeting in September 1979 in which representatives from OSD and the Services presented the existing methodologies for projecting demand for combat consumption. The members reviewed the DoD Sustainability Study and reviewed Service planning documents. The panel met on several occasions for further discussion in connection with the present report. This report embodies the panel's findings.

The questions addressed in the DoD Sustainability Study are vast in scope, and the resources of the panel have been small. Thus, it has been necessary for the most part to consider planning for sustainability from a highly-aggregated, top-down point of view, and to investigate only a few issues, identified by the panel to be important, in detail. In many areas, the panel believes that the caveats and recommendations for future work presented in the DoD Sustainability Study are helpful in identifying areas for methodological improvement.

B. LIMITATIONS OF THE PANEL REPORT

The limitations of the panel report are as follows. The information obtained was current as of September 1979. The Services are presently engaged in various improvements, or are planning to make improvements, not all of which are known to the panel. The panel concentrated on five topics:

(1) Army planning for war reserve equipment and munitions
(2) Air Force planning for air-to-ground munitions
(3) Air Force planning for air-to-air munitions
(4) Navy/Marine Corps planning for air-to-ground munitions[1]
(5) Navy planning for anti-air, anti-surface and anti-submarine munitions.

The panel concentrated on processes and methods, not on data needed to obtain results from planning processes. Since present planning cannot use data from future warfare, all planning data are fundamentally projections. In addition to the broad range of data pertaining to future warfare, the specific

[1]Although the Marines made presentations on other areas, the panel did not investigate their methodologies further.

need to project technical performance of weapons not currently in existence is an ever-present problem in planning. The panel believes, however, that the relative effectiveness of friendly and enemy forces can be more credibly predicted on the basis of technical data than the absolute effectiveness can be predicted. For instance, predicted relative attrition to both sides is credibly a function of predicted relative weapon performance on both sides, while absolute attrition to both sides is not as credibly a function of predicted absolute weapon performance on both sides.

C. FOCUS OF THE REPORT ON MATERIEL

While the DoD Sustainability Study treats both materiel and manpower, the panel concentrated on materiel. The main reason for this concentration was the assumption that conventional weapons effectiveness translates into attrition of materiel more readily than into attrition of manpower. The panel also concentrated on a European conflict because of the heavy demands in that area.

The actions suggested herein would significantly impact on manpower planning if materiel planning and manpower planning were tightly integrated, which they probably should be. However, the panel did not delve into present manpower planning methods. The reader can extrapolate findings of this report on the assumption that manpower attrition assessment methods are less-well-developed than corresponding materiel attrition assessment methods.

D. OUTLINE OF THE REPORT

The summary section appears first and contains the recommendations of the panel. The main body contains the agreed-upon discussion of the problem and recommendations of the panel. Appendix A is a detailed treatment of selected aspects of combat consumption modeling, treating both general and specific problems. Appendixes B, C, D and E are informal comments by panel members written during the course of the work of the panel.

II. CURRENT METHODOLOGY

The DoD Sustainability Study was a one-time analysis. However, the programming and budgeting for purchase of war reserve equipment and munitions takes place each year. The methods used by the Services in contributing to the Sustainability Study are under continuous improvement and are regularly utilized; therefore, the principal impact of the panel report should be felt in changing the planning process.

A. DEFINITIONS OF SUSTAINABILITY

Two definitions of sustainability are given in the Sustainability Study. The first definition is new: A "sustainability profile" is defined as the percent of demand that can be met over time. The second definition is old: "days-of-sustainability" is the number of days of combat during which the friendly forces can engage at their full demand rates.

Both of the above definitions are tied to projections of warfare outcomes over time. The projections are based on D-day forces, additions each day, and attrition each day. If there were full supplies, the war would be predicted to progress in a certain way and certain consumption would take place. The two definitions of sustainability constitute different views of how available supply and projected consumption might be combined.

B. 'LEVEL-OF-EFFORT' AND 'THREAT-ORIENTED' METHODOLOGIES

Two types of methodologies are used in planning. The "level-of-effort" methodology includes multi-stage assessments over time, while the "threat-oriented" (or "mission-oriented") methodology is one-stage. The Army level-of-effort methodology takes into account status of and attrition to forces of both sides; thus it is two-sided. The Air Force and Navy level-of-effort methodologies, used for planning air-to-ground munitions, include status of friendly forces and of a target base of enemy resources over time, but do not directly account for the status of enemy forces (other than the target base being attacked). Attrition to friendly forces is basically an input, not the result of enemy forces remaining. Therefore, it is fair to dub the two methodologies as one-sided. Threat-oriented methodologies are used for Air Force air-to-air and for Navy anti-air, anti-surface and anti-submarine munitions. These methodologies compute how many munitions are needed to destroy a certain target base. They are one-stage and one-sided. The Air Force threat-oriented methodology includes attrition to friendly forces (as an input) but the Navy methodology does not. In summary, the Service methodologies can be characterized as follows:

(1) Army--dynamic, two-sided, computed attrition

(2) Air Force air-to-ground--dynamic, one-sided, input attrition

(3) Air Force air-to-air--static, one-sided, input attrition

(4) Navy air-to-ground--dynamic, one-sided, no attrition

(5) Navy anti-air, anti-surface, anti-submarine--static, one-sided, no attrition.

The Army projects two-sided warfare over time based on a ground-air warfare simulation called the Concepts Evaluation Model (CEM). Initial forces, additions to forces, and attrition, on both sides, are taken into account in estimating consumption. The Army includes the major combat aspects of ground forces and land-based tactical air in its ground-air war. The air forces can be highly interdependent with the ground forces in affecting the war results, depending on assumptions about four related interactions: ground-to-ground, ground-to-air, air-to-air, and air-to-ground.

The Air Force air-to-ground methodology is termed level-of-effort since it has a time dimension, but as mentioned above it is not a two-sided simulation of tactical air warfare. A two-sided simulation would involve, for both sides, at least combat air support, airbase attack and intercept missions, as well as interactions with ground-to-air weapons. Even this scope might not be sufficient to properly analyze air-to-ground weapons, for interactions of air-to-ground and ground-to-ground weapons might significantly affect results.

C. AN OVERVIEW OF CHARACTERISTICS OF CURRENT METHODOLOGIES

The methods of calculating manpower and materiel requirements which are employed by the Services are listed in Table 1. In planning for ground-air warfare, a significant gap is evident in the lack of treatment of friendly ground-to-air weapons.

Table 2 lists considerations in planning for sustainability identified by the panel as a result of the briefings and discussions. Many of these considerations are discussed in the DoD Sustainability Study. They are noted here in order to highlight their importance in terms of improvements to the planning processes.

The planning processes, which for the most part use models, have all the limitations generally associated with models. Command and control, intelligence, leadership and morale are not explicitly modeled but would be crucial to the length and intensity of combat and thus to materiel consumption. Logistics systems are not modeled, and misallocations of logistics assets and attrition to logistics handling resources and materiel inventories are not accounted for. Many other caveats about models, data and assumptions are clearly stated in the Sustainability Study.

It should be kept in mind that the extent to which the models provide reasonable estimates of relative effects is paramount in planning for sustainability. Friendly resources

Table 1. METHODS OF CALCULATING MATERIEL AND MANPOWER SUSTAINABILITY

	Service		
	Army	Air Force	Navy
Munitions	Ground-to-Ground CEM/TRM Ground-to-Air Unknown	Air-to-Ground TAC WEAPONEER TAC SURVIVOR TAC SELECTOR Heavy Attack Air-to-Air Negative Binomial	Air-to-Surface NAVMOR Air-to-Air Surface-to-Air Surface-to-Surface Bose-Einstein
Equipment	Ground-to-Ground CEM/WARF Ground-to-Air Unknown	No Calculation	No Calculation
Manpower	CEM/FASTALS (CEM tuned differently from materiel analyses)	One-Time Analysis	Ad Hoc Calculation

Table 2. CONSIDERATIONS IN PLANNING FOR SUSTAINABILITY

1.	Context of sustainability analysis.
2.	Munition stockpile and war reserve equipment tradeoffs with force structure. Manpower replacement policy (peacetime resources implications).
3.	Definition of sustainability--should couple demand to supply.
4.	Scenario definition--presently one narrow, stylized scenario with no excursions (e.g., nuclear, chemical, catastrophic failure).
5.	Simulated warfare by CEM--credibility of results.
6.	Munitions/equipment/manpower--(a) inconsistent within Services (b) inconsistent among Services (c) omissions in methods.
7.	Point estimates dominate--little consideration of risk and of distribution of possible outcomes.
8.	Intra-theater resupply omitted--not known how to include it in models, and no analysis made of impact. Naval resupply unknown.
9.	Numerous problems of dynamic analyses with CEM.
10.	Numerous problems of dynamics in the static analyses.
11.	Unclear logic underlying attrition costing.
12.	When are threat-oriented methods appropriate in the two-sided context? What are the terminal conditions?
13.	Replacement assumptions--100 percent?
14.	Mixed utilization of dynamic and static analyses--integration not understood.
15.	Confidence levels in theater-oriented models--ambiguities, inconsistencies.
16.	Hierarchical construction of CEM--integration problems.
17.	Manpower attrition of Navy and Air Force subjective.
18.	Integrated top-down structure should replace previous Sustainability Study approach.
19.	Should Air Force and Navy have war reserve equipment?

consisting of forces and supplies face enemy resources consisting of forces and supplies. The objective is to provide sufficient friendly resources to ensure a satisfactory war outcome, regardless of the way in which enemy resources are employed. The models need the capability to generate relative predictions of warfare outcomes for various combinations of forces and supplies.[1]

[1]There is one principal problem, however, which makes prediction of absolute effects important. Since in practical terms a key issue is the tradeoff between (1) how much materiel to provide for sustainability between D+30 and D+60 (or thereabouts) and (2) how much force structure to provide for D-day, it is important to know roughly how much territory is lost by various days of the war. There is a big difference between the enemy conquering 15 kilometers by D+10 and 150 kilometers by D+10. Models have difficulty obtaining absolute predictions of results of warfare. Relative predictions of attrition in ground, air and naval warfare are more believable, but do not resolve some important absolute questions.

III. PROBLEM AREAS

A. OVERALL STUDY PROCESS

There are numerous aspects of the overall process of planning for sustainability that need to be improved. Selected issues identified by the panel are discussed below.

1. Difficulty of OSD Review

The models are in some cases impenetrable, making it impossible to understand where results come from. For instance, the Army's Concepts Evaluation Model (CEM) is composed of tens of thousands of FORTRAN statements and has no current documentation at various levels of detail (say 50 pages, 200 pages and 1000 pages). Thus the user of output from that model cannot understand how the output was produced. Furthermore, the inputs to the CEM are numerous, and understanding what they all are and where they all come from, including their interrelationships, is virtually impossible. The methodologies in other cases involve subjective decisions at various stages. They cannot be fully audited and replicated. There is not adequate simplicity in the planning methodologies to permit dialogue, questions and answers, and further understanding, which would lead to improvement of the methodologies and of the quality of results.

2. Definition of Sustainability

The new definition of sustainability as percent of demand which can be met over time is useful. Also, the old definition of sustainability as number of days of full demand which can be met is useful. Both definitions, however, assume independence of supply and demand. The first definition, with respect to its demand profile, assumes that combat would proceed based on consuming all desired materiel when in fact combat results would be very different if only a percent of the materiel were consumed. The second definition, with respect to its demand profile, also assumes that combat would proceed based on consuming all desired materiel when in fact combat would be different if it were known that supplies would be exhausted on an anticipated day, for rationing would be instituted.

As mentioned previously, *neither* definition can be applied to Air Force air-to-air munitions and to Navy anti-air, anti-surface and anti-submarine munitions, since the models are static.

3. Level-Of-Effort Versus Threat-Oriented Analyses

Level-of-effort analyses of the dynamic, two-sided form permit accounting for friendly and enemy resources over time. Thus the interactions of initial forces, additions to forces, and attrition to forces can be observed throughout the war. The effects of different assumptions about force structure and weapons effectiveness, over time, can be observed. The effects of timing of force increments by either side can be observed. Friendly kills of enemy weapons, and enemy kills of friendly weapons, by weapon type, can be observed period by period.

Level-of-effort analyses of the dynamic, one-sided form permit one to observe outcomes over time. The effects of changing numbers of shooters, times when they enter the warfare, and weapon effectiveness can be observed. But the effect of enemy forces on friendly forces is only based on input rates and not dependent on (1) effects of friendly forces on enemy forces, or (2) allocations of enemy forces.

Threat-oriented analyses collapse a dynamic process into a static process. Proponents would argue that since the timing cannot be known in advance, it might as well be ignored. Opponents would argue that a dynamic model can be run over wide ranges of timing of two-sided allocations, from a game-theoretic viewpoint, to investigate the effects of timing, rather than assuming timing out of the problem.

Threat-oriented analyses do not properly account for attrition to friendly forces. If attrition to friendly forces were such that there were not enough friendly shooters to fire the munitions, the whole analysis would be meaningless. The implicit assumption is that munitions of friendly forces can be fired. The methodology pays no heed to the status of surviving friendly forces beyond this assumption about their ability to fire--surviving friendly forces could be 10 percent or 90 percent of initial forces plus added forces, and not affect the results.

4. Inconsistent Analyses

Army and Air Force sustainability in the context of a NATO versus Warsaw Pact war involves a major portion of the resources being considered in the DoD Sustainability Study and in the planning process for materiel sustainability. Also, the NATO versus Warsaw Pact war is the principal arena for considering tradeoffs between force structures and sustainability. Force structure improvements can include increases in numbers (quantity), increases in weapons systems effectiveness (quality), or increases in trained, up-front, ready-to-go forces.

The ground-air war is highly interactive among the ground forces and tactical air forces on both sides. Following is a list of fourteen interactions, any of which can strongly affect the other and thus cascade through the highly interdependent ground-air war:

(1) Blue ground kills Red ground
(2) Blue ground kills Red air (at the FEBA)

(3) Blue ground kills Red air (in the rear)
(4) Blue air kills Red ground (at the FEBA)
(5) Blue air kills Red ground (in the rear)
(6) Blue air kills Red air (in the air)
(7) Blue air kills Red air (on the ground)
(8) Red ground kills Blue ground
(9) Red ground kills Blue air (at the FEBA)
(10) Red ground kills Blue air (in the rear)
(11) Red air kills Blue ground (at the FEBA)
(12) Red air kills Blue ground (in the rear)
(13) Red air kills Blue air (in the air)
(14) Red air kills Blue air (on the ground).

Additionally, the interactions involving ground weapons could profitably be disaggregated into the quite different categories of small arms, armor, anti-armor, artillery, helicopters, air defense guns and SAMs.

The above fourteen interactions define categories of attrition and weapons, and do not mention munitions. Of particular importance are munitions fired by aircraft, which are often specialized to effectively kill particular kinds of targets. Quantities and qualities of munitions carried day after day may strongly affect the results of the ground-air war. Also of particular importance are the effects of friendly and enemy ground-to-air weapons, both guns and SAMs, on aircraft. Army and Air Force planners have great difficulty choosing effectiveness parameters for friendly and enemy ground-to-air systems. In the DoD Sustainability Study the Army analysis did not present any calculations for requirements of ground-to-air munitions, and the Air Force analysis did not explicitly play enemy ground-to-air systems. This is an example of an interaction to which results can be highly sensitive.

a. Current Army and Air Force Analysis of Ground-Air Warfare

The Air Force currently develops a target data base consisting of various enemy resources to attack, including a specified number of armored vehicles. With Air Force planning assumptions, most of these armored vehicles can be killed by sorties flown in the first few days of combat. Munitions are provided to kill these armored vehicles. Other sorties are used against other targets, and munitions are provided for killing these other targets.

The Army analysis, on the other hand, indicates that the Air Force kills less than one-third as many armored vehicles over a 90-day war. If the Air Force had developed a different target base, their methodology could easily have resulted in their killing twice as many armored vehicles (six times as many as the Army estimates that the Air Force kills).

This point is being made so strongly because war outcome is crucially affected by this task, and the Army and Air Force analyses differ widely in their handling of the matter.

An intimately related topic was mentioned above, namely the effect of friendly and enemy ground-to-air weapons. Army ground-to-air calculations are not given in the DoD Sustainability Study, and the Air Force does not explicitly play enemy ground-to-air weapons in its models. Basically, the effects of friendly and enemy ground-to-air weapons seem to be essentially ignored, even though one, or both, could radically change the conduct of the entire war. If ground-to-air systems are highly effective, the opposed aircraft cannot function. Since NATO seems to be counting on aircraft relatively more than is the Warsaw Pact, it is incumbent on our analyses to treat ground-to-air interactions in a consistent and detailed manner in the context of two-sided analysis of the entire ground-air war.

In summary, the Army and Air Force are approaching munitions planning as though the other hardly exists. The Army is providing itself enough munitions to get by as long as possible, and not crediting the Air Force with many kills. The Air Force is developing a target list, including a certain number of armored vehicles and providing munitions to attack the targets. Why should the Air Force not attack twice or three times as many armored targets? Presumably, the targets could be killed in a few more days and the war outcome would be completely different. Furthermore, neither the Army nor the Air Force is systematically investigating the effects of ground-to-air weapons, which may critically affect the delivery of air-to-ground weapons. The current process is disconnected.

b. Current Navy Analysis of Air-to-Ground Warfare

The Navy uses a process similar to that of the Air Force in planning for air-to-ground munitions. The targets are chosen independent of Army and Air Force activities. The targets are thought of as being in Europe. Those Navy targets in AFCENT should be taken account of within Army and Air Force planning. Planning objectives for Northern and Southern flanks should be integrated with those of Allied and USAF forces.

c. Triple Counting

If the Army, Air Force and Navy all kill tanks in Central Europe, and do not consider each other's kills, perhaps munitions for several times more kills than there are tanks are provided for. This can be viewed as a hedge, but if so it is unquantified and uncontrolled. Hedging would be better performed by systematically specifying alternative scenarios, forces, effectiveness parameters, etc., and observing the results of integrated analyses.

5. Omitted Phenomena

The DoD Sustainability Study clearly and forcefully points out omitted phenomena, limitations and assumptions. The panel refers the reader to the Sustainability Study for discussions in detail of related issues. This section highlights a few such phenomena thought to be of particular importance.

a. Logistics

Intertheater and intratheater transportation are not sufficiently addressed. Intertheater airlift carries troops, some unit equipment, and a small fraction of war reserve equipment and materiel. It may be vulnerable to attack en route or at terminal points. Intertheater sealift carries the majority of sustainability resources and may also be vulnerable en route or at terminal points. Specific analyses of vulnerability of materiel in transit and entering the theater would be useful.

Within the theater, transportation resources and materiel in depots may be vulnerable. POMCUS may be vulnerable in its depots. Current ground-air models do not treat logistics vulnerabilities well, if at all. The models could probably be modified to account for destruction of logistics. Its delayed effects on combat, in terms of rationing and running out of supplies, could be modeled. However, sensitivity to particular items would be very difficult to represent. Alternatively, models might be factored in some way for logistics degradation.

Logistics has usually been an exceptionally serious problem historically. The right supplies at the right place at the right time are needed, and this requires redundancy of supplies as well as a substantial supporting organization. Motivated by the very large amounts of NATO resource commitments implied, logistics should be analyzed better.

b. Command, Control, Communications and Intelligence

These areas are traditionally difficult to analyze. The Service models do not treat resources in these areas. The panel does not foresee methodological improvements on the horizon which will enable explicit incorporation of these factors into warfare models for materiel planning.

c. Warning

Not much stress is laid on warning time in the DoD Sustainability Study. Warning affects D-day forces and reinforcements, as well as overall theater tactics. Alternative warning scenarios are not hard to treat with current methodologies, particularly if the models are fast-running and not exceptionally demanding from the point of view of data. It would seem that the current planning process could easily include various warning scenarios. Warning would affect results if analyses were based on two-sided, dynamic models.

d. Allied Forces

Alliance relationships can be considered to be part of the planning scenario. Materiel stocks of Allies determine their ability to continue warfare over time. Two-sided dynamic models of the future will probably be able to differentiate U.S. and Allies stocks, though present theater-level ground-air models do not differentiate well among stocks.

6. Tradeoffs

The DoD Sustainability Study and the Service methodologies do not concentrate on problems of trading off materiel with other military resources, or on problems of trading off within categories of sustainability-related materiel.

One tradeoff recommended for attention at the outset of the panel's work was termed "Readiness versus Sustainability". Readiness in the context of the problem statement can properly be interpreted as D-day combat power. D-day combat power is improved by adding force structure, by improving quality of munitions, by improving mobility of forces to engage where needed, and by other courses of action. Improving D-day combat power at the expense of sustainability would yield better results at the beginning of war, say at D+10. It would tend to prevent the enemy's seizing territory, and would limit negotiating strength of the enemy at the beginning of the war. It would result in worse results later in the war, if the enemy's sustainability were greater.

Another important class of tradeoffs arises in the contex of budget-constrained analyses. Equal-cost combinations of materiel, or of force structure and materiel, could be analyze and their results displayed for various times of the war.

B. SPECIFIC METHODS

Some specific current problems of the Service methods ar described briefly below.

1. Army

The Army's current approach is based on a patchwork of models and side analyses. Requirements for various types of replacement weapons, munitions, missiles and replacement personnel do not appear to be related in a logical and consistent way.

The Army has recognized this defect and is proceeding towards alleviating it by developing WARRAMP, which will be based on the CEM. To do this well, several deficiencies in the CEM should be corrected. The following two deficiencies seem to be the most significant:

(a) The attrition calculations seem to be weak relative to available alternatives.

(b) The procedure for accounting for the consumption of specific types of weapons, ammunition and missiles is not sufficiently extensive.

As an alternative or as an adjunct to building WARRAMP, the Army could develop a simplified approach not based on the CEM. The CEM is very complex and was designed for purposes not closely related to materiel consumption.

2. Air Force

The Air Force calculates demands for air-to-ground ordnance, air-to-air ordnance, and replacement personnel in essentially unrelated ways. We are not aware of Air Force investigations of whether or not it would be worthwhile to provide wartime replacement aircraft (analogous to the Army's provision for war reserve tanks).

Air Force calculations ignore the options for multi-role aircraft in a two-sided, dynamic war. They also ignore the dynamic interrelationships resulting from attrition to friendly and enemy aircraft.

3. Navy

The Navy separates ordnance into classes and calculates demands within classes independently of each other and of demands for replacement personnel. It has not investigated whether or not it would be worthwhile to provide wartime replacement aircraft or replacements for other major types of equipment.

The Navy ignores, or treats too briefly, many important aspects of combat related to the demand for ordnance. Some examples of these aspects are: scenario, determination of initial allowances, attrition to friendly forces, and the relative impact of killing various types of targets.

IV. RECOMMENDATIONS

A. THE OVERALL CONTEXT

Senior decision makers need to trade off among capabilities for fighting a short war (say 10 days), a medium-length war (say 30 - 120 days) and a long war (say two years). Provision of materiel and manpower resources for sustaining the fighting capabilities of friendly forces of incremental days in medium-length wars involves very large expenditures. The focus of this panel is on the methodology for evaluating outcomes of medium-length conventional wars.

D-day force structures of friendly and enemy forces for various scenarios are fairly well specified. For a short war, models which incorporate various types of quantitative information can be employed to make rough estimates of outcomes. However, decision makers in sustainability planning focus on medium-length wars, for here center the tradeoffs between force structure and materiel. Also, medium-length wars provide more methodological problems than short wars (but less than long wars). In planning medium-length wars, decision makers and analysts must consider D-day forces and materiel, additions to forces and materiel over time, and attrition to forces and materiel. This must be done for both friendly and enemy forces. Forces can be used in many different ways over time, and both quantity and quality of forces effect results over time.

Decision makers should focus on (1) planning scenarios, (2) various options for use of ground, air and naval forces over time, (3) initial force structure and materiel, (4) increments to force structure and materiel, and (5) attrition. Both friendly and enemy forces must be considered.

Decision makers should bear in mind that models are generally believed to be more useful in estimating the relative effects of military resources than the absolute effects. Estimation of relative effects may be very useful for trading off among types of resources. However, absolute effects such as exactly how much attrition is taken or friendly territory lost by D+10 will significantly affect the war-fighting situation, and models are more uncertain in making such absolute assessments. Because the basic underlying phenomena cannot be modeled rigorously, there is little or no potential for improving models to the point where they can credibly predict absolute results. Judgments of various types, and quantitative comparisons of theater force ratios in various past wars with those generated by models, may be used to calibrate the absolute results of the models. For many issues of force structure and sustainability tradeoffs in the medium-length wars, particularly if friendly forces are computed to be approximately holding their own, models can shed light on improvements from marginal changes in various types of resources.

Finally, decision makers should be cautioned that the panel did not sufficiently consider manpower, is not comfortable with what was briefly considered, and recommends further investigation.

B. THE DEFINITION OF SUSTAINABILITY

Two definitions of sustainability are given: (1) percent of full demand satisfied over time, and (2) number of days during which full demand may be satisfied. Only the Army's dynamic two-sided methodology is discussed in terms of either definition. The Air Force air-to-air munitions and Navy anti-air, anti-surface and anti-submarine munitions are planned by static one-sided methods to which the definitions have no relationship.

In the case of the Army, the former definition is weak because if only a percent of full demand were being satisfied, the war would proceed differently; the latter definition is weak because if all of full demand were being satisfied, and running out was anticipated, the war would proceed differently.

The panel recommends that work be done to develop better definitions of sustainability, with the goal of finding measures which would be useful across Services.

As discussed below, the panel favors dynamic, two-sided analyses, and prefers the second measure to the first.

C. MAJOR RECOMMENDATIONS

The panel has found two major methodological problems in planning for sustainability. The Army and the Air Force plan separately to fight a ground-air war, with many disconnects. The Navy plans air-to-ground munitions independent of the other Services, and its procedure for anti-air, anti-surface and anti-submarine munitions is seriously flawed.

The Army and the Air Force should project the outcome of ground-air warfare over time for various planning assumptions. All of the following fourteen interactions should be specified over at least a 90-day war, by both Services:

(1) Blue ground kills Red ground
(2) Blue ground kills Red air (at the FEBA)
(3) Blue ground kills Red air (in the rear)
(4) Blue air kills Red ground (at the FEBA)
(5) Blue air kills Red ground (in the rear)
(6) Blue air kills Red air (in the air)

(7) Blue air kills Red air (on the ground)
(8) Red ground kills Blue ground
(9) Red ground kills Blue air (at the FEBA)
(10) Red ground kills Blue air (in the rear)
(11) Red air kills Blue ground (at the FEBA)
(12) Red air kills Blue ground (in the rear)
(13) Red air kills Blue air (in the air)
(14) Red air kills Blue air (on the ground).

The Army and Air Force can do the above jointly or separately. OSD should help establish the planning scenarios and monitor the planning process. This should include understanding the model or models, and the data inputs, in detail. If the current models and data are too voluminous to be monitored, they can and should be replaced by simpler components.

OSD should suggest various planning assumptions to be analyzed by the Services. If the Services use separate models, and they strongly disagree, OSD should decide which analysis is to be followed.

With respect to the Navy, two methodological problems should be corrected. The procedure for determining air-to-ground munitions should be coordinated with the scenarios of the other Services, or a new scenario proposed. The model is presently adequate. The procedure for determining anti-air, anti-surface and anti-submarine munitions should be discarded. The basic philosophy of this procedure incorporates random attacks on friendly forces by enemy weapons, rather than attacks on friendly forces designed to destroy them.

D. OTHER RECOMMENDATIONS

1. OSD Role and Activities

OSD should monitor the planning process. This includes specification of planning scenarios and assumptions, auditing of model structure and technical details, review of planning data, and identification and resolution of difficulties. These activities imply significant resource commitments by OSD if they are to be done right technically. But, as mentioned above, the processes of the Services should be designed in such a way as to make OSD monitoring feasible.

2. Service Roles and Activities

The Services should continue to improve models and data. The Army, Air Force, and perhaps the Navy, should analyze the ground-air war and take positions on their forecasts of its outcome for various planning scenarios. Combat interactions of great sensitivity, such as those involving the effectiveness of the friendly air-to-ground weapons and of the enemy ground-to-air weapons, should be analyzed more intensively.

3. Treatment of Risk

The planning scenarios should include some with assumptions unfavorable to friendly forces. The impact of short warning, better-than-expected enemy weapons, worse-than-expected friendly weapons, faster mobilization of enemy forces, larger-than-expected enemy materiel stockpiles, and other considerations, should be studied.

The basic planning scenario should be modified as appropriate to allow for hedges against events which would be very bad for friendly forces. Some capabilities provided for in the standard planning scenario might be given up to guard against particularly unfavorable events.

4. Level-of-Effort Versus Threat-Oriented Analyses

Level-of-effort two-sided analyses such as the Army's are generally preferred. Level-of-effort one-sided analyses and threat-oriented analyses should be discouraged for all the reasons discussed in this report.

The two definitions of sustainability are consistent with level-of-effort analyses, but are not flawless. The percent of full demand satisfied over time is worse than number of days during which full demand may be satisfied. The former measure is theoretically wrong from the outset because it ignores the changes in demand and indeed in the course of combat when computed demand is not satisfied. The latter measure becomes wrong later on.

5. Explicit Analysis of Logistics

The improvement of intertheater and intratheater logistics analyses should be of high priority. History strongly supports the argument that military capability breaks down due to lack of POL, ammunition and supplies.

The previous discussions of tradeoffs between D-day force structure and materiel for sustainability have not sufficiently highlighted the issue of fleshing out all force structures to provide better logistics.

In this area the models are very weak. The panel recommends that at the beginning the Services and OSD present hand calculations justifying that logistics resources are sufficient. It should be remembered that sufficiency should not be based on the assumption of perfect allocations. Mismatches of materiel and materiel-handling resources with combat resources should be explicitly treated.

E. RECOMMENDED MARGINAL IMPROVEMENTS TO SERVICE MODELS

The following recommendations are offered for use in two eventualities. First, the Services might be able to rather quickly make some minor changes and incorporate them in their models. Second, in the longer run the recommendations of this report for highly integrated planning might not be implemented. We offer these comments to marginally improve the current process.

1. Army

The Army should continue to develop an integrated methodology based on a theater-level model. It would be desirable to replace or supplement the CEM by a model that treats sustainability-related resources with greater richness, but which is streamlined by the simplification of other (non-attrition) aspects of warfare currently modeled in the CEM.

If the Army continues to use the CEM, then the CEM should be improved as follows:

(1) Its attrition should be improved.

(2) Its procedures for accounting for consumption of specific types of ammunition, weapons and materiel should be improved.

(3) Running time should be shortened, perhaps by deleting some parts of the model.

(4) The revised CEM should be fully documented.

2. Air Force

The Air Force should replace its current methodology with a methodology based on a dynamic, two-sided theater-level tactical air model, perhaps even including a simple ground model.

Improvements to existing air models, such as TAC WARRIOR, would be needed to provide appropriate information related to combat consumption. Additionally, calculations would be needed to provide for the selection of particular types of air-to-ground ordnance. These additional calculations could be made by separate application of the current Air Force air-to-ground methodology, using as input sorties of various types (for instance, close-air-support sorties) produced by TAC WARRIOR.

3. Navy

The Navy should survey its inventory of simulation models to identify proper models for all phases of naval warfare (air-to-ground, anti-air, anti-surface and anti-submarine). It should develop a procedure to link these models for step-by-step simulation of naval warfare. Planning scenarios for sustainability should be specified and analyzed.

In the near term, the Navy should adopt five changes:

(1) One or more straightforward planning situations should be specified.

(2) Attrition to friendly combat and resupply resources should be accounted for.

(3) A lower "risk" factor should be used than that in the present methodology.

(4) A lower value for expenditure of ordnance against any one target should be used.

(5) The definition of what constitutes a platform for each type of interaction should be re-examined.

APPENDIXES

APPENDIX A

SELECTED ASPECTS OF COMBAT CONSUMPTION MODELING

by

Lowell Bruce Anderson

CONTENTS

TABLES

SELECTED ASPECTS OF COMBAT CONSUMPTION MODELING

A. INTRODUCTION

1. Scope

The subject of sustainability is related to all other aspects of combat--consumption, readiness, training, force structure, command, control, communications, intelligence, peacetime support procurement, type of combat (conventional, tactical nuclear, etc.), and scenario assumptions (location of war, size of threat, length of combat, etc.). This paper will discuss one aspect of sustainability, namely, the determination of combat consumption, while assuming that other factors are held fixed.

Clearly this assumption narrows the scope of the discussion. For example, after defining readiness and sustainability, one could attempt to trade off dollars spent on readiness versus dollars spent on sustainability (versus, perhaps, dollars spent on other aspects of combat). However, a major aspect of sustainability (no matter how it is defined) is the determination of how many munitions of each type to purchase (and maintain), and a major portion of these munition purchases are determined (either directly or indirectly, using factors) by estimates of combat consumption.

As mentioned, we assume that estimates of each side's readiness, training, morale, leadership, etc., are held fixed; therefore we do not consider trading off increased purchases of munitions for improvements in these areas. When appropriate, however, we will discuss trading off force structure purchases with the purchase of munitions.

The discussion here will consider only conventional combat. If in some theater, non-conventional combat called for a larger purchase of munitions than did conventional combat, then this additional purchase must be considered by methods other than those discussed here. However, if conventional combat requirements dominate non-conventional ones for conventional munitions, then the purchases of conventional munitions can be determined by considering conventional combat only.

Finally, this discussion will consider only the determination of the mix of purchases subject to a total budget constraint; with one exception (Section E.3), we will not discuss how large this total budget should be. This restriction is made for several reasons. First, this restriction is appropriate given the assumptions listed. Second, results obtained with this restriction can be very useful in contributing both concepts and data toward an attempt to determine an absolute level of spending for munitions. Third, it seems almost certain that one must be able to quantitatively justify the mix of purchases subject to a total budget constraint before one can quantitatively justify an absolute requirement for munitions of all types (and it will be argued below that DoD is currently far from being able to quantitatively justify the mix of these purchases). Fourth, and most important, results obtained under this restriction can be very useful in their own right.

This paper will not produce such results. The purpose of this paper is to recommend improvements to the analytical techniques currently being used to obtain such results.

2. Resources Considered

The term "munitions" was used loosely above. Strictly speaking, the following distinction is drawn: we will discuss (1) munitions for weapons; (2) replacement weapons; and

(3) replacement personnel. The weapons considered here are all conventional weapons of all services. Replacement weapons are those which are not part of the initial force structure, but which are used to replace a weapon in combat if that weapon is destroyed during combat (and includes the support structure needed for those replacements). Replacement personnel are people who are not initially assigned to a unit, but who replace casualties in units (and includes the support structure needed to handle those replacements).

In the final section of this paper we will also consider force structure weapons. When referring to a force structure weapon, we mean the weapon, the crew, and an appropriate slice of the support structure necessary to maintain that weapon as part of an active unit in the force structure.

B. BACKGROUND

1. The Current Overall Approach

The basic premise of the current overall approach used by DoD in determining combat consumption is considerably different from that which we will consider here. That is, we want to address the problem of determining the quantity of each type of munition, replacement weapon, and replacement personnel one can purchase or hire given a fixed budget. Insight, understanding, and aids to decision-making can then be developed by varying the size of this budget. The basic premise of the current overall DoD approach is to divide the problem into three separate problems (that for munitions, for replacement weapons, and for replacement personnel), and then to subdivide each of these three problems into separate problems for each of the three Services (four Services, if the Marines are counted separately). These resulting nine problems are then considered in separate (and inconsistent) ways. For example, the problem of determining the quantity of munitions to buy for the weapons (of a Service) is further subdivided according to arbitrary groupings of weapons, and (sometimes) is still further subdivided into the individual types of weapons systems. Once the problem is sufficiently subdivided, then absolute requirements for, say, munitions for a particular type of weapon are determined. Adding up the costs of the munitions for all types of weapons in all the Services gives the total number of dollars to be spent on munitions. Thus, the current overall DoD approach does not explicitly make any trade-offs of buying munitions for one weapon versus buying munitions for different types of weapons in order to achieve a fixed budget for munitions. The same comments apply to replacement weapons and personnel.

2. The Two Component Approaches Within the Current Overall Approach

As discussed in Annex 1 to this Appendix, there are two basic approaches now being used to compute demand for munitions. One is the static approach (in the Annex, the "defeat the entire threat" approach; in the Sustainability Study [1], the "threat oriented" or the "mission oriented" approach). No attempt is made to determine how attrition is taking place over time. The static approach assumes that a given size threat must be killed (by a given group of weapons) sometime or another, and the problem is to determine the quantity of munitions needed to do this killing. The second approach is the dynamic approach (in the Annex, the "meet the demand day-by-day" approach; in the Sustainability Study, the "level-of-effort" approach). In the dynamic approach, the time-phasing of the demand for munitions is explicitly considered. We will use the terms static approach and dynamic approach. (Later, we will distinguish among various types of dynamic approaches.)

There are two points to be noted. First, weapons (and munitions) do not necessarily belong to groups that can be analyzed by one approach but not by the other. For example, the demand for air-to-air munitions can be analyzed dynamically as well as statically, and the demand for tank munitions can be analyzed statically as well as dynamically. Annex 1 contains a possible explanation as to why some weapons have been analyzed one way and some the other, but this division appears to have occurred because of the alternative methodologies that were available at the time. In a sense, this division is an historical accident.

The second (and closely related) point to note is that dynamic models now exist that can address all of the major weapons and munitions types considered in the Sustainability Study, whether that Study considered them dynamically or not. Likewise, the static methods developed for so-called mission- (or threat-) oriented items could be used to analyze the so-called level-of-effort items.

To summarize, modern dynamic models consider the size of the threat as well as the mission of the weapons they model, and, if used reasonably, they will not produce a requirement to kill more threat than exists. Likewise, static analyses assume that a certain task is to be accomplished, which is, in a sense, equivalent to assuming the level of effort needed to accomplish that task. Further, since combat is basically dynamic, static analyses make (perhaps implicit) assumptions concerning the dynamics. These assumptions could be stated explicitly and their impact evaluated. If these assumptions turn out to be reasonable, then the static methods based on them might be appropriately applied to all weapons. If these assumptions turn out not to be generally reasonable, then it might be that the static methods are appropriate for very few, if any, weapons.

In short, a decision to use a static or a dynamic approach can now be made based on the factors of combat involved and on the intended use of the analysis, not on a choice restricted to arbitrarily simplified approaches.

C. STATIC VS DYNAMIC APPROACHES

1. General Future Courses of Action

The course of future work on determining combat consumption depends in large part on the intended use of this work. If it is to be used to justify certain requirements for certain types of munitions (or for certain types of replacement weapons or replacement personnel) in isolation from the requirements for other types of munitions (and replacement weapons and replacement people) and in isolation from a total budget constraint, then this work can continue to analyze small groups of weapons one at a time. This piecemeal structure has considerable merit for such a use. On the one hand, narrowing the scope to munitions for a few types of weapons allows a study to examine these weapons in greater detail and/or under a wider variety of conditions. On the other hand, there is no direct benefit from being consistent with the methods and assumptions used to determine other requirements for munitions if a study is only interested in justifying the munitions requirements for a few types of weapons.

However, if future work is to be used to determine the purchase mix of munitions and replacement weapons (and replacement people) subject to a total budget constraint (as discussed in Section A), then the current piecemeal approach appears to be totally inadequate. Some common framework needs to be developed and used.

One possibility is to build structurally consistent static models for determining the munitions, replacement weapons, and replacement personnel requirements for all of the weapons in all of the Services and then exercise these static models in a consistent manner. Likewise, another possibility is to build structurally consistent dynamic models for determining these requirements for each of the Services and then exercise these dynamic models in a consistent manner.

For the reasons stated in Section A, we assume that a major intended use of future work in this area is to determine the mix of purchases subject to budget constraints. Accordingly, relatively comprehensive approaches will be emphasized here. Allowing multiple approaches (such as both a static and a dynamic approach) will be considered, but the long term use of piecemeal approaches, which due to their inconsistency preclude comparison of alternative mixes, will not be recommended.

2. A General Comparison

a. Advantages of Dynamic Approaches Over Static Approaches

(1) The Time-Phasing of Demand

The most obvious advantage of the dynamic approach is that it directly gives a time-phased demand, not just a total demand. However, this advantage is of relative unimportance because the total demand produced by a static analysis can be spread out over time (time-phased) using either judgment or an analytic method specifically designed to do this (note, this spreading out of total demand is not now done in static analyses). Another reason for the relati\ unimportance of this advantage is that a change in combat intensity might change both the total demand for and the timing of the demand for munitions, but not the relative proportion of the demand (i.e., the mix), and so might not affect how a fixed sized budget would be spent. Thus, the time phasing of demand may not be as important as some of the other advantages of dynamic approaches for determining how to spend a fixed budget.

(2) The Capability to Add Additional Details

It is generally easier to add additional details, interactions, and characteristics to dynamic models than to static models. If certain additional details are clearly called for, then this advantage can be significant. However (as will be described below), if the ability to add additional details results in developing an overly detailed model for the problem at hand, then this advantage of dynamic approaches becomes a disadvantage.

(3) The Time-Phasing of Interactions

While it may be reasonable to assume that a theater (or task force) is faced with a specific size of enemy threat, it is not reasonable to assume that each type of weapon in that theater (or each type of weapon in that task force) is faced with a fixed portion of that threat. For example, the effects of saturation, the layering of defenses, and friendly attrition during an enemy air raid are important factors for determining weapons, munitions, and personnel requirements, yet these factors cannot be represented (or can only be very poorly represented) in static methodologies. Also, interactions due to the sequential nature of raids or battles cannot be represented in static methodologies. For example, enemy tanks killed on Day 1 are not there to be killed on Day 2, while friendly tanks killed on Day 1 can do no killing on Day 2. Likewise, enemy aircraft killed on the ground on Day 1 cannot fly missions to do killing (or to be killed) on Day 2, which affects the number of aircraft available to do killing and be killed on

Day 3, and so forth. The inadequacy of static methodologies to consider these interrelationships may be the most significant relative advantage of dynamic approaches, and will be discussed further below.

(4) The Capability to Compare Analyses

It is not reasonable to assume that the Army, the Navy, the Air Force, and the Marines will soon use one joint methodology (be it static or dynamic) to determine all of the requirements for munitions, replacement weapons, and replacement personnel; nor is such an event necessarily desirable. What is desirable is to be able to compare analyses done by the separate Services (and done by separate components within a Service). For example, such a comparison is necessary to evaluate alternative mixes for various budget levels, and to test for "double counting" and "gaps" among the analyses. Relatively quick comparisons of several static analyses can be made, but these comparisons may only skim the surface of the problem. For example, such a comparison of static results might only uncover a different assumption on how much of the threat is to be allocated to each weapon for killing. It usually takes longer to compare dynamic analyses, but such a comparison can produce relatively more fundamental differences, such as different availability factors, P_k's, or "corridor" widths.

Making comparisons is clearly aided when the analysis of one Service uses a methodology which includes all of the weapons of the other Services likely to be in the same theater. Static approaches inhibit such inclusion because interactions are hard to portray statically, and without interactions there is no direct reason to model weapons of other Services. On the other hand, dynamic approaches encourage including all interactions perceived to be relevant, and so encourage inclusion of weapons of other Services.

b. Falsely Claimed Advantages of Static Approaches Over Dynamic Approaches

This section lists three concepts which are sometimes claimed to be advantages of static approaches over dynamic approaches but which, on closer examination, are not. Some real advantages of static approaches over dynamic approaches are given in Section c below.

(1) Scenario Independence

It is sometimes claimed that static analyses are scenario independent (as well as being independent of other inputs related to the dynamics of combat) because static analyses require few or no scenario-related inputs and (in general) a lesser number of other inputs than are used in dynamic analyses. A more precise claim would be that static analyses do not give different answers if used to model different scenarios. Clearly, this is not an advantage if the answers should depend on the scenario, but the methodology ignores this dependence.

Perhaps more importantly, there is often an implicit scenario within the static analysis. For example, suppose a static analysis treats aircraft carriers as if they were all vulnerable to a heavy attack. Then (depending on the details) this analysis may be modeling a scenario where all aircraft carriers are simultaneously vulnerable to a heavy attack, as opposed to a scenario where, say, at most nine carriers can simultaneously be vulnerable to heavy attack. Accordingly, static analyses may well have a strong dependence on an implicit scenario. If this implicit scenario is not reasonable, then the apparent scenario independence is neither true nor advantageous.

(2) Lack of Predictive Pitfalls

A frequently used red herring is roughly as follows: "Dynamic models are intended to predict the outcome of combat. Since it is obvious that the outcome of combat cannot be predicted in advance, it follows that dynamic models have no use." A follow-on to this argument could be that, since dynamic models have no use, static analyses should be performed.

In truth, dynamic models have many uses but none involves calculating definitive answers. One use involves comparing alternative purchases to see which ones are relatively preferred (i.e., more cost-effective). Such a comparison should be used as a check on currently planned purchases, not to dictate these purchases. In those areas where the current planning matches the analytical results obtained using models, one could have more confidence in the current planning and so might implement this planning more quickly and spend relatively less staff time and research effort on these areas in the future. In those areas where the current planning is not supported by the analytical results, long-term commitments to the current planning might be deferred and relatively more staff time and research effort could be devoted to analyzing the current planning vs the alternatives suggested by the results of the dynamic models.

Another use involves making a type of prediction (more accurately, a "net assessment"). The important ideas here are twofold. First, such predictions should not be used to dictate policy--with one potentially important exception they should only be used as an analytical check to show where more work may be needed. (The potentially important exception occurs when a prediction is needed and there is no better way to make it than by using models. In this case the question is not "Are dynamic models good enough?" but

"Is there anything better than these models?".[1]) Second, the outcomes of using a dynamic model to make net assessments should be considered as dynamic assessments only of what that model assesses (force structure, munitions, replacement weapons, etc.); these outcomes are not assessments of all aspects of combat, and hence are not absolute predictions. As discussed in the Sustainability Study, these outcomes can serve as predictors if a prediction is desired which (1) is numeric and (2) does not (or need not) consider "intangible" factors of combat, such as leadership and training. But note that static analyses like the ones used in the Sustainability Study are also numeric and do not consider these "intangible" factors. Thus, static analyses could also serve as predictors; but they are usually not even considered because dynamic methods are clearly more appropriate. The fact that static approaches are not considered suitable for such a use is, if anything, a disadvantage of static approaches relative to dynamic approaches.

(3) <u>Necessary Simplicity</u>

As will be discussed below, simplicity can be of great advantage, and static methodologies are frequently much simpler than dynamic ones. What is not true is that static methodologies are necessarily simpler than dynamic ones. For example, Volume IV of the NNOR [2] gives a static method for analyzing munitions requirements for a single type of naval weapon (i.e., it considers naval weapons one at a time). This method is considerably more complex than several simple dynamic models of naval combat. "Simpler" is not

[1]If one argues that pure human judgment should always be considered as being better than the outcome of models (until further analysis shows this judgment to be wrong), then one is essentially arguing that there is no exception here and that dynamic models should always just serve as an analytic check on this judgment.

necessarily "better" (because the complexity may be important), and static is not necessarily simpler than dynamic.

c. Real Advantages of Static Approaches Over Dynamic Approaches

(1) De Facto Simplicity

The relative ease with which details can be added to dynamic models (combined with the desires of many model builders and model users to produce and use more "credible" models) results in dynamic models becoming quite complex. That is, while both static and dynamic models can be "made simple," it is relatively easier to keep static models simple because there are natural barriers (related to the lack of dynamics) against making them more complex. On the other hand, "credible," when it applies to dynamic models, is frequently taken to mean something like "an absolute belief that the model portrays war like it really would be"; and since war is really complex, and since it is easy to make a dynamic model more complex, that's what is done. Accordingly, static models are usually much simpler than dynamic models.

Simplicity is not always an advantage, but there are significant advantages to simplicity. Simple models are easier to understand, and people deservedly hesitate to use the results of a model they don't understand. It is frequently easier to avoid errors in obtaining data and in interpreting outputs and it is certainly easier to avoid computational errors in simple models than in complex ones. Finally, simpler models are easier and quicker to run and so several different cases (or variations of the data) can, in some sense, be run with a simpler model for each case run with a more complex model. Since, in general, models should be used to make comparisons, not to compute a once-and-for-all correct answer, the ability to run many cases is important. Other potential advantages of simple models over complex ones could be given, and all these advantages apply to those static models which happen to be simpler than the corresponding dynamic models.

(2) The Capability to Add Static Concepts

On a case-by-case basis, advantages are to be found for static models, but these advantages do not fall into an easily labeled group. For example, certain types of concepts might be more easily added to a static model than to a dynamic one. Some of these additions might be easier to add because these static models happen to be initially simpler than their dynamic counterparts, and so are more easily modified (as described above, this capability would then be a de facto advantage for these static models). Other additions to other static models might be easier to add because these static models have an analytically tractable representation or solution (this type of capability would be an intrinsic advantage of these static models). Other types of static models might have other similar features.

This type of advantage of static models is probably best described through examples. One concept worth mentioning as a potential advantage of static approaches is that of risk in terms of the statistical variation in the amount of munitions required to kill a certain number of targets, where the statistical variation is due to the assumptions concerning the firing doctrine and the probability of kill.

For example, suppose that one weapon is attempting to kill 10 targets by firing missiles at these targets. Suppose that the targets remain in range long enough so that the missiles can be fired one at a time, and kill assessment of of the targets can be made between each firing (i.e., shoot-look-shoot), and suppose that the P_k per missile is 0.5. That weapon will need an average of 20 missiles to kill all 10 targets. This, however, is an average; if the weapon had 20 missiles, then sometimes it would have excess missiles and sometimes it would run out of missiles before it had killed all 10 targets. The risk of running short can be analytically treated in this simple situation. For example, if a planner desires that, with probability 0.8, this weapon will have enough missiles to kill all 10 targets, then the weapon will need 24 missiles (90 percent confidence of killing all 10 targets requires 26 missiles, 95 percent confidence requires 28 missiles, and 99 percent confidence requires 33 missiles, while 50 percent confidence requires only 19 missiles).

This capability to determine the number of missiles required for a weapon, based on a desired confidence of not being short of missiles due to certain statistical variations, is a potential advantage of this type of static analysis. Some dynamic analyses might theoretically be able to produce these results, but actually doing so could be very difficult due to the typical complexity of dynamic models. However, one reason that the corresponding dynamic models tend to be more complex is that the static model described above is oversimplified. Not only is the shoot-look-shoot assumption generally unrealistic, portioning out the threat so that each type of weapon can engage only a fixed number of targets is unrealistic. That is, "targets" usually have to penetrate through several layers of defenses, and the static approach for assessing risk as described above (and as used by the Navy and the Air Force) appears to be inadequate to handle layered defenses. Details concerning this potential defect will be discussed later. The point here is that if portions of this static approach are totally inadequate, then the fact that this approach has an additional feature which strongly depends on these inadequate portions is not an advantage. However, if these inadequate portions can be fixed, then there may be an important advantage here (depending on whether or not the results that consider this type of risk are significantly different from results which ignore this risk). As it stands now, this assessment of risk can, at best, be called a potential advantage.

D. DISCUSSION OF SPECIFIC METHODOLOGIES

Section C above discussed some general advantages and disadvantages of static and dynamic models. In contrast, the discussion which follows is specifically related to the particular methodologies used by the Services to model combat consumption. Limitations and suggested improvements to the Services' methodologies will be discussed, but a review of the strong points of these methodologies will not be given here. The point of this presentation is to discuss difficulties and suggest improvements, not to provide an overall summary of these methodologies. Limitations that the Services are aware of and are in the process of correcting will not be discussed in detail (or may not be mentioned at all). Accordingly, this discussion does not critique all aspects of the Service methodologies as they were used in conjunction with the Sustainability Study. Finally, this discussion will consider only the methodologies themselves, not the particular data that were used in the Sustainability Study for these methodologies. This restriction allows an unclassified discussion of limitations of methodologies, but prevents detailed considerations of the importance of these limitations. Whether these limitations have significant or minor impact depends on the data; further work is needed to determine the extent of this impact.

This discussion is arranged as follows. Army methodologies are discussed in Section D.1. Air Force methodologies are discussed in Section D.2 (with the exception of statistical risk mentioned in Section C.2.c(2) above). Since the concept of risk is common to portions of both Air Force and Navy methodologies, it is discussed separately in Section D.4. Section D.3 discusses interrelationships between the Army and the Air Force combat consumption methodologies. Section D.5 discusses the Navy methodologies (other than the risk structure discussed in D.4). Section D.6 discusses interrelationships between the Navy and the Army and Air Force methodologies. Marine Corps methodologies are not discussed here; however, parts of the discussion of the other Services' methodologies may be directly relevant to Marine Corps analyses.

A summary of principal recommendations is presented in Section E.

1. Army Methodologies

a. The Army's New Approach

Previously, the Army used separate methodologies to compute combat demands for munitions (other than surface-to-air missiles), surface-to-air missiles, replacement weapons, and replacement people. The Army has done some work on developing a new methodology, WARRAMP, which is intended to simultaneously consider all of these demands. In terms of budget-constrained analyses, the primary advantage of WARRAMP is that it could allow demands for all Army munitions, replacement weapons, and replacement personnel to be compared on a consistent basis. Accordingly, the WARRAMP approach (if implemented in a reasonable way) could enable the Army to take any fixed budget and determine analytically how that budget should be spent on these various resources (i.e., to determine the mix of these resources). The point here is not that such a determination supplants the need for judgment, but rather that this determination is analytical and so can be used to supplement judgment.

The present Army approaches (and the current approaches of the other Services) do not allow analytical trade-offs of the overall mix of these resources. For example, the Army currently cannot analytically estimate the impact of buying more surface-to-air missiles and fewer tank rounds, or vice versa; they should be able to do so when WARRAMP is finished. In contrast, the other Services are not now considering developing a methodology that would allow, for example, estimating the impact of buying more air-to-air missiles and fewer air-to-ground munitions, or vice versa. Accordingly, the Army appears to be at least one step ahead of the other Services in this area.

b. Suggested Improvements

While the Army's new approach appears to be generally on the right track, several details of the proposed WARRAMP structure could be improved.

(1) Documentation

Current Army analyses were made using, in part, an undocumented version of a theater-level combat model--Concepts Evaluation Model (CEM). If the goal of using models is to provide analytical results for comparison (rather than to produce a one-time correct answer), then documentation is important in order to evaluate the results and make intelligent comparisons. The Army intends to use a new version of the CEM in WARRAMP, and it is important that this new version be adequately documented.

(2) Ground Attrition Calculations

While earlier versions of the CEM had some advantages over other theater-level models, they also had severe defects related to artificially aggregated attrition calculations. (Indeed, an early version of the CEM attempted to downplay combat attrition in order to concentrate on other aspects of warfare.) There is no reason to continue using these artificial attrition equations just because previous versions of the CEM did so. Attrition calculations form a very important part of determining the demand for munitions, replacement weapons, and replacement personnel. If the developers of WARRAMP believe that the current (artificial) equations are appropriate, then they should justify their beliefs. On the other hand, if they do not have strong reasons for continuing to use these equations, then these equations should be replaced by more appropriate attrition structures.

Two general approaches for improving the ground combat calculations in the CEM are as follows.

First, if the CEM is not intended to model combat attrition per se, but only to provide good approximations to attrition as computed in more detailed models, then the quality of these approximations needs to be explicit. In particular, if the equations used in the CEM are intended only to be curve fits, then good "curve fitting equations" should be used and the quality of these fits should be discussed. It should be noted, however, that if the fits are not very good, or if the quantity or quality of results from the more detailed models are not very good, then this approach might not result in a net improvement to the CEM.

Second, the attrition equations in the CEM could be replaced by equations intended to model combat attrition. Generally speaking, changing the attrition equations inside a computer model of combat is not very difficult (compared to, say, changing the structure of the model or adding additional resources to be modeled). New attrition equations for the CEM could be based on those already used in VECTOR-2 (see [3] and [4]) or in IDAGAM I (see [5], [6], [7], and [8]), so new research is not required.[1] Since attrition calculations are important in determining combat consumption, since the attrition calculations in the CEM are not as good as other methods currently available (cf, the critique of the CEM given in [9]), and since changing these equations may be relatively easy for the Army to do, we recommend that the Army improve the attrition calculations in the CEM.

(3) Air Combat Modeling

In the CEM, air combat is modeled in much less detail than ground combat. This imbalance may be appropriate for an Army model, since it may only be necessary for the Army to reflect the effect of air combat, not model it in detail. However, since the actions of the Army and the Air Force are not independent in combat, it is appropriate to compare the results of Army models with those of Air Force models. Such a comparison could be enhanced if there were to be some planning on the part of the Army to model Air Force assets in a manner that is reasonable to the Air Force, perhaps in a manner that is consistent with the way that the Air Force models these resources. (The same applies to the way that the Air Force models Army resources.)

This comment is not meant to imply that the Army and Air Force should necessarily use the same data--there may be many data values on which they disagree. (Indeed, using similar models and methodological procedures can help to

[1] Of course, the Army may want to perform additional research to improve on these already developed equations.

specify, illuminate, and understand such disagreements, which otherwise might be hard even to define.) Nor is it intended that the Army and Air Force model all resources and interactions in precisely the same way. If there is disagreement on how to model certain resources and interactions, then such disagreement should be reflected in the models. However, the Air Force might be able to suggest improvements or alternatives to the ways in which the Army is currently modeling Air Force resources. The Army might not agree with all of these suggested improvements, but they should at least attempt to match Air Force models in these areas where they do not clearly disagree and where computer running time and core storage requirements are not violated. The Army may be doing all this now (i.e., it may be coordinating the air combat portion of the CEM with the Air Force), but the existence of such coordination is not clear in the Sustainability Study or in related documents and briefings. (One of the difficulties here is that, while the Air Force has developed models of air combat, these models are not used to determine munitions requirements. This lack of use of Air Force models is described in more detail below.)

Whether or not Army and Air Force models can be made more compatible, the Army should build WARRAMP so that (as an option) it can be used with Air Force inputs. For example, if the results of Air Force models and data say that the Air Force will fly certain numbers of close air support sorties on the various days of the war, and that these sorties will kill certain numbers of tanks, APCs, etc., on these days, then the Army should be able to insert these sorties and kills into their model to determine the potential impact of these Air Force results on the Army's demand for munitions.

(4) Complexity and Computer Time

An important characteristic of the Army's approach is that it involves use of a complex dynamic model, the CEM. This characteristic means that the Army's approach has the general advantages and disadvantages discussed above. A clear disadvantage of this approach is that the CEM apparently takes a long time (several hours on the computer) to run even a moderate length war. This disadvantage can be very significant if it means that the CEM can be run only a few times during a study. An appropriate use of models is to use them to make comparisons, and making comparisons usually requires making many runs.

If the CEM can be speeded up (at least in turn-around time if not in computer running time), then this can help alleviate the problem. Whether or not the CEM can be speeded up, the Army might consider developing a simplified approach to complement a CEM-based WARRAMP. This simplified approach might be a static approach or a simple dynamic approach, and one of its uses could be to filter many different cases down to a few to be run through the CEM. Other aspects of using both a complex dynamic model and a simple model on the same problem will be discussed in Section E.

(5) Use of the New Approach

The previous Army methodologies essentially restricted the Army to conclusions of the form: "If the Army is to fight for N days with no shortage of munitions and full weapon and personnel replacements, then the Army needs to spend a total of D dollars on munitions, weapons, and people." Then the Army could list specific types of munitions and replacements to provide for out of these dollars. This type of conclusion is very limited because it makes no relative comparison (e.g., could the same D dollars be spent more usefully on a different mix of the various types of munitions and replacements?). Instead, it sets up an absolute standard: D dollars is enough money to spend on munitions, replacement weapons, and replacement personnel to fight a war for N days without having a shortage of any of these items.

For the reasons argued above, models can be more appropriately used for making comparisons than for setting absolute standards. Further, very useful results can be obtained by comparing alternative ways to spend a fixed budget on various types of munitions, on various types of replacement weapons, and on replacement personnel. With WARRAMP, the Army should be able to make such comparisons. They can address such questions as: Out of D dollars to be spent, should more money be spent on munitions and less on replacement weapons, or vice versa? Should more money be spent on certain types of munitions and certain types of replacement weapons, and less on other types? Should more money be spent on replacement personnel and less on hardware, or vice versa?[1] As argued above, the answers to these questions can be useful in their own right, and addressing these questions for various sizes of total budget, D, can lead to a better understanding of, and (perhaps) conclusions for, broader problems. Of course, the answers to these questions may depend on the measure of effectiveness selected.

Another advantage of a consolidated approach, such as WARRAMP, is that it allows several measures of effectiveness to be considered. Each of these measures, if properly defined, can be used to compare a wide variety of potential options, ranging from buying more replacement tanks to buying more missiles for SAM launchers. In general, one hopes to find options which are robust across several different (but broadly defined) measures of effectiveness, and judgment is required if no such uniformly robust options exist.

---

[1]It is important to significantly expand and improve the CEM's accounting procedures so that these questions can be adequately addressed by WARRAMP.

2. Air Force Methodologies (Less Risk)

The Air Force uses separate methodologies to compute combat demands for (a) air-to-air missiles, (b) air-to-ground munitions, and (c) replacement personnel. Additionally, the Air Force assumes that it is not worthwhile to purchase replacement aircraft for combat attrition. Part of the computation of the combat demand for air-to-air missiles considers possible statistical variations in this demand (i.e., risk), which will be discussed in Section 4, below. The other Air Force computations are considered here.

a. Dynamic Interrelationships

Dynamic interrelationships among weapons (and the uses for these weapons) are important to all of the Services, but especially to the Air Force. For example, Red aircraft that are killed on the ground on Day 1 by Blue air base attackers are not available to fly air base attack missions against Blue on Day 2, and so cannot be killed by Blue interceptors on Day 2. Red aircraft not killed on the ground on Day 1 might be killed by Blue interceptors on Day 2; and those that are not might kill Blue aircraft on the ground on Day 2, which would leave Blue with fewer aircraft to fly close-air support sorties on Day 3, and so on.

The dynamics of air warfare play a central role in theater-level air combat modeling. Several Air Force briefings and several publications have discussed these relationships. In particular, a rather careful discussion of these relationships is given in the TAC CONTENDER documentation [10]. (TAC CONTENDER may be a somewhat oversimplified model, and it appears to have been replaced in Air Force analyses by TAC WARRIOR [11], but its discussion concerning missions for aircraft and their dynamic relationships is still appropriate.)

In spite of this Air Force work (and corresponding work outside the Air Force), their methodologies ignore virtually all of the dynamic aspects of air combat. For example, the air-to-ground methodology might buy more munitions in one case than in another in order to kill more enemy aircraft on the ground early in the war, yet the air-to-air methodology might ignore this additional capability because the air-to-air calculations are done separately. Likewise, their air-to-air capability might be sufficient to kill large numbers of the enemy aircraft very early in a particular war; yet the air-to-ground methodology might buy munitions for air base attack sorties to be flown near the end of that war.

Some aspects of the Air Force air-to-air methodology will be discussed in Section 4. Their air-to-ground methodology essentially consists of two parts. One determines what munitions are to be loaded on an aircraft given that that aircraft is to attack a specific type of target. This part of the methodology is discussed in Section (e) below. The other part determines which types of targets to attack on which days of the war. This determination is made, in part, by giving subjective values to the different types of targets.

The use of subjective values may be appropriate for comparing the different types of targets that aircraft would fire on in support of ground forces; i.e., those targets that would be acquired on close-air support or interdiction missions.[1] However, such subjective values are not appropriate

[1]Subjective values for all of the different types of targets are currently determined by Air Force personnel, which may be reasonable if subjective values are needed to compare killing tanks with bombing runways. However, if subjective values are required only for targets for aircraft that are flying missions in support of ground forces, then these values might more appropriately be obtained from the supported forces, not from the supporting forces. That is, since these Air Force missions are supporting the Army, the Army should determine the relative value of the targets. These values could be determined either by experienced Army personnel or by using models of ground combat which properly account for air-delivered munitions.

for determining whether aircraft should fly these ground support missions or should fly air base attack missions instead. The benefit from flying air base attack missions (as well as that from flying escort, SAM-suppression, and defensive missions) should be measured in terms of the number (and types) of ground support missions flown. The rationale behind this statement has been presented in [10], in several Air Force briefings, and elsewhere (cf, Appendix N of the IDA Air Defense Requirements Study [12]). In developing its munitions requirements, the Air Force gives no reason for not following this rationale; this rationale is simply ignored and a piece-meal, noncoordinated (in a dynamic sense) approach is used. The arguments in favor of this rationale (for measuring the outcome of air warfare in terms of its net impact on ground forces) are relatively convincing. With no arguments to the contrary, one must consider that the Air Force is in error in not using this rationale to derive their munitions requirements.

The impact of this error is not easy to determine without simulating combat (with a model such as TAC WARRIOR) to calculate the munitions requirements in a dynamically coordinated way (in fact, it may be small for some types of munitions). However, this dynamic coordination affects the demand for all Air Force munitions, air-to-air as well as air-to-ground, and so the impact of dynamic coordination might affect the balance between air-to-air and air-to-ground munitions (a balance that is essentially ignored in the current Air Force approach). While one cannot say for sure what this impact is without doing the analysis, what can be said is as follows: The Air Force and others have argued for considering the effects of the dynamics of air warfare, the Air Force has (or is close to having) the capability to consider such effects in models such as TAC WARRIOR, and such effects are potentially significant (especially in a budget-constrained environment). Yet the Air Force is currently ignoring (and, apparently, plans to continue to ignore) these effects in determining their munitions requirements.

b. Multi-Role Aircraft

An important aspect of air warfare is that many different types of aircraft (produced anywhere in the world) are multi-role aircraft. Indeed, if one defines "roles" or "missions" so that SAM suppression in support of close-air support aircraft is a distinct mission, separate from the mission of the close-air support attackers themselves, and that air base attack of enemy runways is a separate mission from that of attacking sheltered aircraft, then all of the world's aircraft are multi-role. Further, aircraft can be used on one mission on one day, and then be used on a different mission on the next day, simply by loading that aircraft with different munitions. In addition, many aircraft on both sides can fly (or can be modified to fly) any combat mission (other than EW and reconnaissance) on any day of a war (provided that there is suitable weather), and can fly any other mission on the next day of that war.

This aspect has important implications in virtually every type of analysis of air warfare, and it is important in analyzing the demand for munitions, replacement personnel, and wartime replacement aircraft (if any are to be bought). For example, if the enemy uses most of its aircraft to fly attack, escort, and SAM suppression missions early in a war, and we use most of our aircraft on defense (i.e., as interceptors) and the rest on close-air support, then we will need enough air-to-air missiles for all these defensive missions, but we may need no munitions for air base attack missions. On the other hand, if we react to their attack by using most of our multi-role aircraft to fly air base attack missions in order to kill their aircraft on the ground, then we will need fewer air-to-air missiles and more shelter killing munitions. If instead of attacking deep into our territory, the enemy only flies shallow close-air support missions, we might fly fewer defensive missions and more close-air support missions. This would decrease requirements for air-to-air missiles (relative to the first case just mentioned), but would increase requirements for air-to-ground munitions and for ground-to-air missiles. If the enemy only flew defensive missions over their ground forces with their multi-role aircraft, then our requirement for munitions would depend on how many escort (or fighter sweep) missions we flew versus how many close-air support missions we flew with our multi-role aircraft.

The concept of multi-role aircraft in air warfare is closely related to that of dynamic interrelationships discussed above, and it is also discussed in some detail in the TAC CONTENDER documentation ([10]) and elsewhere (cf, [13]). Analyses of air warfare which ignore the multi-role capabilities of aircraft ignore potentially significant aspects of the problem they are addressing. In determining its requirements for munitions and replacement personnel, the Air Force apparently ignores these important capabilities.

Again, the impact of this defect in the Air Force approach is hard to determine without doing all the work "right," and then comparing the results; but the potential impact is very significant. For example, it appears that the Air Force currently assumes that the enemy is going to fly certain types of missions on certain days of a war, and it buys its munitions accordingly. If the enemy uses their aircraft the way we think they will, then we've bought the right munitions; if not, then we have the wrong munitions, but perhaps they would be flying the wrong missions--which is like virtual attrition. But there is no indication that this "balancing out" will occur. Indeed, since the Air Force apparently does not even consider what would happen if the enemy were to use its aircraft in a different manner, it may be that the enemy has alternative uses for their multi-role aircraft that are much better for them (and much worse for us) than the uses we think they will employ. If so, and if we buy munitions based on what we think the enemy will do (as opposed to what we estimate the enemy can do), then we would be much worse off in a war if the enemy used their alternative and better strategy. Thus we would possess multi-role aircraft, but we could not use them properly because we based our munitions purchases on our estimate of enemy intentions rather than capabilities.

Another way of looking at this aspect of air warfare is that multi-role aircraft potentially can be used in several ways, and we should buy munitions taking direct account of this flexibility. Flexibility itself can be an important goal, depending on how it is defined. For example, we could buy enough munitions of each type to be flexible enough to kill, say, 50 percent of the enemy's aircraft in 30 days of combat, no matter how the enemy uses its aircraft. Or we could buy enough munitions of each type to allow our multi-role aircraft to fly those missions that would maximize some particular measure (such as Blue minus Red ordnance delivered in support of ground forces through 30 days of combat), assuming that all of the Red strategies for their aircraft are equally likely. Or we could buy enough munitions of each type to allow our multi-role aircraft to fly those missions that would maximize this measure assuming that Red will use its aircraft in such a way as to minimize this measure. Each of these examples represents a type of flexibility, but the first two are examples of false flexibility (or "sub-flexibility"). The third example is a meaningful form of flexibility, and it represents a minimum amount of flexibility that should be considered in Air Force munitions procurement. More broadly defined concepts for flexibility might also be considered, but the Air Force should not continue to ignore (or narrowly define) the flexibility of combat aircraft in determining its munitions requirements.

c. Replacement Personnel

The discussion above concerning dynamic interrelationships and multi-role aircraft concentrated on the impact of these characteristics of air warfare on the demand for munitions. These characteristics also affect (though perhaps less strongly) the demand for replacement personnel. Currently, the Air Force computes its demand for replacement personnel separately from its demand for munitions. Clearly the two demands are related, and computing each while ignoring the other can lead to imbalances in the results. A comprehensive approach which relates the demand for munitions to that for personnel (while considering the factors described above) should be used to balance these demands.

d. Replacement Aircraft

The Air Force currently has no ongoing methodology to determine the value of purchasing some aircraft expressly as replacements for aircraft lost through combat attrition. If a gross comparison of the costs and capabilities of such attrition replacement aircraft indicates that purchasing some such aircraft might be worthwhile (as opposed to other types of purchases), then a methodology should be developed to analyze in sufficient detail the value of replacement aircraft. Such a methodology should directly consider the characteristics of dynamic interrelationships and multi-role aircraft discussed above.

e. Attrition Costing

One aspect of the current Air Force methodology for computing air-to-ground munitions requirements is that attrition rates and replacement costs for destroyed aircraft are used to compute the optimal munitions to load on an aircraft for each target/aircraft/weather configuration (see Section II.B.3 of the NCAA [14]). This raises several potential problems. It may be that if these potential problems were adequately addressed, the results would be similar. However, it is appropriate to point out these problems in a methodological discussion so that future analyses can correct these problems.

One way of looking at this attrition costing methodology is to view it as combining wartime costs (replacement costs and sortie costs) with peacetime costs (the costs of the munitions). Typically, studies consider peacetime costs for a wartime capability. Indeed, all of the costs considered in the Sustainability Study (except for corresponding air-to-ground munitions calculations by the Navy) are peacetime costs for a wartime capability. There are good reasons for the typical approach. For example, the war (or wars) being analyzed may never occur. Also, if one considers wartime costs, it seems reasonable to consider all wartime costs, and the Air Force methodology ignores the cost of the lost pilots. It may be possible to do a reasonable analysis that considers both peacetime and wartime costs. But, if such an analysis is employed, then (1) the rationale for considering wartime costs (as opposed to just peacetime costs for a wartime capability) should be given, (2) the wartime costs should be weighed by the probabilities of occurrence of each type of war, and (3) all relevant wartime costs (not just equipment costs) should be considered.

Another way of looking at this attrition costing methodology is to consider both the munitions cost and the aircraft replacement costs as peacetime costs. That is, the Air Force might reasonably want to answer the following question: "Given a fixed force structure (in terms of UE aircraft) and given that D dollars are available to spend on munitions and replacement aircraft, how should this money be spent?" This question might be answered by buying those types of munitions and replacement aircraft that maximize the total enemy value destroyed subject to the constraint of not spending more than D dollars. Answering this question would require determining and using the (peacetime) cost for purchasing and maintaining replacement aircraft.

However, the Air Force assumes that purchasing replacement aircraft cannot be worthwhile, but they then go on to use the cost of replacement aircraft to determine their munitions purchases. They seem to imply (in determining munitions purchases) that buying replacement aircraft is somehow very worthwhile or even mandatory, which contradicts their actions concerning the purchase of replacement aircraft.

The error caused by these inconsistencies may be very small. Indeed, it can be shown that, if several significantly simplifying assumptions[1] are made, then the Air Force methodology will buy the same munitions regardless of the (nonnegative) replacement cost of an aircraft; that is, the exact same set of munitions will be bought whether replacement aircraft cost nothing or cost 30 million dollars each. Therefore, if these (or similar) simplified assumptions hold, the Air Force methodology might be providing reasonable results. But these simplified assumptions may not hold now and, even if they do, they might not hold in the future.

---

[1]See Annex 2, A Set of Simplifying Assumptions Under Which the Current Air Force and Navy Attrition Costing Technique Is Reasonable, for details.

Suppose that sometime in the future no such simplified assumptions hold, and that the munition buys change significantly as the replacement costs for aircraft change. Suppose further that, in the future, the cost of the air-to-air radars on the F-16 and F-18 change significantly, thus changing the replacement costs of these aircraft. Suppose that the Air Force and Navy decide to buy the same number of these aircraft under the new costs. Then, if the Air Force and Navy are still using the current "attrition-costing" methods, the change in air-to-air radar costs might cause them to buy different air-to-ground munitions which could result, for example, in a different number of enemy tanks being killed. It may be possible that if all possible interactions were carefully considered, then more (or less) expensive air-to-air radars would cause the Air Force and Navy to kill more (or fewer) tanks with the same number of aircraft; but such a result should be obtained from a logically consistent approach--not as an artifact of the current methodology.

f. Summary of Suggestions

As indicated in Sections a and b above, the Air Force approach should be completely overhauled to consider the effects of dynamic interrelationships and multi-role aircraft. Models currently exist that directly consider these effects, and these models can be relatively easily modified to address the impact of these effects on the purchase of air-to-air missiles, air-to-ground munitions, and replacement aircraft.[1]

[1]For example, in addition to TAC WARRIOR [11], IDATAM [15] also considers the effects of dynamic interrelationships and multi-role aircraft in some detail. TAC WARRIOR and IDATAM are relatively detailed air combat models that do not internally optimize the allocation of aircraft to missions but can accept various input allocations for aircraft (and thus allow an enumerative examination of selected strategies as discussed in [13]). There are several less detailed models of air combat that attempt to optimize these allocations (see [10], [16], [17], [18], [19], [20], and [21]).

Therefore, changing the Air Force approach would not require new, large-scale computer models to be built. Expansions and improvements may be needed to the accounting procedures of existing models (depending on which model or models are selected for use and what those models already do), and a few "off-line" calculations may need to be made; but making these accounting modifications and additional calculations should be much easier than starting from scratch. The determination of requirements for replacement personnel should be done consistently with this integrated approach, and a new method for selecting air-to-ground munitions should be developed which addresses the problems raised in Section d and which is consistent with this new approach.

3. Interactions Between the Army and the Air Force

a. A Suggested Approach

The following fourteen categories of attrition have been suggested for consideration:

(1) Blue ground weapons kill Red ground weapons
(2) Blue ground weapons kill Red aircraft (near the FEBA)
(3) Blue ground weapons kill Red aircraft (in rear areas)
(4) Blue aircraft kill Red ground weapons (near the FEBA)
(5) Blue aircraft kill Red ground weapons (in rear areas)
(6) Blue aircraft kill Red aircraft (in the air)
(7) Blue aircraft kill Red aircraft (on the ground)
(8) Red ground weapons kill Blue ground weapons
(9) Red ground weapons kill Blue aircraft (near the FEBA)
(10) Red ground weapons kill Blue aircraft (in rear areas)
(11) Red aircraft kill Blue ground weapons (near the FEBA)
(12) Red aircraft kill Blue ground weapons (in rear areas)
(13) Red aircraft kill Blue aircraft (in the air)
(14) Red aircraft kill Blue aircraft (on the ground).

This report suggests that (1) the Army and the Air Force develop and provide OSD with the results of these attrition interactions over time (e.g., for each day of the war or at jointly agreed upon times during the war) and by type of target; (2) the Army and the Air Force provide OSD with the major assumptions and data behind these results; (3) the Army's planned purchases of munitions, replacement weapons, and replacement personnel be consistent with the assumptions data, and results provided by the Army; and (4) the Air Force planned purchases of munitions, replacement aircraft (if any) and replacement personnel be consistent with the assumptions, data, and results provided by the Air Force. The Army and Air Force could provide this information to OSD in two general ways: they could each provide separate results, or, if they could reach agreement, they could provide one set of joint results.

b. <u>Rationale for This Suggestion</u>

The underlying reason for asking the Services to provide this information to OSD is that, since these fourteen categories of attrition are interrelated in combat, any analysis related to combat attrition should (at a minimum) consider these categories of attrition in a consistent manner. Some specific reasons for OSD to request this information from the Services are as follows:

First, if all of the "shooting weapons" aren't considered in a consistent manner when determining the quantity of munitions to buy, DoD could end up over-buying munitions to kill one type of target and, perhaps, not buying enough to kill another type. For example, the Air Force currently uses a static (threat-oriented) approach to attempt to determine how many air-to-air missiles to buy. Suppose, in doing so, the Air Force assumes that the Army will kill only 25 percent of the threat, and that the Air Force will kill 75 percent. At the same time the Army is buying ground-to-air missiles on the basis that it will kill 75 percent of the threat while the Air Force will kill 25 percent. While the calculations of each Service may be internally consistent, taken together too many anti-air missiles are being purchased. (Conversely, if each Service assumes the other would kill 75 percent, too few are being purchased.) One may want to be on the "safe-side" by buying more of certain types of munitions than is called for on average; but such safe-siding should be intentional and consistent in size with the safe-siding for other types of munitions, not an unintentional and possibly disproportionate by-product of how the Services did their calculations. Providing the assumptions, data, and results for these fourteen categories of attrition could (1) help avoid unintentional "over-killing" or "gaps," (2) help explain inconsistencies (if any) among the Services' assumptions on how much of the threat each is likely to kill, and in what manner and when the threat is likely to be killed, and (3) help in computing "safe-siding" in a consistent and appropriate manner.

Second, attrition results over time are important because a static proportioning of the threat may lead to purchasing inefficient munitions in place of efficient ones. For example, suppose that 2,000 enemy tanks are to be killed during the first 30 days of combat and that the Air Force is "assigned" 10 percent, and the Army 90 percent, of these kills. It may be that the Army could kill its 1,800 tanks over the whole 30 days provided that the Air Force limited its kills to 200 tanks, which the Air Force might achieve in 2 days. Clearly, if the costs are equal, and if the Air Force could kill more tanks given the munitions to do so, then buying anti-tank ammunition based on this 90/10 split is unreasonable. Similar hypothetical examples could be given concerning the proportioning of enemy aircraft to the various weapons that kill aircraft, and the timing of when these weapons can kill these enemy aircraft. Accordingly, more information is needed (than is given in a static proportioning of targets to shooters) in order to determine whether munitions purchases are reasonable and efficient with respect to the timing of the kills by the various types of munitions. Such timing considerations might also strongly affect decisions as to whether to buy (for example) more replacement aircraft and fewer replacement tanks or to hire fewer replacement airmen and more replacement soldiers.

Third, providing these results by type of target is important to ensure that (when considered together) the Services aren't unintentionally planning to "over-kill" some types of enemy weapons while not planning to kill enough of other types of enemy weapons.

Fourth, how the enemy uses its multi-role aircraft clearly affects all fourteen of these attrition results, over time and by type of target, and so affects the demand for munitions and replacement weapons (and aircraft) through changes in these attrition results. Therefore, if DoD chooses to consider alternative uses of enemy multi-role aircraft in determining combat consumption, then the time-varying impact of all fourteen attrition results must be considered. Also, as argued above, it could be a severe error not to consider alternative uses of enemy multi-role aircraft. (Furthermore, enemy and friendly uses of multi-role aircraft are interdependent from a two-sided point of view, and the impact of this interdependence should be analyzed.)

It is clear from these arguments why OSD should request information on the fourteen types of attrition from the Army and the Air Force, especially in a budget constrained environment. It may not be so clear why the Air Force should be interested in determining ground-to-ground kills, or the Army interested in determining air-to-air kills. The answer is that if the Air Force is to determine how many tanks it can kill on Day 2, it needs to know how many tanks and ground-to-air weapons the Army kills on Day 1, and so on. The same argument applies to Army kills of enemy aircraft. Thus, each Service (separately or in conjunction with the others) should attempt to determine the appropriate results for all fourteen types of attrition.

4. The Consideration of Risk by the Air Force and Navy

a. The Basic Methodology for Considering Risk

The Air Force and Navy define risk in essentially the same way, their calculations of risk have the same mathematical core, and they both have the same methodological error. Because of this similarity and the amount of detail required to discuss this error, the discussion of this aspect of both the Air Force and Navy methodologies is combined herein.

While the core calculations are the same, the Air Force and the Navy approach these calculations in different ways, they apply their calculations to different weapons systems, and they use different data. Therefore, the significance of the error discussed below can depend on the particular weapon of the particular Service being considered (it might be significant for some weapons but not for others).

The basic approach of the Air Force is to divide the total number of enemy aircraft to be killed anywhere in the world into enemy aircraft to be killed in each theater. The enemy aircraft to be killed in a theater then are divided up among:

(1) air-to-ground kills by

  (a) US Air Force
  (b) US Navy
  (c) Allies,

(2) surface-to-air kills by

  (a) US Army
  (b) Allies,

(3) air-to-air kills by

  (a) US Air Force
  (b) US Navy
  (c) Allies.

Those enemy aircraft to be killed by the Air Force in air-to-air combat (group 3a in this categorization) are then subdivided by altitude bands in which the killing is to occur, and by which type of Air Force air-to-air missile (AIM-7E-3, AIM-7F, AIM-9E, AIM-9J, AIM-9L) is to do the killing. The end result is a requirement to buy enough air-to-air missiles of type i to kill a_{ijk} enemy aircraft in altitude bank j in theater k, subject to the specified risk. If this consideration of risk yields a requirement to buy r_{ijk} missiles of type i, then summing r_{ijk} over j and k gives the total requirement for this type of missile.

The Navy has a slightly different approach, and it applies this approach to three general classes of weapons: (1) surface-to-surface missiles, (2) anti-air warfare weapons, and (3) submarine/anti-submarine weapons. For simplicity, only the second class (anti-air warfare weapons) will be explicitly considered here; but since the methodology discussed below applies to all three classes, it is potentially significant for any one of them.

The types of anti-air warfare weapons considered by the Navy are PHOENIX, SPARROW, SIDEWINDER, SM-ER/MR, SEASPARROW, 8" GP, and 5" GP.[1] The enemy threat is considered to be of two types: aircraft and anti-ship missiles. Based on this grouping of weapons, random variables of the form $A_{ij}(k_i)$ are considered, where $A_{ij}(k_i)$ is the number of targets of type j to be killed by weapons of type i associated with a particular platform, given that there is a total of k_i platforms that can be associated with weapons of type i (these platforms are assumed to have identical characteristics). For example,

[1]It is not clear why the PHALANX is not considered here. The PHALANX could contribute both towards killing an expected number of the threat and towards reducing the "risk" by killing portions of the threat assigned to (but unkilled by) the weapons that are considered. Thus, analyzing the PHALANX elsewhere and not considering it here could lead to a significant error.

if the weapons are air-to-air missiles or long-range surface-to-air missiles, then the number of platforms (k_i) might be the number of carrier task forces; if the weapons are short-range surface-to-air missiles, the number of platforms (k_i) might be the number of individual ships that carry these weapons. The end result here is a requirement to buy enough munitions of type i *per platform* to kill $A_{ij}(k_i)$ targets of type j, subject to the specified risk. If this consideration of risk yields a requirement to buy r_{ijk} munitions of type i, then summing over j and multiplying by k_i gives the total requirement of munitions of type i.

For the Air Force, let M_{ijk} be the random variable which gives the number of munitions of type i that are needed to kill a_{ijk} enemy aircraft in altitude band j in theater k.[1] For the Navy, let M_{ijk} be the random variable which gives the number of munitions of type i (associated with any one of the identical k_i platforms) that are needed to kill $A_{ij}(k_i)$ enemy weapons of type j. Let p be a "risk" factor.[2] Then each Service calculates r_{ijk} by

$$r_{ijk} = \min\{N \mid P(M_{ijk} \leq N) \geq p\} \ .$$

That is, if integer constraints are ignored, r_{ijk} is the value that satisfies

$$P(M_{ijk} \leq r_{ijk}) = p \ .$$

(Theoretically, p could be a function of i, j, and k; but it usually isn't such a function in either the Navy or the Air Force methodologies.)

---

[1]That is, if p_K is the probability of kill of one missile and if the firing doctrine is one missile per salvo, then M_{ijk} is binomially distributed with parameters a_{ijk} and p_K.

[2]In a sense, p is a "safety" factor rather than a "risk" factor because the closer p is to 1.0, the less the risk is.

b. The Methodological Error

The methodological error here is twofold. First, "extra" missiles (or, in general, munitions) are purchased to reduce the risk of running short when shooting at a particular group of targets, yet the methodologies do not allow these extra missiles to be used against any other targets when they are not needed against that particular group of targets. Second, if enough of each type of missile is bought to kill its share of targets with probability p (i.e., the risk factor is p), and if there are n different types of missiles, and if using "extra" missiles of one type to shoot at the targets assigned to another type of missile is not allowed, then the overall probability of killing all the targets is p^n, not p.

For example, suppose that there are only two types of missiles ($n = 2$, $i = 1,2$), and one altitude band and one theater for the Air Force, or one type of target and one platform for the Navy (so that $j = k = 1$). Suppose also that each type missile is to be fired in single missile salvos, that each type has the same p_K, and that each type can be used against all of the enemy targets. Then the Services will solve for values of r_{i11} to satisfy

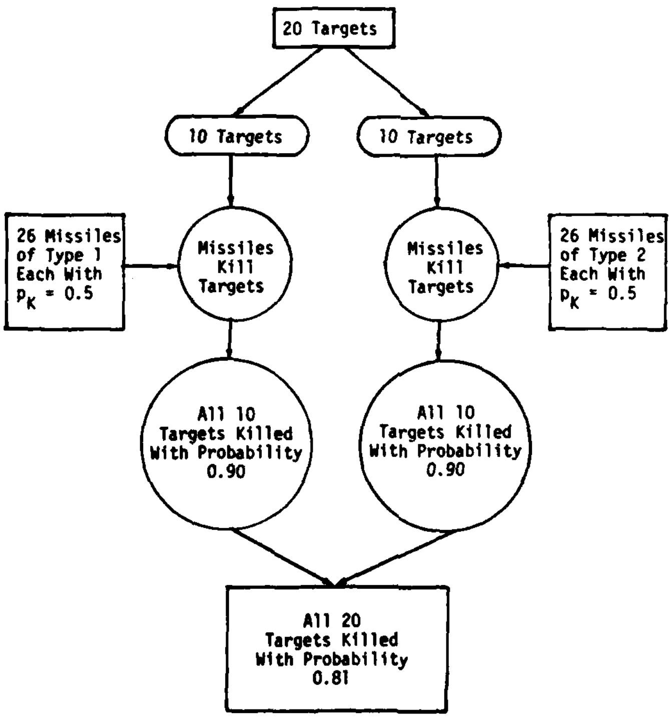
$$P(M_{i11} \leq r_{i11}) = p$$

for $i = 1$ and 2, and this would result in an overall risk (of killing all the targets) of p^2. If there are no firing restric 'ons (each missile can be used against any of the targets) and if an overall value of p^2 is desired, then r_{i11} should be values which satisfy

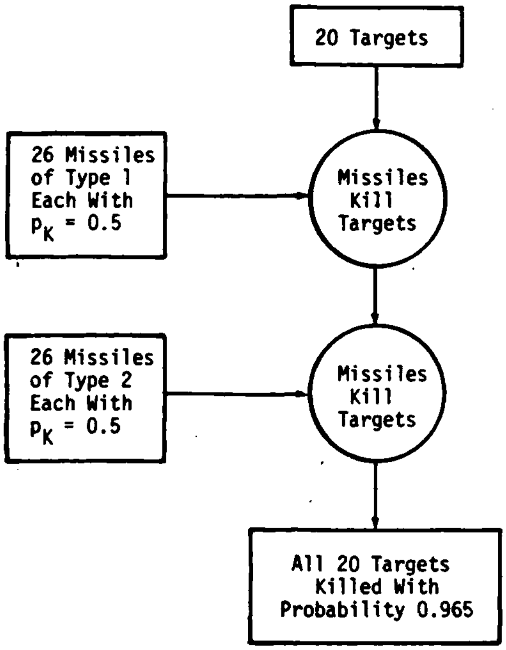
$$P(\overline{M}_{11} \leq (r_{111}+r_{211})) = p^2 ,$$

where $\overline{M}_{11}$ is the random number of missiles (of either type--since by assumption here they are virtually interchangeable) needed to kill $a_{111}+a_{211}$ targets (for the Air Force) or $A_{11}(1) + A_{21}(1)$ targets (for the Navy).

These calculations are not equivalent (even if an overall risk of p instead of p^2 is desired). Following the assumptions above, suppose that the p_K of both missiles is 0.5, and that $a_{i11} = A_{i1}(1) = 10$ for $i = 1,2$ (so that there are a total of 20 targets to be killed), and that the risk factor is 0.90. Then the current Air Force and Navy methodologies would calculate that 26 missiles of each type are needed (for a total of 52 missiles); and if each type of missile is restricted to shooting at no more than 10 targets, then the probability of killing all 20 targets is 0.81. One way to describe this result is to consider two parallel streams of targets, each stream coming within range of one type of missile but not the other. A picture of this is:



If, instead of two parallel streams, attrition took place in series (so that each target was potentially vulnerable to both types of missiles), then 26 missiles of each type would result in an overall effectiveness of 0.965. This could be pictured as:



Therefore, if attrition is assumed to take place in parallel, 52 missiles are needed to yield an effectiveness of 0.81 (in terms of the probability of killing all 20 targets). If attrition is assumed to take place in series, 52 missiles would yield an effectiveness of 0.965. For comparison, if the series assumption holds and if an effectiveness of 0.90 is desired, then only 48 missiles are required (and if an effectiveness of only 0.81 is desired, then only 45 missiles are required).

These values are given in tabular form in the middle of the first block of values on the first page of Table 1. For comparison, that block also gives values for the cases where the desired overall effectiveness is 0.50 (for the values on

Table 1. A COMPARISON OF REQUIREMENTS PRODUCED BY SERIES AND PARALLEL ATTRITION

			PARALLEL				SERIES	
T	S	P	T/S	P_S	M_S	M	M	%
20	2	0.50	10	0.701	21.5	43	39	10
		0.81	10	0.900	26	52	45	16
		0.90	10	0.949	27.5	55	48	15
		0.965	10	0.982	21	62	52	19
		0.99	10	0.995	34	68	57	19
60	2	0.50	30	0.701	63.5	127	119	7
		0.81	30	0.900	70	140	129	9
		0.90	30	0.949	73	146	134	9
		0.965	30	0.982	77.5	155	141	10
		0.99	30	0.995	82.5	165	148	11
60	6	0.50	10	0.891	25.5	153	119	29
		0.81	10	0.965	29	174	129	35
		0.90	10	0.983	31	186	134	39
		0.965	10	0.994	33.5	201	141	43
		0.99	10	0.998	36	216	148	46

T = Total number of targets to be killed.

S = Number of different types (or classes) of shooters.

P = Desired probability of killing all of the targets.

T/S = Number of targets per type of shooter (PARALLEL ATTRITION).

P_S = Probability that each type of shooter kills its (uniform) share of the targets (PARALLEL ATTRITION).

M_S = Average number of missiles required for each type of shooter (PARALLEL ATTRITION).

M = Total number of missiles required for PARALLEL or for SERIES ATTRITION.

% = Percent difference between M(PARALLEL) and M(SERIES) based on M(SERIES).

(continued on next page)

Table 1. (concluded)

T	S	P	PARALLEL T/S	PARALLEL P_S	PARALLEL M_S	PARALLEL M	SERIES M	%
120	2	0.50	60	0.701	125	250	240	4
		0.81	60	0.900	134	268	250	7
		0.90	60	0.949	138	276	260	6
		0.965	60	0.982	144	288	270	7
		0.99	60	0.995	150	300	280	7
120	6	0.50	20	0.891	47.5	285	240	19
		0.81	20	0.965	52	312	250	25
		0.90	20	0.983	55	330	260	27
		0.965	20	0.994	58	348	270	29
		0.99	20	0.998	61.5	369	280	32
120	10	0.50	12	0.933	31.5	315	240	31
		0.81	12	0.979	35	350	250	40
		0.90	12	0.990	37	370	260	42
		0.965	12	0.996	40	400	270	48
		0.99	12	0.999	43	430	280	54

T = Total number of targets to be killed.

S = Number of different types (or classes) of shooters.

P = Desired probability of killing all of the targets.

T/S = Number of targets per type of shooter (PARALLEL ATTRITION).

P_S = Probability that each type of shooter kills its (uniform) share of the targets (PARALLEL ATTRITION).

M_S = Average number of missiles required for each type of shooter (PARALLEL ATTRITION).

M = Total number of missiles required for PARALLEL or (approximately) for SERIES ATTRITION.

% = Percent difference between M(PARALLEL) and M(SERIES) based on M(SERIES).

the first line) and 0.99 (for the values on the last line). The other five blocks of values in this table give data for these same overall effectiveness levels (0.50, 0.81, 0.90, 0.965, and 0.99), but for different numbers of targets and types of shooters. All of the values in Table 1 are based on the assumptions above; namely, that missiles are fired in single-missile salvos on a shoot-look-shoot basis with all missiles having a probability of kill of 0.5, that targets are uniformly divided among the various types of missiles in the parallel case, and that missiles of each type can potentially engage any of the targets in the series case.

Clearly, the values in Table 1 depend on the assumptions concerning how attrition takes place, and, in particular, on the assumption that a shoot-look-shoot firing doctrine can be used. The shoot-look-shoot assumptions are needed whether the Air Force/Navy is using the approach of shooting at targets in parallel or shooting at targets in series. The key distinction is whether or not an a priori allocation of targets to shooters prohibits shooters of one type from engaging targets assigned to shooters of another type. (E.g., can SPARROWs only shoot at the targets that are preassigned to SPARROWs, and SIDEWINDERs only shoot at targets preassigned to SIDEWINDERs; or are SPARROWs able to shoot at all the targets and can SIDEWINDERs shoot at all the targets that escape the SPARROWs?)

Attrition in large-scale combat probably would not take place exactly in parallel or exactly in series, but the question can be raised as to which is a better model for which types of combat. Within a short period of time (such as within one raid), attrition by one type of shooter against one type of target might take place somewhat in parallel. But this type of attrition is what the Air Force and Navy (implicitly) assume is taking place in series. Across types of weapons and, perhaps, types of targets (and certainly across time periods), attrition seems more likely to take place in series. For example, the Navy's concept of using layered defenses to defend a carrier task force implies that attrition occurs in series. Forcing enemy submarines to travel through several barriers to reach the ocean, then through open-ocean search areas, and then through task force or convoy defenses in order to reach their targets, implies that attrition occurs in series to these enemy submarines. The concept of using Air Force fighters behind a SAM belt but in front of point SAM defenses implies that attrition occurs in series. And combat that takes place day after day certainly implies attrition in series. Simply put, the current Navy and Air Force methodologies for considering risk are in error, and the relevant questions are: How significant is this error, and how difficult is it to fix?

c. The Impact of This Error

From a numeric viewpoint, if all else is held fixed, the significance of this error decreases as the total number of targets increases. Likewise, if all else is fixed, this error increases as the number of different types of shooters (or partitioning of targets to shooters) increases;[1] and the error increases as the desired probability of killing all of the targets (i.e., the risk factor) increases.

From a methodological viewpoint, there are three ranges in which the impact of this error could fall. First, it might be significant. Second, it might be minor (because the impact of considering risk is minor; that is, considering attrition in parallel and in series both could give about the

[1]The discussion above centered on a partitioning of one type of target to multiple types of shooters. In general, however, this error occurs whenever any partitioning of the total number of targets is made among the total number of shooters, other than a partitioning due to intrinsic parallel attrition (such as by theater).

same requirement for missiles that would be generated by ignoring risk and just requiring that the expected number of needed missiles be purchased). Third, the impact of this error might be minor while the impact of considering risk (as compared to buying just the expected number of missiles) is major. Different classes of missiles could fit into different categories.

If a class of missiles (and, in general, munitions) fits into the first category, then the error is significant and this type of risk analysis should not be used until this error is corrected. If a class of missiles fits into the second category, then the consideration of risk is not important (and so the fact that risk is considered in the static analyses used by the Air Force and Navy is not a meaningful advantage of these analyses over other possible approaches which do not consider this type of risk). If a class of missile fits into the third category, then this error (by itself) does not invalidate the current Navy and Air Force approaches.

Note the possibility that a class of missiles might fit into the third category due to counterbalancing errors. For example, suppose that there are 60 total targets, 2 types of shooters, that an overall probability of 0.90 is desired for killing all 120 targets, and that the other assumptions behind Table 1 hold. Suppose that an error of 5 percent or less is considered insignificant while an error of 10 percent or more is significant. Finally, suppose that users of the current approach ignore the fact that, under parallel attrition, buying enough missiles so that each type of shooter kills all 30 of "its" targets with probability 0.90 yields an overall probability of killing all 60 targets of 0.81. Then users of the current approach might consider the 0.90 under the P_s column in Table 1 (not the 0.81 under the P column) and buy 70 missiles for each of the two types of shooters for a total of 140 missiles. Since the correct total number of missiles to buy (assuming series attrition) to achieve an overall probability (P) of 0.90 is 134 missiles, the net error is (140-134)/134 = 4.5 percent which, by the assumptions above, is insignificant. However, the expected number of missiles needed is 60 ÷ 0.5 = 120, so the error in using the expected number would be (134-120)/134 = 10.4 percent which, by the assumptions above, is significant.

Analyses of individual cases are needed (using "real" data) to determine which classes of missiles fit into which categories. Such analyses would seem to require "doing it right," at least for the important cases, and "doing it right" requires fixing this error. Some aspects of this error may be very amenable to repair. Other aspects of this error (such as how to handle attrition which occurs in series because the interactions occur widely spread out over time) may not be readily amenable to repair within a static framework, and so may require the use of a dynamic approach.

5. Navy Methodologies (Less Risk)

Like the Air Force, the Navy uses a simple dynamic methodology to compute its demand for air-to-surface munitions, it uses a static methodology to compute its demand for all other munitions, it assumes that it is not worthwhile to purchase replacement weapons, and it considers its demand for replacement personnel independently of the combat interactions which consume munitions and cause attrition. Section a (below) discusses the Navy methodology for computing the demand for air-to-surface munitions. Section b discusses the Navy's static methodology. The comments in Section 2.c (above) concerning the Air Force methodology for computing the demand for replacement personnel, and in Section 2.d concerning the lack of an Air Force methodology for computing the demand for replacement aircraft, apply directly to the corresponding Navy approaches, and so will not be discussed further here.

a. Air-to-Surface Methodology

Three limitations of the Navy's air-to-surface methodology are: (1) The Navy uses basically the same attrition costing methodology as the Air Force and hence has the same problems discussed in Section 2.e above; (2) attrition to Navy aircraft is independent of the Navy's effort to limit this attrition; and (3) the Navy's contribution to ground combat appears to be measured independently of this ground combat. The discussion in Section 2.e applies virtually directly to the first limitation and so is not discussed further here. The second limitation is discussed below. The third limitation is discussed in Section 6.a, because it is closely related to interactions between the Navy and the other Services.

In the Navy methodology, fighters fly a certain number of sorties (in air-to-air fighter roles) in support of power projection missions, and attackers fly defense suppression missions as part of power projection. One would expect that the number and quality of these sorties (and the number of enemy weapons and their quality) would affect the attrition rate, and hence affect the number of combat sorties of aircraft on power projection missions. However, according to Volume II of the NNOR [2] no such interactions appear to be considered. This raises two problems. First, no evidence or argument is given that flying the specific number of escort and defense suppression missions would yield the specified attrition rates. (Indeed, these rates seem to have been developed independently of the consideration of these missions.) Second, and more importantly in a budget-constrained environment, this structure precludes attempts to compare the cost-effectiveness of ordnance bought for escort missions versus ordnance bought for defense suppression missions versus ordnance bought for direct attack on enemy ground forces (not counting ground-to-air forces). Yet all three of these types of ordnance are logically closely related in the attempt to destroy enemy ground forces. Thus, the current Navy methodology appears to be incapable of addressing questions concerning how to spend a given amount of dollars on ordnance, even if the ordnance is to be used in an interrelated manner as just described.

b. Static Methodologies

As stated above, the Navy uses basically the same static approach to calculate its requirements for (1) surface-to-surface missiles, (2) ordnance used in anti-air warfare, and (3) ordnance used in submarine/anti-submarine warfare. The application of this static approach to these three categories of requirements produces, in a sense, three separate static methodologies. We will only discuss here the application of this approach to the Navy's ordnance requirements for anti-air warfare, and then only as it applies to the air defense of carrier task forces. In a general way, the comments here also apply to the other aspects of anti-air warfare and to the other two categories of requirements, but the specifics of these comments would change (and could change considerably) with the change in categories. The intention here is that by discussing one application in detail, the nature of the limitations of this approach can be understood and applied, where appropriate, to the other categories.

Even with the restriction to only one application, the discussion in this section is lengthy. The reason for discussing the Navy approach in greater detail than either the Army or Air Force approach is twofold. First, the Army and the Air Force currently have dynamic theater-level models which (with some improvements) can be used as the methodological basis for determining ordnance requirements.[1] The Navy does not have as clear a direction in which to proceed and so it is appropriate to comment in greater detail on their current approach. Second, the Sustainability Study [1] discussed the Army's modeling more extensively than that of the Air Force and discussed the Air Force modeling more extensively than that of the Navy. Therefore to complement (rather than repeat) the Sustainability Study, it is appropriate to discuss the Navy model in greater detail than those of the other Services.

This section consists of five subsections. The first subsection discusses a fundamental but unstated assumption which could significantly affect the Navy's determination of ordnance requirements. The second subsection discusses the effects of saturation, attrition, and resupply on the determination of these requirements. The third subsection discusses a "gap" between the model presented in Volume IV of the NNOR [2] and its application presented in Volumes I and III. The fourth subsection discusses some technical problems involving the model presented in Volume IV. It should be noted, however, that the discussions in all four subsections overlap in that the problems discussed in any one are not independent of the problems discussed in the other three. A general suggestion is presented in the fifth subsection.

---

[1] A distinction between the Army and the Air Force here is that the Army has stated that it intends to implement the use of such a model, whereas the Air Force appears satisfied with its current approach.

(1) An Implicit Scenario Assumption

The Navy assumes that each type of ordnance must be distributed, in some sense, among a specified number of platforms. As a slightly oversimplified example, the number of platforms for air-to-air missiles and for ship-based area-air-defense missiles might be the number of carrier task forces (say, 12); and the number of platforms for ship-self-defense missiles and guns might be the number of ships in all of these carrier task forces (say, 84).

The Navy also assumes a particular probability distribution of the threat over these platforms. For example, suppose that one type of ordnance, say a specific type of air-to-air missile, is assigned to kill 120 designated enemy aircraft, and suppose that there are 12 platforms (i.e., carrier task forces) associated with this air-to-air missile. The Navy assumes that the probability that k aircraft attack a particular platform is

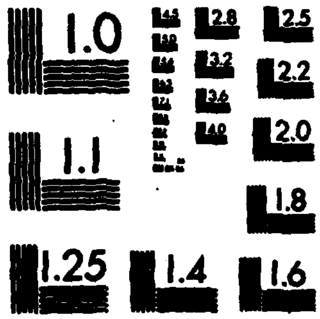
$$\frac{\binom{-1}{k}\binom{-11}{120-k}}{\binom{-12}{120}} \simeq \left(\frac{1}{11}\right)\left(\frac{10}{11}\right)^k ,$$

where $\binom{-n}{r} = \frac{-n(-n-1)\ldots(-n-r+1)}{r!} = \frac{(-1)^r n(n+1)\ldots(n+r-1)}{r!}$

The impact of this assumption can be demonstrated as follows. Suppose that the air-to-air missile in question has a probability of kill of 1.0, so that the Navy needs only one missile per platform per enemy aircraft that attacks that platform. If the enemy were to attack the 12 platforms perfectly (and deterministically) uniformly with its 120 designated aircraft, then 10 missiles per platform (for a total of 120 missiles) would be needed to kill all of the enemy aircraft. However, if the enemy aircraft attack the platforms according to the probability distribution above, and if the Navy desires a probability of 0.90 that each platform has enough missiles to kill all of the designated aircraft that attack it, then each platform needs 24 of these missiles (with p_K's of 1.0) for a total of 288 such missiles; and if the Navy desires a probability of 0.99 that each platform has enough of these missiles to kill all of the designated aircraft, then each platform needs 48 such missiles for a total of 576 missiles. For comparison, if each of the 120 designated enemy aircraft were to attack any one of the 12 platforms with probability 1/12, and if each aircraft selects a platform to attack independently of the other aircraft, then a total of 156 of these missiles (13 per platform) would be needed to obtain a probability of 0.90 of not being short of missiles; and a total of 204 missiles (17 per platform) would be needed to obtain a probability of 0.99 of not being short of these missiles. Thus, in this simplified case, the Navy would be using a probability distribution that concentrates the enemy's attack in such a way that 85 percent more missiles are required in the 0.90 confidence case (and 182 percent more missiles are required in the 0.99 confidence case) than would be required by a random, but uniformly and independently distributed attack.

The Navy attempts to justify its use of this probability distribution by saying that this distribution is consistent with some historical data and that it is logical that the enemy might concentrate its attack. However, a crucial aspect of the Navy's approach here is that the Navy (implicitly) assumes that it has no way of knowing which platforms are likely to receive the more heavily concentrated attacks versus which platforms are more likely to receive lighter attacks. That is, the Navy is essentially assuming a scenario in which all platforms (i.e., all carrier task forces) are equally likely to be subjected to a heavily concentrated attack.

AD-A091 882 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA PROGRAM --ETC F/G 15/3 2/3
REPORT OF COMBAT CONSUMPTION MODELING IMPROVEMENT PANEL.(U)
JUL 80 J BRACKEN, J R BODE, S BONDER MDA903-79-C-0320
UNCLASSIFIED IDA-P-1455 IDA/HQ-79-21815 NL



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

A more reasonable argument (cf, [22]) is that there are some geographical areas in some scenarios where carrier task forces would be vulnerable to heavy enemy attacks, and there are some where carrier task forces would be vulnerable only to medium or light attacks. Carriers off-line in US ports may not be vulnerable to any air attack. In this case, the distribution of the number of attackers on a randomly (i.e., uniformly) selected carrier might be similar to the distribution used by the Navy, but with the important distinction that the Navy would know in advance which carriers might be subjected to heavy attack (and so might need all 288 to 576 missiles as computed above), and which might be subject only to light or no attacks (and so would need few if any missiles). Therefore, in this case, large numbers of missiles (large in the sense of being in excess of expected values) need only be bought for those carriers likely to be simultaneously vulerable to heavy enemy attacks, instead of buying these large numbers of missiles for all aircraft carriers (as the Navy plans on doing now).[1]

If the Navy disagrees with this type of argument, and instead believes that enough missiles should be bought so that all carriers (i.e., all platforms) can simultaneously be

[1] If the Navy agrees with this argument and wants to incorporate heavy threat, medium threat, light threat, and no threat areas into its static model, it might consider using different parameters (in addition to using different size threats) in each of these areas. For example, Volume IV of the NNOR [2] employs a probability distribution which distributes the threat among the platforms. This probability distribution is defined in terms of a concentrated parameter, β. Volume III of the NNOR uses $\beta=1$ for all of its analyses (and the formula above for the probability that k aircraft attack a particular platform assumes that $\beta=1$). It may be that in some cases, such as heavy threat areas, high enemy concentration is likely. In terms of the mathematics of Volume IV, this high concentration means that β should be positive but very close to zero. It may also be that in other cases, such as low threat areas, attacks are independent. In terms of Volume IV, independent attacks mean that β should be near $+\infty$ (or near $-\infty$). If, in some cases, attacks are likely to be evenly spread out (as opposed to being concentrated), then β should be some negative number between $-\infty$ and -1.

used in geographical areas where they are subject to heavy enemy attacks, then this fundamental assumption on naval combat should be clearly and explicitly stated so that it can be evaluated in comparison with other assumptions and other requirements.

(2) Saturation, Attrition, and Resupply

The saturation of Navy weapons by enemy attackers which arrive virtually simultaneously, the attrition to Navy weapons caused by these enemy attackers, and the capability of the Navy to resupply ordnance to these weapons are all potentially important, interrelated, and not well treated in the current static approach.

(a) Resupply. First, suppose that saturation cannot occur, that no Navy weapons ever suffer attrition, and consider only resupply. It is clear (both logically and from the arguments given in Volume IV of the NNOR) that the Navy's capability to resupply its ships can strongly affect the total requirement for ordnance. Yet Volume III of the NNOR appears simply to state initial allowances and resupply reserves. This raises two questions: First, can the Navy resupply its ships from these reserves in a timely way? Second, are these initial allowances too large or too small, and what impact does this have on the size of the resupply reserves?

For example, suppose that the Navy has the capability to resupply ships and that, from a cost and effectiveness viewpoint, this resupply capability should not be reduced. Suppose that a ship has a larger initial allowance than it needs to meet one raid of the expected attack, considering risk, and that the ship can be resupplied before a second raid.[1] Then the initial allowance can be reduced with a less-than-equal increase in the resupply reserve. (As explained in Volume IV of the NNOR, the reason that trade-offs between initial allowance and resupply are less than one-for-one is due to the consideration of risk.)

Alternatively, suppose that the initial allowance is not large enough to meet the first raid of the expected threat considering risk because the ship cannot hold that much ordnance. Then, even though there may be enough ordnance in the resupply reserve, the portion of this reserve that was bought to meet the first raid is essentially wasted because it cannot be supplied to the ship in a timely manner. That is, suppose (1) that the Navy desires a 99 percent confidence factor and buys ordnance accordingly; (2) that a ship can hold only enough ordnance to produce a 90 percent confidence factor against the first raid; (3) that all (or a portion of) the remaining ordnance is stored in a resupply reserve; and (4) that reserve ordnance cannot be supplied to the ship in time for use against the first raid. Then the Navy really has only a 90 percent confidence factor and it is buying ordnance for no purpose if the planned ordnance purchases are based on a confidence factor higher than 90 percent.

Another possibility is that resupply capability is very expensive relative to the cost of ordnance, and the Navy could save money by giving up some resupply capability and increasing its initial allowances instead.

There are three other resupply-related issues.

First, how is the initial allowance/resupply reserve mix affected if it is reasonable to assume that one or more

---

[1] A similar argument holds if the initial allowance is larger than needed to meet n raids, and the ship can be resupplied before the n+1st raid.

carrier task forces are initially off-line, and they move (when appropriate) to replace carrier task forces on station?

Second, if it is reasonable to assume that, say, two carrier task forces are operating in proximity, then these carrier task forces may be two platforms from a threat-distribution point of view, but one platform from a resupply point of view. How does the Navy methodology handle this case? The current methodology appears to require either that the carrier task forces be considered as one platform (which might underestimate requirements) or as two or more platforms (which would overestimate requirements if resupply is used).[1] Also, it would seem certain that all ship-self-defense weapons on all ships in the same carrier task force should be considered as one platform from a resupply point of view, yet each ship might be considered as being a separate platform (for ship-self-defense weapons) from a threat-distribution point of view. Again, the NNOR does not explain how this multiple definition of platforms is (or can be) handled.

Third, it appears that the mix of types of ordnance stored as initial allowance on a ship can be very important. For example, should more PHOENIX missiles and fewer SPARROW missiles be part of a carrier's initial allowance, or vice versa? The answer to this type of question depends, among other things, on the details concerning how the threat is allocated and on the way that risk is considered.

[1]Note that this issue is related to the scenario assumptions discussed in Section (1) above. If all of the carriers are operating in high threat areas, then some would seem to be operating in proximity. Conversely, if none of the carriers are operating in proximity, then perhaps not all of the carriers can simultaneously be operating in high threat areas. The answer here depends, in part, on the scenarios being analyzed, and these scenarios are not described in the NNOR.

In summary, how ships can be resupplied and how ships should be resupplied from a cost-effectiveness viewpoint are important in determining the amount of ordnance to buy; and it is not clear from the NNOR that the Navy has adequately considered the important aspects of resupply in determining its ordnance requirements. The point here is not that the other Services are far ahead of the Navy in considering resupply capability--they are not. The point is that in the Navy methodology (especially considering risk among multiple platforms), resupply can be a much more important factor than in Army and Air Force methodologies. As a result, the Navy should consider alternative resupply options at least at a "ball park" level of detail.

(b) <u>Attrition</u>. There are two general ways in which attrition to Navy ships can affect the demand for ordnance.

First, suppose that no resupply is made to a ship, that the ship has an initial allowance of 48 missiles of a particular type to help kill a heavy threat with probability 0.99, and that if the ship is put out of action then all of its missiles are lost. Further, suppose that the heavy threat is likely to put that ship out of action before all 48 missiles can be used. For example, suppose that due to attrition, the probability that the ship will ever need more than 36 missiles is less than 0.01. Thus, in this case, a 0.99 confidence can be achieved by buying only 36 of this type of missile for that ship, not 48. However, since that ship is now out of action, other ships may now be subjected to an even heavier attack, and so they might need an initial allowance greater than 48 missiles. Volume IV of the NNOR proves that, under a particular set of conditions, these two effects precisely cancel, and so (in this example) an initial allowance of 48 missiles is "correct" whether or not attrition is considered. However, as will be explained in Section (4)(c) below, the particular set of considerations assumed in Volume IV appears to be quite unreasonable. Accordingly, under reasonable conditions, these two effects might not cancel each other; if they do not cancel, then the total demand for ordnance could be changed due to attrition. (Again, one may need to "do it right" to determine whether this change in demand is significant or not.)

The second way that attrition to Navy ships can affect the demand for ordnance is either if resupply reserves are being used or if a ship that is put out of action can off-load its ordnance for use on another ship. In this situation, ordnance intended (as either initial allowance or as resupply) for use on the neutralized ship can be used on other ships. The attrition analysis in Volume IV of the NNOR does not consider this aspect of attrition, and so it is not known (even in simplified cases) how this aspect of attrition would affect the total demand for ordnance.

Note that this second aspect of attrition is related to the first aspect (discussed above) in the following manner. If the entire enemy attack occurred over a short period of time, then there may be no time to resupply ships or to off-load ordnance from damaged ships for use on undamaged ships. However, there also may be no time for the enemy to retarget his attackers in order to increase the size of the attack on the other (undamaged) ships. On the other hand, suppose the attack were sufficiently spread out over time so that, when a ship is put out of action, attackers can be retargeted against other ships. Then there may also be time to off-load ordnance from damaged ships and/or take ordnance from resupply reserves in order to resupply undamaged ships. Thus, timing can be important in either case, and the Navy's static approach does not consider this timing.

(c) Saturation. In general, there are three basic ways that an attacker can avoid being killed by defensive systems: First, an attacker might "leak" through the defensive systems (for example, it might never be detected, or all shots at it might miss). Second, attackers might saturate the defensive systems in that not enough defending weapons are available to shoot at all of the attackers.[1] Third, previous attackers might have exhausted the ordnance of the defenders so the remaining attackers can now penetrate. The Navy methodology considers only this third cause of not killing attackers. The first cause (leakage) can lead to the attrition of Navy ships which, in turn, can affect ordnance requirements as discussed above.

The second cause (saturation) has two aspects. First, saturation can also lead to attrition of Navy ships and so can affect ordnance requirements as discussed above. Second, saturation can fundamentally affect the rationale behind the Navy's approach. This effect can be demonstrated as follows: Suppose that 120 anti-ship missiles (ASMs) are attacking a carrier task force over the space of a few minutes and that the Navy desires to kill 60 of them with area-air-defense missiles. But suppose that these ASMs are vulnerable to area-air-defense missiles only long enough for 30 of them to be engaged. Should the Navy be buying enough area-air-defense missiles to be 99 percent sure of killing 50 percent of these ASMs (30 out of 60)? (That is, is it worthwhile to buy missiles which raise the risk factor for killing "unsaturated" ASMs from, say, 90 percent to 99 percent, if this only raises the risk factor for killing all designated ASMs from 45 percent to 49 percent?) Should the Navy be

[1]A related aspect is that some of the defensive systems might not be in action (perhaps because they had been damaged, or destroyed, by previous attackers), and fewer defensive systems in action makes saturation easier for the attackers.

buying enough area-air-defense missiles to be 99 percent sure of killing all of the ASMs which they would kill if the enemy would only slow down and space out the attack so that the Navy's weapons would never be saturated? This is the type of question that can be addressed by a methodology that ignores saturation. The point here is that saturation is a serious problem for naval defense; it can affect (among other things) the consumption of ordnance in combat, and the Navy should not plan its ordnance purchases by ignoring the possibility (and resulting effects) of the saturation of its defenses.

(3) <u>Maximum Expenditure Against a Single Target</u>

Volume IV of the NNOR can be viewed as treating enemy targets as if all rounds fired against each enemy target must be fired in a short period of time. Targets for which this assumption is plausible (such as enemy ASMs) are referred to here as one-time targets, and these targets are discussed in Section (a) below. Targets for which this assumption may not be plausible (such as enemy aircraft) are referred to here as recurring targets, and are discussed in Section (b).

(a) <u>One-Time Targets</u>. If a target is available to be shot at by a Navy weapon for a relatively short period of time, then reasonably there is an upper bound on the number of salvos that the weapon can expend against that target. If salvos are fired in a shoot-look-shoot mode (as the Navy assumes), then the maximum number of salvos that can be fired is generally quite small. For example, it may be that at most two or three salvos can be fired at an enemy target, even one that is detected far away from the shooting weapon. There may be only enough time for one salvo (or none at all) to be fired at a target that is close-in before it is detected and a Navy weapon becomes available to fire at it.

Thus, an average of the maximum number of salvos that can be fired against a detected target might be between zero and two. (For example, it may be that 1/8 of the enemy targets are detected so late--or Navy weapons may become available so late--that no time is available to engage those targets, that 3/8 of the enemy targets are detected in time to fire one salvo at them, and that 1/2 of the enemy targets are detected in time to fire two salvos at them--but only one of these salvos would be fired if the first salvo kills the target. In this example the average maximum number of salvos that can be fired is 1 3/8.)

Volume IV of the NNOR presents a reasonable way to incorporate this average maximum number of salvos into the Navy's static methodology. Volume III of the NNOR apparently ignores this maximum value, and it may be that this is equivalent to assuming that the maximum value is infinite. If this is the case, then the results given in Volume III could be significantly in error. Accordingly, if this is the case, the Navy should stop using these results as a basis for planning their ordnance purchases and, at a minimum, should rerun their static model with reasonable values for the average maximum expenditure against a single target.[1]

If Volume III of the NNOR used reasonable values for the average maximum expenditures, then these values should have been discussed in that volume--and should be so discussed in the future.

(b) Recurring Targets. Recurring targets could be treated in one of several ways in the current Navy methodology.

---

[1]The authors of Volume IV might be able to modify this model so that the maximum expenditure can be treated as a random variable, in which case distribution parameters instead of average values could be used.

First, they could be treated by making the maximum average expenditure against targets infinite. The disadvantages of this approach are threefold. (1) Attrition to platforms could occur between the recurring attacks of a single enemy target. Such mid-attack attrition is not allowed in the current Navy methodology; in fact, making the maximum expenditure infinite would (in a sense) cause a destroyed platform to expend munitions after it had been destroyed. (2) A recurring attacker might attack different platforms on each attack, and would certainly attack a different platform on succeeding attacks if the first platform it attacked had suffered attrition. The current Navy methodology appears to require each attacker to attack the same platform throughout the war. (3) A recurring attacker might have to return to base to rearm and refuel. While this is occurring, the platform could be resupplied. The current Navy methodology does not allow a platform to be resupplied between the recurring attacks of a single attacking target, no matter how long it is between these attacks or how many different attacks are required.

Alternatively, recurring targets could be treated by making the maximum average expenditure equal to what it would be against one attack of that target, and then increasing the total number of that type of target to be killed by an attrition factor. For example, if the average maximum expenditure of a particular type of missile against a particular type of recurring target is 2 salvos per attack, and if the p_K per salvo of those missiles against that target is 0.5 (which gives a p_K of 0.75 per attack), then the average number of attacks that a recurring target of that type makes is 1/.75 = 1 1/3, provided that the target is not engaged by any other type of Navy weapon. Therefore, if there is a total of 300 targets of that type to be killed by the type of missile in question, then the current Navy methodology could be used by setting the number of these targets equal to 400 and the average maximum expenditure equal to 2 salvos.

This second approach might reasonably be used for obtaining a "ball park" estimate of combat consumption, provided that the risk factor used by the Navy is not too high. However, it may not make sense to use this approach with a high risk factor, and this is not the approach currently used by the Navy.

Other approaches for handling recurring targets may be possible, but none seem to fit entirely within the Navy's static methodology. Thus, if this methodology is to be used, some work is needed to understand the impact of calculating the demand for ordnance employed against recurring targets by using a static methodology. Some approach may exist which produces reasonable approximations, but this is not clear from the current NNOR.

(4) Technical Difficulties

Some technical difficulties with Volume IV of the NNOR are discussed in this section. These difficulties are discussed roughly in the order encountered when reading the volume, not in order of importance. In terms of importance, the major technical difficulty with Volume IV is the way that it considers attrition to friendly forces, as discussed in Subsection (c) below. Other significant difficulties relate to the definitions of platforms discussed in Subsection (d). The comments in Subsections (a), (b), and (e) are, relatively speaking, less significant.

It should be noted again that the purpose of this paper is to discuss problems with the methodologies currently in use and to suggest improvements, not to give a balanced review of both the strong and the weak points of these methodologies.

Thus, the several strong points of Volume IV are not discussed here.[1]

(a) Kills vs Engagements. The random variable $S^{(\ell)}$ is defined on page 6 of Volume IV to be the number of salvos required to kill ℓ targets, so that $S^{(1)}$ is the number of salvos required to kill one target. Equation (3) on page 7 states that if the maximum expenditure against a single target is d, then

$$Pr\{S^{(1)}=j\} = \begin{cases} (1-pK)^{j-1}pK & 1 \leq j < d \\ (1-pK)^{d-1} & j=d \end{cases},$$

where pK is the single salvo probability of kill against an enemy target. This equation is wrong. Three ways that it can be corrected are as follows:

First, this equation becomes correct (as written) by changing the assumptions leading to it. In particular, it would be correct if it is assumed that the ordnance used in the d^{th} salvo is different from that used in all the preceding salvos in that the ordnance used in the d^{th} salvo has a pK of 1.0. Clearly no such ordnance exists; and if it did, it ought to be fired in the first salvo, not in the last one. Thus, this is not a reasonable way to correct Equation (3).

Second, one could define the random variable I_k to be 1 or 0, depending on whether the target would be killed by the first d salvos ($I_k=1$) or not ($I_k=0$). Then one could replace Equation (3) with

$$Pr\{S^{(1)}=j \mid I_k=1\} = \frac{(1-pK)^{j-1}pK}{1-(1-pK)^d}$$

[1]To assist readers interested in developing a balanced review, some strong points of Volume IV are presented in Annex 3.

The difficulty here is that a new random variable is introduced (which would then have to be treated), and the form of Equation (3) is changed, which may require significant changes in the rest of Volume IV.

Third, one could redefine $S^{(\ell)}$ to be the number of salvos expended in an attempt to kill ℓ targets, so that $S^{(1)}$ becomes the number of salvos expended in an attempt to kill one target. Equation (3) then holds as written.

The third solution seems to be the best. The difficulty with assuming that this solution is the correct one, and then attempting to read Volume IV as it is currently written, is that the word "kill" now has two meanings. For example, in the definition of pK "kill" means destroy, while in the definition of $S^{(\ell)}$ "kill" means engage. It is clear, initially, which definition of "kill" is meant, but later on in Volume IV it gets harder and harder to sort out the implications of having two different definitions of "kill."

If the third solution is correct, Volume IV should be rewritten using "engage" where engage is meant, and "kill" only where destroy is meant. If rewriting Volume IV in this manner exposes errors or unreasonable assumptions, then these errors should be fixed and the assumptions changed. If this third solution is not correct, then the correct solution should be incorporated into Volume IV.

If either the second or third solution (or some similar solution) is correct, then the probability that the enemy target is not killed is $(1-pK)^d$. Further, if the enemy target is not killed, then it should have the opportunity to kill the platform (or Navy weapon) at which it is shooting or aimed. Thus, correcting Equation (3) can lead to attrition of Navy systems being directly caused by enemy targets, and this aspect of Volume IV is discussed in Section (c), below.

(b) <u>Proportioning Kills by Target Type</u>. The quantities $K^{(i)}$, K, and τ_i are defined on page 23 of Volume IV by:

$K^{(i)}$ = the random variable representing the number of targets of type i killed by the platform for i=1,2,...,m target types.

$K = \sum_{i=1}^{m} K^{(i)}$ = the random variable representing the total kills for the platform.

τ_i = the fraction of targets of type i the platform is expected to kill, $\sum_{i=1}^{m}\tau_i=1$.

After these definitions are given, Equation (10) is presented. Equation (10) states that

$$\Pr\{K^{(1)}=k_1, K^{(2)}=k_2, \ldots, K^{(m)}=k_m \mid K=k\}$$

$$= \frac{k!}{k_1!k_2! \ldots k_m!} \tau_1^{k_1}\tau_2^{k_2} \ldots \tau_m^{k_m} ,$$

where $k = \sum_{i=1}^{m}k_i$.

The difficulty here is that the definition of τ_i is not precise, and, as a result, Equation (10) is hard to understand. A briefing on the NNOR stated that a precise definition of τ_i is that $\tau_i = r_i/r$, where r_i and r are defined on page 24 by

r_i = number of targets of type i, i=1,2,...,m,

r = total number of enemy targets

$= \sum_{i=1}^{m} r_i$.

This definition of τ_i is precise, but it doesn't help in understanding Equation (10). For example, suppose that m = 2, r_1 = 1, r_2 = 1, and that both of these enemy targets are killed (so that K = 2). Then, according to Equation (10),

$$\Pr\{K^{(1)}=2,\ K^{(2)}=0 \mid K=2\} = 0.25$$

$$\Pr\{K^{(1)}=1,\ K^{(2)}=1 \mid K=2\} = 0.50$$

$$\Pr\{K^{(1)}=0,\ K^{(2)}=2 \mid K=2\} = 0.25 \ .$$

Yet, since there is only one target of each type, it must be that

$$\Pr\{K^{(1)}=1,\ K^{(2)}=1 \mid K=2\} = 1.0 \ .$$

Also, the results presented in Section 2 of Volume IV seem to depend on τ_i, though not on r_i except through τ_i.

One solution here might be to assume that r is known but that $r_1,\ldots,r_m$ are multinomially distributed random variables, where the distribution parameters are known to be $\tau_1,\ldots,\tau_m$. But whatever the solution to this difficulty is, the solution should be incorporated into Volume IV, and its impact on the results presented in Volumes I and III should be evaluated.

(c) Attrition to Navy Platforms. Volume IV considers enemy systems, called targets, which are attacking Navy systems, called platforms. These platforms are attempting to kill the targets, and Volume IV has a method to account for the platforms themselves being killed. One might expect that the platforms are killed by the enemy targets that are attacking them; but, in the methodology of Volume IV, this does not appear to be the case.

Specifically, in this methodology, whether or not the platforms kill the targets has no effect on whether or not the platforms themselves are killed. Therefore, either the targets always get to shoot first, or the targets are not killing the platforms. But, for two reasons, it cannot be that the targets always shoot at the platforms before the platforms shoot back. First, there is no explicit probability (or rate) of kill of platforms by targets in Volume IV. One could assume that this probability is implicitly either zero or one; but zero would mean that platforms are never killed while one would mean that each target always kills a platform, and neither of these events follows from the methodology. Second, the methodology directly assumes that all targets always attack "live" platforms, and (as a result) ordnance is always expended against all attacking targets. In terms of the balls, urns, and lids discussed in Volume IV, a ball never bounces off a lidded urn--the balls only fall into one of the urns without lids.[1] As a result of these arguments, it appears that implicit in the methodology of Volume IV is--while platforms suffer attrition, this attrition is not caused by the enemy targets which are attacking them.

One way to picture this structure is as follows. The enemy can attack Navy platforms with two general classes of weapons (say, air weapons and underwater weapons). All enemy air weapons are duds (i.e., they all have a p_K of zero). But the Navy doesn't know that these enemy air weapons are duds, so it is buying ordnance to attempt to kill these weapons. Meanwhile, the Navy platforms can be killed by

[1]Accordingly, the Navy's methodology implicitly assumes that all enemy targets can instantly re-aim themselves so that they always attack "live" platforms. At first, this assumption may seem like a Navy-pessimistic assumption in that the Navy should do better (in some sense) if the enemy did not have this "instant-re-aiming" capability. In fact, it is not Navy-pessimistic because (as argued here) these enemy attackers don't kill anything, and so this assumption does not make the outcome of combat worse for the Navy than it would be otherwise. The only impact of this "instant re-aiming" assumption appears to be that, when the enemy targets are one-time targets (such as ASMs), this assumption creates an artificially high requirement for ordnance. That is, this assumption guarantees: (i) that all enemy targets are able to "consume" their specified amount of Navy ordnance—none ever escape being engaged by Navy weapons because they have been aimed at platforms which have suffered attrition, and (ii) that the enemy attack will always concentrate on "live" platforms, which can drive the ordnance requirements up for all platforms because of the way that the Navy considers risk.

the other class of weapons (underwater weapons), which is why attrition to Navy platforms is independent of whether or not the air weapons are killed.[1] If this picture is valid, then the static (threat-oriented) analyses of the NNOR are analyses of the Navy's requirement for ordnance to kill duds, and these analyses ignore the Navy's need for ordnance to kill potentially dangerous enemy weapons.

While it might be desirable to kill some duds, it is certainly desirable to plan ordnance requirements around the capability to kill dangerous enemy weapons. A model of killing dangerous enemy weapons that considers attrition to friendly weapons should directly consider the interaction that, if an enemy weapon is not killed, then it might kill a friendly weapon. The current Navy methodology does not consider this interaction, and so the best that can be said about this aspect of the methodology is that it currently is not capable of considering attrition to Navy systems. As argued above, attrition to Navy systems can be significant, and it should be considered in reasonable ways by future analyses of naval ordnance requirements.

(d) <u>Multiple Definitions of Platforms</u>. Volume IV of the NNOR assumes that the term "platform" has been defined elsewhere. That is, Volume IV does not address whether the platform is a carrier task force, an aircraft carrier within a carrier task force, or an individual ship. Volume III, which implements the model of Volume IV, apparently uses various definitions for what constitutes a platform. Whether or not the results of Volume III are reasonable depends, in part, on the definition of what constitutes a platform and on the number of different platforms; and these

[1]These observations explain the claim made in Section (2)(b) above, namely that the conditions in Volume IV (under which attrition does not affect results) are unreasonable.

concepts are not clearly explained in Volume III. The fact that platforms can be defined in several ways raises the following three methodological problems. First, there is a problem with assuming that the same type of urn model can be applied to all types of platforms. Second, there is a limitation of this urn model with respect to intrinsically different types of platforms (carriers versus escorts). Third, there is a problem with the relationship between platform definitions and attrition. These methodological problems are discussed here.

The first problem is as follows. In determining ordnance requirements for weapons that can defend an entire carrier task force (i.e., air-to-air missiles and area-air-defense surface-to-air missiles), Volume III apparently defines platforms to be carrier task forces. Therefore, suppose that there is some value of the concentration parameter, β, such that the urn model of Volume IV is valid.[1] That is, suppose that enemy targets (bombers and ASMs) are distributed among carrier task forces according to the urn model with parameter β. Volume III also apparently defines platforms to be individual ships when determining ordnance requirements for ship-self-defense systems. Thus, to use the model of Volume IV properly, it must be the case that ASMs are distributed among individual ships according to the urn model with parameter, say, β_0.

This structure raises two questions: (1) Is this possible? That is, is it possible for both bombers (which carry two or more ASMs) and (after launch) the ASMs to be distributed among carrier task forces according to the urn model with the same parameter, β, and is it possible that

[1]If the suggestion that geographical areas with different threat levels is implemented, then assume that there is a concentration parameter, β, that is valid for the portion of the total threat that is attacking a particular threat-level area.

these ASMs are also distributed among individual ships according to the urn model with parameter β_0? If these events are possible, then this aspect of the Navy's methodology is theoretically correct; if they are not possible, then the methodology is either incorrect or very unrealistic assumptions may be required concerning which ASMs attack which ships in which carrier task forces. (2) Are these events possible when $\beta = \beta_0 = 1$? That is, Volume III uses $\beta = \beta_0 = 1$; so even if the methodology of Volume IV can be valid for some β and β_0, the results of Volume III appear to be valid only if it is possible for bombers and (after launch) ASMs to be distributed among carrier task forces according to the urn model with parameter $\beta = 1$, while these ASMs are also distributed among individual ships according to the urn model with parameter $\beta_0 = 1$.

The second problem, which is related to the first, is as follows: Suppose that it is possible and reasonable to assume that both bombers and ASMs are distributed among carrier task forces according to the urn model with parameter β. Then, when considering the ASMs attacking a particular carrier task force, one may not want to consider the ships as indistinguishable platforms. That is, suppose that in the time period under consideration, the enemy has some capability to selectively attack the high value ships in a carrier task force. The enemy may want a majority of his ASMs to be directed at the carriers in a carrier task force, and he may have sufficient capability to cause, say, half of them to be so directed. As it is currently described, the urn model does not seem to have the capability to allow preferential attack of high value targets, and this can be a serious defect of the model if it is used for cases in which the enemy probably will have this capability.

The third problem is as follows. Platforms are apparently defined as carrier task forces when analyzing air-to-air missiles (PHOENIX, SPARROW, and SIDEWINDER) or area-air-defense missiles (SM-ER/MR), and are defined to be individual ships when analyzing ship-self-defenses (such as SEASPARROW and 5" GP). The description of the Navy's methodology reads as if these platforms are distinct; but, of course, they are not. That is, if a PHOENIX platform suffers attrition, then a platform for SPARROW and SIDEWINDER and at least one platform for ship-self-defenses necessarily must suffer attrition at the same time; but the AAW escort ships for SM-ER/MR missiles need not suffer attrition, then or ever.

Part of the problem here is that the NNOR does not explain what the phrase "the platform suffers attrition" means when the platform is a carrier task force consisting of several escort ships and one or more aircraft carriers. But whatever this phrase means, there are potentially significant problems here. Some ships (i.e., aircraft carriers) launch (indirectly) PHOENIX, SPARROWs, SIDEWINDERs, and (directly) SEASPARROWs, but do not launch SM-ER/MR missiles. Other ships (AAW escorts) launch SM-ER/MR missiles and SEASPARROWs, but not air-to-air missiles; and still other ships (ASW escorts) might launch SEASPARROWs only. It is not clear that a methodology is appropriate if it considers attrition to PHOENIX platforms separately from attrition to SPARROW or SIDEWINDER platforms, and these separately from attrition to SM-ER/MR platforms, and all these separately from attrition to SEASPARROW platforms. It might work out somehow, but it is not well explained.

One framework which might be used to help solve these three problems (involving multiple definitions of platforms) is as follows. First, the enemy threat could be apportioned between attacking carrier task forces and attacking independent ships (and other targets). The threat that attacks carrier task forces could then, if desired, be apportioned among attacking carrier task forces in high threat cases, attacking carrier task forces in medium threat areas, and attacking carrier task forces in low threat areas.[1] Within a threat area, platforms could then be defined to be carrier task forces for analyzing all ordnance (including SEASPARROWs and other ship-self-defense systems), and a carrier task force would suffer attrition when all of the aircraft carriers inside it have suffered attrition. This is just a framework, many problems still need to be addressed, and it may not be possible to solve all of these problems within this framework; but it would be a start on solving problems arising from defining platforms to be individual ships in some cases and to be groups of ships in other cases, and it might help solve the problem of preferential targeting of high value ships (i.e., aircraft carriers) within carrier task forces.

(e) Experience. Volume IV defines an experience parameter, β', and uses this parameter to determine the sequence of attrition to platforms and targets. The fundamental problem with the use of this parameter is that its value does not affect either the number of platforms that are killed or the number of targets that are killed--this parameter merely helps determine the order in which these kills occur. It is not unreasonable to believe that an experienced participant in combat might kill more of the enemy, and be less likely to be killed himself, than an inexperienced participant. However, it is not at all clear why experience should affect the order in which kills occur (by side) while not affecting the number of kills that occur on either side.

If the Navy believes that experience would affect only the order in which kills occur, then it should justify this

[1]Each of these divisions of the threat (between carrier task forces and other targets, and among threat areas for carrier task forces) could be either made stochastically (according to an appropriate probability distribution if one exists) or deterministically (according to a game-theoretic analysis that considers enemy flexibility).

belief more carefully than is done in Volume IV. Conversely, if the Navy does not believe that experience is limited to this sequencing effect, then they should change the way that they model experience. For example, they might ignore experience on the basis that it is an intangible factor that various participants on both sides possess in similar degrees, which is how virtually all other methodologies (including the Navy's air-to-surface analysis) treat experience; or they might somehow incorporate experience into the way that it corrects the problems concerning attrition described in Section (c) above.

A detail concerning the β and β' parameters, as currently used in the NNOR, is as follows. Neither of these parameters affects the number of targets (or platforms) killed, but both affect the amount of ordnance needed to kill these targets. Thus, as currently used, it is reasonable to relate these parameters; and Volume IV does this by assuming that they are equal. This assumption raises two questions: (1) Why should the degree of concentration be equal to the degree of experience; and (2) if one accepts that the degree of concentration should equal the degree of experience, is this achieved by setting $\beta = \beta'$?

The NNOR does not answer the first question; but Volume IV seems to provide enough information to answer the second, and the answer appears to be no. In particular, Table 2 is based on the formulas presented in Volume IV. This table shows the possible values that β and β' can assume, and it briefly describes the conditions under which these values would be assumed. Based on Table 2, it would seem that if one wanted the degree of concentration to equal the degree of experience, then $\beta = 0$ would correspond to $\beta' = 0$, but $\beta = +\infty$ (or $-\infty$) would correspond to $\beta' = 1$, and

Table 2. CONCENTRATION AND EXPERIENCE AS DEFINED IN THE NNOR

CONCENTRATION		EXPERIENCE	
Condition	Value of β For This Condition	Condition	Value of β' For This Condition
Maximum Concentration	$\beta = 0$	Experience Is Most Desirable	$\beta' = 0$
Somewhat Concentrated	$0 < \beta < \infty$ (the lower β is, the more concentrated the attack is)	Experience Is Somewhat Desirable	$0 < \beta' < 1$ (the lower β' is, the more desirable experience is)
Independent Attacks	$\beta = \infty$ or $\beta = -\infty$	Experience Is Irrelevant	$\beta' = 1$
Somewhat Spread Out	$-\infty < \beta < -1$ (the higher β is, the more spread out the attack is)	Inexperience Is Somewhat Desirable	$1 < \beta' < \infty$ (the higher β' is, the more desirable inexperience is)
Perfectly Spread Out	$\beta = -1$	Inexperience Is Most Desirable	$\beta' = \infty$
Impossible Region	$-1 < \beta < 0$	Impossible Region	$-\infty \leq \beta' < 0$

$\beta = -1$ would correspond to $\beta' = \infty$. One way that this correspondence could be achieved is to set

$$\beta' = \frac{\beta}{1 + \beta}$$

The point here is not that this formula for β' is necessarily correct. The point is that even if one agrees with the way that concentration and experience are defined in Volume IV, and even if one believes that the degree of concentration should equal the degree of experience, there still appears to be no reason to set $\beta' = \beta$. Yet the results of the static (threat-oriented) portions of the NNOR seem to be based on setting $\beta' = \beta$ (as well as on all the other assumptions discussed here).

(5) A General Suggestion

The purpose of this section is to present a general suggestion concerning the Navy's static (threat-oriented) methodologies. (Suggestions concerning the Navy's analysis of air-to-surface ordnance will be made in Section 6, below.)

Some specific suggestions concerning the Navy's static methodologies have been made above. These suggestions address fixing some defects in the Navy's current approach, as opposed to starting over with an entirely different approach. The general suggestion made here is that the Navy should consider the development of a new approach which would serve to *supplement* (and, perhaps, eventually replace) the current static approach.

The fundamental problems with the Navy's static approach are: (1) It depends on an input and inviolate apportionment of enemy targets to the various types of Navy weapons associated with various Navy platforms; and (2) these enemy targets seem to exist only to be killed (in that they "stay around" until they are killed by the specified Navy weapon, and they cause no damage themselves). These characteristics appear to be basic assumptions which are necessary to implement the Navy's current approach. With them, the Navy just needs to "turn the crank" to determine how much ordnance is needed for each type of weapon on each platform to kill the designated number of enemy targets with the required confidence. Without them, the Navy's approach cannot be used. It appears that changing these basic assumptions requires using a new approach.

Many of the discussions in Section 4 and Sections 5.b(1) through 5.b(4) have resulted in arguments that these basic assumptions should be changed. These discussions have considered these assumptions from different viewpoints, but the result is the same--these assumptions are untenable. If it is agreed that these assumptions should be changed, then the next question is: What assumptions should be used, and what approach can be employed with these new assumptions?

One answer to this question is to go back to the data sources used in Volumes I and III of the NNOR. For example, the partitioning of the enemy threat for maritime air superiority warfare was taken from another Navy study. Its assumptions, data, and models might be usable to determine ordnance consumption. If that study determined ordnance requirements which are still valid, then these requirements can be taken from that study and the NNOR is unnecessary. Alternatively, if that study used models or procedures that could easily be modified to account for ordnance in an appropriate manner, and if these modified models or procedures could reasonably be used (with updated data, if appropriate) whenever the NNOR is to be updated, then the NNOR could base its results directly on these updated models or procedures.

Of course, the data sources used in Volumes I and III may not be appropriate for determining ordnance requirements (say, on a yearly basis), and it may be very difficult to modify and update these sources to make them appropriate.[1]

If this difficulty precludes using these sources to determine ordnance requirements, then another answer is needed. There probably are many models of combat involving one or more of the weapons considered in Volumes I and III. The Navy could make a survey of these models to determine which (if any) are appropriate for use in determining ordnance requirements.

Some criteria that the Navy may want to consider in making this survey are as follows. First, the models should be reasonable models of what they simulate, they should be documented (either currently or when they are used by the Navy), and they should help answer the questions and problems raised above. In particular, they should consider attrition (including attrition caused by saturation) to both sides in a reasonable way, and they should not be dependent on a fixed, input partitioning of enemy targets to Navy weapons for killing. Second, these models should not be so complex as to preclude their use in a timely and efficient manner for the NNOR. Third, if the Navy continues to consider stochastic risk in future analyses, these models must be stochastic (or Monte Carlo). Fourth, these models should consider more than just a few types of ordnance--the more types of ordnance they consider the better. If these models do not consider all types of ordnance likely to be involved in a particular combat situation, then they should be able to be correlated with other models that simulate use of the other types of

[1]Another potential difficulty is that, even if these sources can be used to determine ordnance requirements for a few specific types of weapons, they may not be able to be coordinated with the sources related to the other types of weapons.

ordnance. Fifth, these models should either directly consider resupply, or be able to be used within a procedure that considers resupply; and these models should be able to distinquish (or be used in a way that distinguishes) between one-time enemy weapons and recurring enemy weapons. Finally, these models should (directly or indirectly) be able to distinguish among high-threat areas, medium-threat areas, low-threat areas, and areas in which combat essentially cannot occur.

If this survey uncovers some models suitable for use, the Navy should consider using them as soon as practical to supplement the static analyses made in the NNOR. If not, the Navy should consider either building suitable models (perhaps based on the best of the existing models) or developing procedures which could tie together existing models.[1] Tying together existing models is theoretically possible if suitable models exist of each portion of a combat situation. Such models of limited scope probably do exist, but it may be more practical to build a new model than to tie these existing models together--the decision here depends on the details of the existing models, and these details could be determined in the Navy's survey.

In a budget-constrained environment, the goal would be to develop a model (or a procedure using models) that would address the question: If the Navy has D dollars to spend on all of the types of ordnance considered in Volumes I and III of the NNOR, how should these dollars be spent? The model or procedure selected should be able to address this question for various values of D. This goal may be too hard to achieve in one step, and sub-goals may be more appropriate initially. The sub-goals would be to develop models or procedures to address this type of question for various types

[1]An existing model which might be suitable for this use is described in [23]. This reference also discusses some limitations of the current Navy methodology.

of combat. For example, the following questions could be considered: If the Navy has D_1 dollars to spend on all of the types of ordnance used in maritime air superiority, how should these dollars be spent? If the Navy has D_2 dollars to spend on surface-to-surface missiles and anti-surface-ship missiles, how should these dollars be spent? If the Navy has D_3 dollars to spend on ordnance for submarine/anti-submarine warfare, how should these dollars be spent? Obtaining the capability to address these questions for various values of D_1, D_2, and D_3 could lead to a major improvement in the analysis of naval ordnance requirements.

6. Interactions Between the Navy and the Army and Air Force

Two ways of employing naval resources that might result in significant interactions between the Navy and the other Services are discussed below; power projection is discussed in Section a, and ocean control (including protecting the sea lines of communication) is discussed in Section b.

a. Power Projection

Scenarios wherein the Navy might be used to project power ashore range from (1) conducting destructive raids into hostile countries where there is no friendly ground or air force (and no other friendly forces are involved), to (2) supporting the US Army and Air Force in a war against the Warsaw Pact in Central Europe. Some other scenarios include power projection (a) in support of amphibious operations, (b) in support of the deployment of airborne forces, (c) in support of US Allies, (d) in support of the flanks of a theater in which US forces are involved, and (e) in support of the US Army and Air Force in theaters other than Central Europe. The degree of interaction between the Navy and the other Services in these scenarios ranges from virtually no interaction to as much interaction as exists between the Army and the Air Force when operating in the same theater.

However, while the degree of interaction varies with the scenario, this does not mean that the Navy should plan its ordnance requirements independently of the other Services. For example, a reasonable mix of ordnance for the Navy given that they are flying missions into a section of Central Europe where there are no Air Force or Army units may be an unreasonable mix of ordnance either for a more realistic scenario in Central Europe (involving the Army and Air Force) or for a scenario elsewhere in the world where the Navy might be operating independently. The current Navy approach for determining ordnance for power projection does not take direct account of interactions with the Army and Air Force, and so would appear to be unreasonable on its face value. Of course, it might work out that the same mix of ordnance would be purchased whether or not account was taken of these interactions, but such a result would be fortuitous--and the Navy gives no evidence that this result would likely occur.

An alternate approach is as follows. The Navy should specify several scenarios on which to base its ordnance purchases for power projection. Judgment would be required in determining these scenarios as well as their relative importance.[1] With each scenario, care should be taken to include all important interactions between the Navy and the other Services that are likely to occur in that scenario. In particular, if the Navy believes it reasonable to consider scenarios in which it is operating in the same geographical area as (either US or Allied) Army and Air Force units, then the interactions involving the fourteen categories of attrition

[1]For example, if Munition 1 were very worthwhile in Scenario 1 but not in Scenario 2, while Munition 2 were very worthwhile in Scenario 2 but not in Scenario 1, then judgment would be needed to determine the appropriate mix of Munition 1 and Munition 2 to be purchased.

listed in Section 3.a above apply just as much to the Navy as they do to the Army and the Air Force. If the Navy is supporting US Army and Air Force units, then each of the three Services should (1) provide OSD with the results of each of these fourteen attrition interactions over time (e.g., for each day of the war), by type of target, and (for aircraft) by Service of the shooter; (2) provide OSD with the major assumptions and data behind these results; and (3) plan the purchase of ordnance, replacement weapons/aircraft (if any), and replacement personnel consistently with the assumptions and data so provided. The rationale for this suggestion is the same as given in Section 3.b, except that it now applies to three Services instead of two.

Similar data, assumptions, and results should be provided to OSD by the Navy (only) for scenarios in which the Navy is supporting Allied Armies and Air Forces. The reason for providing this information is that such information is necessary in order to compare the amount of support given the Allies by the US Navy to the amount of effort supplied by the Allies themselves (such a comparison is especially important when this naval support could be used to assist US forces instead).

b. Ocean Control

Concerning Navy resources used for ocean control, the degree of interaction between the Navy and the other Services varies with each scenario just as it does for resources used for power projection. Some scenarios involve little or no interaction. Others can involve significant (though, perhaps, indirect) interaction. The most important example of the latter type of scenario is the protection of the sea lines of communication (SLOC) in the event of a war in Europe, and only this scenario will be discussed here.[1]

The key distinction between the interactions involved in power projection and those involved in SLOC protection is as follows. The interactions involved in power projection are direct and are basically similar to those between the Air Force and the Army; methods and models have been developed which (perhaps with some modification) can directly address these interactions. The interactions involved in SLOC protection, however, are indirect. The primary reason for providing SLOC protection is to allow ordnance and other logistical support to be sent from the US to Europe (or to wherever the war is being fought). But clearly having the ability to deliver such logistical support is useful only if (1) the needed ordnance and other logistical items can be manufactured quickly enough, or already have been manufactured and are stored in the US ready for shipment; and (2) there is enough ordnance and other logistical support in Europe (or wherever) to allow friendly forces to fight effectively until the shipments from the US arrive. It would be foolish to buy ordnance to protect the SLOC if a reasonable amount of ordnance (and other logistics) had not already been bought to satisfy conditions (1) and (2) just stated.

If combat consumption could be accurately estimated, then the method for handling this indirect interaction would be clear: No ordnance should be bought for protecting the SLOC until enough ordnance has been bought to allow friendly ground and air forces in theater to fight until the first shipments of supply from the US arrive. Once this amount of air and ground ordnance has been bought, the mix of purchases

[1]The comments made here, however, would apply with little change to any scenario in which the US Army and Air Force require resupply from the Continental United States via a SLOC.

between naval ordnance for SLOC protection and air and ground ordnance for use in theater should be that which maximizes the effectiveness of the friendly forces in the theater. However, combat consumption is dependent on many factors such as scenario and enemy tactics, and it probably cannot be estimated accurately enough to warrant buying no ordnance for SLOC protection (provided that there are not gross discrepancies between estimates of when the ordnance in theater would be consumed and when the first shipments from the US would arrive).

In summary, there is a strong interaction between the amount of ordnance that should be bought for SLOC protection and the amount of ordnance that should be (or has been) bought for use in theater, but this interaction is indirect and may be difficult to analyze. Accordingly, this interaction may be an appropriate topic for future research. For the present, it is not clear what should be done about this interaction other than to recognize that it exists and that it should be considered, if only judgmentally, in determining ordnance purchases.

E. PRINCIPAL SUGGESTIONS FOR IMPROVEMENT

Section 1, below, summarizes the Service-related suggestions made in Section D. Section 2 presents some corresponding suggestions for OSD analyses. Section 3 considers some aspects of the general problem: "How much sustainability is enough?".

1. A Summary

The Army would appear to be on the right track if they continue the development of an integrated approach for analyzing combat consumption based on a theater-level dynamic model. Some specific suggestions have been made in Section D.1.b above, and there is no point in repeating them here.

The Air Force does not appear to be on the right track in that it is using fundamentally weak methodologies. The primary weaknesses of the Air Force approach have been discussed in Sections D.2.a and D.2.b above. One (though not necessarily the most important) impact of these weaknesses is that the Air Force approach is unable to address the question of what is the best mix of all types of ordnance (for aircraft) to purchase subject to a budget constraint of D dollars to spend on this ordnance, where the value of D is specified in advance. However, while the Air Force's current approach is quite weak, methodologies exist which, perhaps with some modification, could address the problems cited in Sections D.2.a and D.2.b, and could be used to help address the question of how to spend a fixed budget for the purchase of ordnance. Some suggestions for a new approach are summarized in Section D.2.f. Since a new approach is recommended, detailed suggestions for marginally improving the current Air Force approach are not given here.

The Navy's approach also has several methodological weaknesses. However, it may be difficult to develop new models and methodologies (or to modify current ones) to uniformly correct these weaknesses; and, once started, such development (or modification) may take considerable time to implement. Accordingly, a few general suggestions concerning the Navy's air-to-surface methodology are given in Sections D.5.a and D.6.a, and many general and specific suggestions for marginal improvements to the Navy's static (threat-oriented) methodologies are given in Sections D.4 and D.5.b.

A general suggestion oriented towards making fundamental improvements in the Navy's threat-oriented methodologies is presented in Section D.5.b(5). Until such fundamental improvements can be incorporated into Navy analyses, the

Navy should consider making near-term "stop-gap" improvements to its methodologies. A summary of such near-term improvements is as follows.

First, the Navy should select and carefully describe one or more reasonable scenarios, and it should base its analyses on these scenarios. (One scenario would be sufficient if it were plausible and if all other plausible scenarios were less demanding in terms of ordnance requirements.) Second, the Navy should consider attrition of, and resupply to, ships and weapon systems in some direct and clearly defined way. Such considerations might have to be simplified in order to be used within the current Navy model, and the specifics of these considerations would generally depend on the scenarios selected. Third, the Navy should consider using a lower "risk" factor, which might offset the potential error induced by treating attrition as if it occurs in parallel as opposed to occurring in series.[1] Fourth, the Navy should use a realistic (i.e., low) value for the maximum expenditure of ordnance against one-time targets. Finally, the Navy should carefully consider and discuss the impact of its determination of what constitutes a platform for each of its uses of the current threat-oriented model.[2]

---

[1]A formula or a tabulation that gives the "fleet risk" (i.e., the probability that all platforms have enough ordnance) as a function of the attack parameters should be developed and compared with the "platform risk" (i.e., the probability that a randomly selected platform has enough ordnance—as currently used in the NNOR). The reasons for calculating and discussing fleet risk are that it can be a more meaningful measure of potential shortfalls than platform risk, it can be significantly different from platform risk, and the NNOR does not give a method to calculate fleet risk or discuss its impact. Annex 4 presents some formulas that can be used as a start towards calculating and comparing fleet risk with platform risk.

[2]For example, anti-ship missiles (ASMs) might be separated into two categories: those attacking carrier task forces (CTFs) and those attacking convoys defended by escorts. The number of platforms defending against those ASMs attacking CTFs might be the number of CTFs—which would be consistent with a low (near zero) value for the concentration parameter β; or it might be the number of ships in the CTFs— (continued on next page)

Neither OSD nor the Services seem to be handling the impact of combat interactions among the Services in a reasonable way. A general approach for considering some of these interactions is described in Sections D.3 and D.6, and some suggestions concerning this general approach are given in the following section.

2. The Development and Use of Simple Dynamic Models

a. Criteria for Development

In order to compare and coordinate Service requirements, this report suggests that OSD develop the capability to use a model (or models) to determine combat consumption. Some criteria for such a model are as follows.

First, it should be relatively simple (highly aggregated). Several advantages of a simple model are stated in Section C.2.c(1) above. In addition to these advantages, a simple model would require less of OSD analysts' time to maintain and run. Further, since OSD may not (and usually should not) be interested in making as detailed an analysis as the Services, a simple model may frequently suffice.

Second, the model should be dynamic. Much of the discussion in Section D concerns the weaknesses of static models when used to determine combat consumption. Since relatively simple dynamic models can be built and used, there is no strong reason to restrict an OSD model to being static.

(cont'd.) which would be consistent with a very high (near infinity) value for β. The number of platforms used in the calculations for those ASMs attacking convoys might be the total number of ships (both escorts and cargo ships) in the convoys (the fact that only escort ships can expend ordnance may be irrelevant to the determination of which ships are attacked by the ASMs). Other plausible definitions of platforms are possible, and appropriate definitions may depend on the scenarios used. The point here is that the Navy should develop and use more carefully structured definitions of platforms in its analyses.

Third, the model should be oriented towards making comparisons with Service models and Service results, not towards producing an independent and absolute answer which can be justified against all objections. This criterion is more a vague goal than definitive specification, but it may be an important goal to keep in mind.

Initially, such a model should be a dynamic ground-air model. It could be based directly on the outputs of one or more detailed (and, perhaps, Service run) models, or it could be a model whose inputs and outputs correspond to what appear to be the most significant inputs and outputs of Service models. Other concepts (and combinations of these concepts) can be considered, and some specific ideas and structures for such a model are suggested in this report. The point here is that the development and use of an appropriate yet simple ground-air model is well within reason.

As indicated in Section C.2.c(1), one of the first things an analyst is tempted to do with a simple dynamic model is to make it more complex. For OSD's purposes, it might be a mistake to make such a model significantly more complex by making it more detailed. However, once defined and understood, OSD might consider including the effects of delays and losses in shipments from the US (i.e., the effects of not having full protection of the SLOC), and (if appropriate) including naval power projection in the ground-air combat being modeled. These inclusions should not significantly increase the complexity of the model and would allow the joint consideration of Navy resources as well as of Army and Air Force resources.

b. OSD Uses

The relationship between a simple (OSD) model and a detailed (Service) model is very much like the relationship between a model and judgment. In both cases, the former does not replace the need for the latter, but the former can help in developing, examining, and explaining the latter. Some specific uses for a simple model are as follows.

A simple model can serve as a structure (or vehicle) on which discussion of critical issues can be based. In this use, the simple model would not provide "answers" but would provide some definitions and consequences of assumptions that could facilitate discussions. This use of a simple model can be very important to OSD in discussions with the Services if the Services are using complex detailed models, or are using mixtures of narrowly-scoped models, assumptions, and judgments.

OSD can use a simple model to test its understanding of Service results. For example, if certain Service results seem plausible to OSD analysts and if very similar results are given by OSD's simple model, then OSD analysts' time might be better spent doing something other than checking into the details of these results. However, if some Service results do not seem plausible and a simple model gives very different results, then OSD analysts' time might be well spent checking into these results. Analysis of these results sometimes may only reaffirm known defects of the simple model which are "taken care of" by the details of the Service model. However, such an analysis might uncover implicit assumptions or driving factors behind the Service results that, at a minimum, OSD should be aware of.

A simple model which is broad enough to consider the resources of more than one Service can be used to compare the results of one Service's analysis with the results of analyses of other Services. This use of a simple model not only can test for consistency, it can give estimates of the magnitudes of inconsistencies and can point to specific areas in which such inconsistencies are occurring.

Suppose that a detailed model has been run for several different cases, and that the results of a simple model match the results of the detailed model for these cases. Suppose that results are desired for a case not considered by the detailed model, but that this new case is, in some reasonable sense, bounded by the cases that were run (or is logically very close to a case that has been run). Then the simple model can be used to "interpolate" the results of the detailed model by running only the simple model for this new case. This use of a simple model can be appropriate for handling "last-minute changes" and updates in data or assumptions not deemed to be sufficiently significant to warrant rerunning the (larger) more detailed model.

Finally, a simple model can be used to extrapolate results from a more detailed model. That is, a few runs of a detailed model may produce many unanswered questions of the type, "What-would-happen-if...". These questions could be filtered through a simple model. When the answer is "Not much would change", then these questions need not be addressed by making use of the (more time consuming) detailed model. However, when the simple model indicates that significant changes would occur, then these questions could become high-priority questions to be addressed by the more detailed model. It should be noted that this use of a simple model is only to suggest new cases to be considered by the more detailed model--not to provide results directly.

c. <u>Service Uses</u>

The discussion in Section b, above, centered on possible OSD uses of a simple dynamic model. Generally speaking, these potential uses apply to the Services as well--since a simple model can complement but not replace a complex detailed model, the Services might wish to develop and run simple models (in addition to more detailed models) for essentially the same reasons as given in Section b. This suggestion has already been made in Section D.1.b(4) for the Army. If the Air Force and Navy were to implement detailed dynamic models for determining combat consumption, they probably would (and certainly should) continue to run their static models for comparison. Once they are satisfied with their new detailed dynamic models, they could use simple models (either improved versions of their static models or some simple dynamic models) for the purposes stated in Section b.

3. <u>How Much Sustainability Is Enough?</u>

As stated in Section A.1, the scope of this paper is generally limited to considering problems involved in determining how a fixed budget should be spent; and the discussions so far have been limited to this scope. Two (related) objections can be made to this limitation in scope. First, "decision makers" need to determine budget levels as well as the mix of purchases within a budget; and they can reasonably ask whether combat modeling can contribute useful information to the determination of the budget to spend on sustainability (other than that which can be implied from examining the mix of expenditures subject to a fixed budget). Second, one can argue that the US is planning to have a certain number of weapons of each type in its force structure, and the question that should be addressed is "How much ordnance should be bought for this fixed number of weapons?", not "How much ordnance should be bought for a fixed number of dollars to spend on ordnance?"

Both objections can be addressed by the same expansion in scope, and this expansion in scope can be addressed by the same models that have been recommended above for the more narrowly scoped problem of how to spend a fixed budget on sustainability.

Before discussing this expansion in scope, it should be noted that generally there is no absolute answer to "How much sustainability is enough?" What can be done, either purely judgmentally or with the assistance of quantitative analyses, is to compare buying various levels of sustainability with buying various levels of other resources or attributes. In a sense, the problem of "How much is enough" at one level becomes the problem of determining cost-effectiveness trade-offs at a higher level; the question here is "Can combat modeling contribute to solving this problem at some appropriate higher level?"

There are many "higher levels" where the answer to this last question is no. For example, it does not appear that combat models can contribute to the question of whether more money should be spent on buying munitions or whether the same amount of money should be spent on improving leadership and morale instead. However, a higher level question on which combat models can make contributions is whether more money should be spent on sustainability (in terms of ordnance, replacement weapons/aircraft, and replacement personnel) and correspondingly less spent on force structure weapons/aircraft and personnel, or vice versa.

In particular, the models and methodologies recommended above directly consider force structure weapons (and, at least implicitly, force structure personnel); they can directly compare the impact of having more of these force structure resources and less ordnance, replacement weapons/aircraft, and replacement personnel, versus having less force structure resources and more ordnance and replacement resources.[1] Thus, instead of determining how to spend D dollars on ordnance and replacement resources, these models and methodologies can be used to address the following question: "Given a total of D_0 dollars to spend on force structure resources, replacement resources, and ordnance, how much should be spent on force structure resources (by type) and how much should be spent on replacement resources and ordnance (by type)?" This question can be addressed for various values of D_0.

Suppose that addressing this question for a particular value of D_0 indicates the D_1 dollars should be spent on force structure resources and that D_2 dollars should be spent on replacement resources and ordnance (where $D_0 = D_1+D_2$). Then the first objection stated above (related to how much should be spent on sustainability) would, in a sense, be addressed by saying that if D_0 dollars is to be spent on these resources in total, then D_2 dollars should be spent on the sustainability portion of these resources.

The second objection stated above would technically be addressed by the fact that if force structure resources are traded off for sustainability resources, then the numbers of the various types of force structure weapons are not fixed. More importantly, an intuitive rationale behind the second objection is that DoD should either buy "enough" ammunition for all of the weapons/aircraft it buys, or it should not be buying so many weapons/aircraft in the first place. It is this intuition that is directly addressed by making cost-effectiveness comparisons among force structure resources, replacement resources, and ordnance.

[1]These models and methodologies do not consider all of the types of weapons and ordnance in the force structure, but they consider enough different types to provide useful information.

Finally, it is sometimes suggested that new (or more) weapons are bought at the expense of needed ordnance for existing weapons. Making cost-effectiveness trade-offs between buying new (force structure) weapons and buying ordnance will not automatically solve this problem any more than running any model automatically solves any complex problem. But making these trade-offs can contribute to the identification, understanding, potential magnitude, and possible solutions to this problem in many of the cases where such a problem might exist.

F. SOME TOPICS FOR FUTURE RESEARCH

Several suggestions for future research are contained in the discussions above. Three additional suggestions follow.

First, the development of a new type of ordnance (or of a new type of weapon or aircraft that can deliver new ordnance) can create a sudden demand for the new ordnance; that is, a comparison of the new ordnance with the older types of ordnance would show that the new ordnance is preferred. In this case, future purchases should be oriented towards buying the new ordnance in place of buying more of the older types of ordnance. However, an important question here is "How much of this new ordnance should be bought to replace existing stockpiles of older ordnance, and how quickly should this replacement of stockpiles be made?" On the one hand, the fact that new ordnance is available does not necessarily render the older ordnance useless. Accordingly, the fact that new ordnance is available does not mean that enough of this type of ordnance should be bought to satisfy all the combat consumption that was previously satisfied by the older ordnance. On the other hand, since enemy capabilities are likely to be increasing, the older ordnance is likely to become less and less valuable over time and so should be replaced eventually by newer ordnance.

A second topic for future research concerns hedging. One might want to buy forces and ordnance to hedge against variations in enemy tactics, changes in the effectiveness of weapons,[1] changes in enemy force structure, alternative weather and environmental conditions, and alternative possible scenarios. The first of these reasons for hedging (variations in enemy tactics) frequently can be addressed by appropriate applications of game theory. However, there is generally no easy answer for the other types of hedging. It may be that meeting some set of minimum requirements dominates the need for hedging against alternative possibilities. But once these minimum requirements are met, it seems reasonable to consider the various types and degrees of hedging in some (at least) roughly consistent manner; and additional research may be needed to help address this aspect of hedging.

Finally, intertheater logistics (in terms of protecting the SLOC) and the resupply of Navy resources have been discussed briefly above. Intratheater logistics in terms of the capability to resupply Army and Air Force units in theater can also be important and should be considered. It may do no good to have ordnance and replacement resources arrive by ship and air if the ports and air bases have been destroyed; and it may do no good to store ordnance and replacement resources in theater if they can be destroyed by enemy air attacks. Even if replacement resources and ordnance are available in theater, in order to use these resources effectively the transportation, information, command and control have to be available to move these resources from where they

[1]For example, what should be done to account for the possibility that precision guided munitions on both sides may not be as effective in combat as is currently estimated?

are stored (or unloaded) to where they are needed. If this logistics capability is sufficiently large, then only expected numbers of replacement weapons and ordnance are needed (and interoperability of weapons and ordnance may not be needed). However, if this logistics capability is not sufficiently large, additional replacement weapons and ordnance may be needed (and some weapons and ordnance may have to be, in some sense, interoperable) in order to account for the possibility that resources may be one place when they are needed somewhere else. How the impact of logistics affects both sides in combat, how interdiction by either side can affect this impact, and how we should allocate funds between improving logistics and buying more (or better) replacement weapons and ordnance are questions which may be appropriate subjects for future research.

ANNEX 1

AN ALLEGORICAL RATIONALE FOR THE CURRENT DOD OVERALL APPROACH

AN ALLEGORICAL RATIONALE FOR THE CURRENT DOD OVERALL APPROACH

A. THE POINT OF THE ALLEGORY

The reason for presenting the following allegory is to help one understand the current approach. It is not that the description below is exactly the way it happened (DoD's current approach might not have come about this way at all); nor is the point that munitions are considered haphazardly, but the "requirements" for replacement people and replacement weapons are determined in a reasonable way (the three "requirements" are necessarily interrelated, which is not considered in the current approach).

For example, advocates of the "defeat the entire threat" method have argued that if you didn't do it that way, the demand for ammunition would be even greater. This argument doesn't make sense unless one limits the alternatives as described below.

More importantly, the following allegory can help explain how taking a simple idea and making independent, step-by-step "improvements" can lead to an overall system which, while perhaps better than the original idea, is not nearly as good as it could have been (using a similar amount of effort) if a sufficiently broad perspective had been taken. This statement is not meant to criticize past efforts--it may only be by hindsight that one can see the broad perspective. But it is meant to criticize continuing the current approach when more reasonable approaches are now clearly available.

B. THE ALLEGORY

A possible rationale for the current DoD structure is to view the problem from a so-called requirements perspective as follows: Suppose DoD is not budget constrained, but instead can buy all the munitions, replacement weapons, and replacement personnel that it can "justify."

For example, consider the problem of determining the requirements for munitions. A simple solution to this problem is to buy munitions for all of the weapons in the force structure. For example, suppose that a tank in combat expends an average of 20 rounds per day (whether or not it is killed that day), and that tanks in combat suffer an average attrition rate of 2 percent per day. Then the Army can say it "requires" 1,000 rounds per tank in combat, computed as 20 rounds per combat day times 50 days (the average lifetime of a tank in combat). The same concept could be applied to Air Force aircraft and Navy ships.

However, applying this simple solution to the Air Force (for example) can produce a requirement for more ordnance than could reasonably be expended against an expected enemy threat. Suppose that certain aircraft are limited to flying air defense missions, that each such aircraft suffers an average of 1 percent attrition per sortie, and that on each sortie it expends 2 salvos of 2 missiles with a p_K per salvo of 0.5. Then each aircraft can be expected to expend a total of 200 salvos of 2 missiles. Now if there are 500 such aircraft in the theater, this means that 100,000 salvos are expended, requiring 200,000 missiles. But if the enemy has only 2,000 attack aircraft in the theater, then 100,000 salvos with a p_K of 0.5 seems excessive. That is, since the simple solution does not account for the size of the threat, it can result in buying too much ordnance. As a result, if one were restricted to use either the simple solution or some simple variant, it would seem reasonable to buy either the amount of ordnance given by the simple solution or the amount of ordnance required to defeat (in some sense) the entire expected threat, whichever is less.

Apparently, this reasoning (or some similar reasoning) has been followed, and requirements for types of munitions that are limited to use against certain types of targets (such as air-to-air and surface-to-air missiles) have not been calculated by the simple solution. Instead, these munitions requirements have been determined by buying "only" enough munitions to defeat the entire expected threat (it being assumed that the minimization mentioned above always results in the number required to defeat the entire threat being smaller than the number given by the simple solution).

As the example indicates, if one is forced to choose between buying munitions according to the simple method or buying only enough munitions to defeat the entire threat, then it is possible that it is cheaper to buy only enough munitions to destroy the entire threat.

Analyzing munitions requirements for the weapons that were separated into the "defeat the entire threat" category produces the problem that several different types of munitions (surface-to-air missiles of various types and air-to-air missiles of various types, for example) can be used against the same threat (enemy aircraft). This problem was "solved" (within the Services) by assigning a certain portion of the threat to each type of weapon. This "solution" to this particular problem (given that one is committed to using the "defeat the entire threat" approach) might have been reasonable if (1) a reasonable way to proportion the threat were used and (2) the statistical variation in the number and distribution of engagements needed had been adequately considered when considering "risk."

Analyzing munitions requirements for the weapons that were not put into the "defeat the entire threat" category (such as ground-to-ground and air-to-ground weapons) uncovered two more defects of the simple solution. First, if these weapons suffer very low attrition, or if replacement weapons are bought to keep the force structure full, then the amount of ordnance "required" grows roughly linearly with the length of the war. (If the simple solution, which is not a function of the length of the war, is used without modification, then very low attrition results in very high munitions "requirements;" and complete replacement of all destroyed weapons results in infinite munitions "requirements" as well as infinite "requirements" for replacement weapons.) A solution here is straightforward. A length of war is specified, and munitions are purchased to satisfy demands through that length of war. This is an easily implemented solution; but, unlike the "defeat the entire threat" approach, it requires specifying a length of war.

The second problem that was uncovered is more difficult to solve. Many weapons can use several types of munitions, with the preferred type depending on the type of target. Accordingly, to create a requirement for munitions by type, the number of weapons in the threat (not just in total, but also by type) has to be considered. As a result, both approaches (the "defeat the entire threat" approach and the "meet the demand day-by-day" approach) now consider the threat. Of course, the "day-by-day" approach then runs into the same problem as the "entire threat" approach concerning which weapons should shoot at which targets. The Army addressed this problem by using dynamic simulations of combat; the Navy and Air Force addressed the problem by dividing the threat weapons among the shooters.

ANNEX 2

A SET OF SIMPLIFYING ASSUMPTIONS UNDER WHICH THE CURRENT AIR FORCE AND NAVY ATTRITION COSTING TECHNIQUE IS REASONABLE

A SET OF SIMPLIFYING ASSUMPTIONS UNDER WHICH THE CURRENT AIR FORCE AND NAVY ATTRITION COSTING TECHNIQUE IS REASONABLE

Suppose that there is one type of aircraft whose replacement cost is c, that the cost of one sortie's worth of munitions of type i is m_i, that the attrition rate per sortie carrying munitions of type i is a_i, that there is one type of target, and that the value of these enemy targets killed per sortie carrying munitions of type i is v_i (no matter when during the war these targets are killed). For simplicity, assume that all attrition to aircraft occurs after the ordnance has been delivered (i.e., on the way home), and that the O&M cost per sortie can be neglected. Then the current Air Force methodology is to select the munition type, i, that solves the problem

$$\min_i\{(ca_i+m_i)/v_i\} \;.^{1} \tag{1}$$

Under these assumptions, the expected cost of type i munitions for all sorties flown by each aircraft in a sufficiently long war, M_i, is

$$M_i = m_i(1+(1-a_i)+(1-a_i)^2+\ldots) = m_i/a_i \;;$$

and the expected value killed by all sorties flown in a sufficiently long war by each aircraft using type i munitions, V_i, is

$$V_i = v_i(1+(1-a_i)+(1-a_i)^2+\ldots) = v_i/a_i \;.$$

[1]The Navy uses an essentially identical methodology. For convenience, this methodology is called simply the "Air Force methodology" here.

Assume that all of the various types of munitions have the same effectiveness considering attrition--that is, suppose that the expected value killed by all sorties flown by one aircraft is some constant, V_o, no matter which type munition is used (so that $V_i \equiv V_o$). Then the Air Force might want to purchase and use the munition with the lowest munitions cost (not including the cost of replacement aircraft). That is, the Air Force might want to buy the type of munition, i, that solves the problem

$$\min_i\{M_i\} = \min_i\{m_i/a_i\} \qquad\qquad (2)$$

$$\text{subject to } v_i/a_i = V_o \text{ for all } i.$$

Note that Problem 2 minimizes the cost of munitions subject to constant effectiveness. Note also that the munition which minimizes Problem 2 is the same munition that minimizes Problem 1. That is, i* minimizes Problem 1 if and only if i* minimizes $\{(ca_i+m_i)/v_i\}$, no matter what the nonnegative value of c is. Therefore, if the assumptions and conditions described above hold, then the current Air Force approach would select the same type of munition as would be selected by minimizing the total cost of munitions, subject to constant effectiveness (no matter what the Air Force uses as the cost of replacement aircraft).

Now assume instead that all of the various types of munitions have the same munitions cost considering attrition--that is, suppose that the expected cost of all of the munitions used on all of the sorties flown by one aircraft is some constant, M_o, no matter which type of munition is being used (so that $M_i \equiv M_o$). Then the Air Force might want to purchase the most effective type of munition considering attrition. That is, the Air Force might want to buy the type of munition, i, that solves the problem

$$\max_i\{V_i\} = \max_i\{v_i/a_i\} \qquad (3)$$
$$\text{subject to } m_i/a_i = M_o \text{ for all } i.$$

Note that Problem 3 maximizes the effectiveness of aircraft sorties subject to constant munitions cost. Note also that the munition that maximizes Problem 3 is the same munition that minimizes Problem 1. That is, i* maximizes Problem 3 if and only if i* minimizes $\{(ca_i+m_i)/v_i\}$, no matter what the nonnegative value of c is. Therefore, if the assumptions and conditions described above hold, then the current Air Force approach would select the same type of munition as would be selected by maximizing the total effectiveness of munitions, subject to constant munitions cost (no matter what the Air Force uses as the cost of replacement aircraft).

Two of the assumptions made above which should be expressly noted are: (a) the value of the enemy targets remains constant over the course of the war, and (b) the war lasts sufficiently long for aircraft to fly all the sorties they can before they suffer attrition.[1]

Proofs of the equivalencies of the problems stated above are as follows.

Notation: "=" means that the problems are identical;

"≐" means that the same values minimize (or maximize) the objective function of the problems.

[1]These assumptions are not the assumptions currently made by the Air Force in determining their requirements for air-to-ground munitions. Instead, these are assumptions under which the current Air Force attrition-costing methodology is, in some sense, reasonable.

Proof that solving Problem 1 is equivalent to solving Problem 2:

$$\min_i\{(ca_i+m_i)/v_i\}$$

$$= \min_i\left\{\frac{ca_i}{v_i}+\frac{m_i}{v_i}\right\}$$

$$= \min_i\left\{\frac{c}{V_o}+\frac{m_i/a_i}{V_o}\right\} \quad \text{s.t. } v_i/a_i \equiv V_o$$

$$\hat{=} \min_i\{m_i/a_i\} \quad \text{s.t. } v_i/a_i \equiv V_o \;.$$

Proof that solving Problem 1 is equivalent to solving Problem 3:

$$\min_i\{(ca_i+m_i)/v_i\}$$

$$= \min_i\left\{\frac{ca_i}{v_i}+\frac{m_i}{v_i}\right\}$$

$$= \min_i\left\{\frac{ca_i}{v_i}+\frac{M_o a_i}{v_i}\right\} \quad \text{s.t. } m_i/a_i \equiv M_o$$

$$= (c+M_o)\min_i\{a_i/v_i\} \quad \text{s.t. } m_i/a_i \equiv M_o$$

$$\hat{=} \min_i\{a_i/v_i\} \quad \text{s.t. } m_i/a_i \equiv M_o$$

$$= \max_i\{v_i/a_i\} \quad \text{s.t. } m_i/a_i \equiv M_o \;.$$

ANNEX 3

SOME RELATIVE STRENGTHS OF THE THREAT-ORIENTED MODEL USED IN THE NNOR

SOME RELATIVE STRENGTHS OF THE THREAT-ORIENTED MODEL USED IN THE NNOR

This annex notes several strong points of the research and the model described in Volume IV of the NNOR [2]. We present these strong points to provide some balance to the discussion in Appendix A concerning the limitations of the model. The points discussed here are presented in increasing order of importance relative to the specific subject of determining naval ordnance requirements, which is not necessarily the order that would result from using a more abstract measure (such as the quality of this research as compared to other DoD-funded research).

First, the quality of the mathematics of Volume IV is generally very good, and the main result described on page 55 (Exhibit 4-5) is excellent. In particular, this main result provides a significant yet seemingly unexpected simplification of the formulas that precede it.

Second, the results of Volume IV are not arbitrary theorems about an abstract mathematical structure; rather they appear likely to have some applications. Several potential applications have been suggested both to and by the authors of Volume IV. It can be argued that research that produces mathematical results which appear to have several possible applications is good applied mathematical research. One possible application (to the determination of naval ordnance requirements) turns out to have severe limitations, as described in Appendix A. However, these limitations of this particular application do not preclude the existence of other areas in which this research could have fruitful applications.

Third, Volume IV clearly presents the elementary assumptions which are the basis for its formulas and results, and it carefully derives these formulas and results from these assumptions. This approach stands in sharp contrast to the more typical approach of simply stating some formulas and then making vague and unjustified claims about them. Models based on this more typical approach are more difficult to understand and critique, but are just as easy to use (if one is only interested in "turning the crank"), and are more easily defended. The approach taken in Volume IV allows reviewers to point out fundamental limitations of the model where such limitations exist. Thus, if the Navy chooses to replace the model of Volume IV with another model, it should be careful not to jump "from the frying pan into the fire," especially if the "fire" is a model whose defects are hidden by using the approach of merely stating formulas and making vague, unjustified, and potentially unjustiable claims about them.

Fourth, Volume IV defines and considers a significant number of important factors related to the consumption of naval ordnance (e.g., initial allowance and resupply reserves, weapon effectiveness, false attack expenditures, maximum expenditure against a single target, and attrition to friendly forces). As argued in Appendix A, there are some severe limitations in the way that these factors are considered in the NNOR; but defining and attempting to consider these factors is a major step towards adequately addressing them--and is certainly preferable to totally ignoring them.

Finally, it appears that the research reported in Volume IV is ongoing research. That is, it appears that a more basic model than that given in Volume IV has been used by the Navy, that Volume IV produced a model that expanded and enhanced the basic model, and that future research may attempt to produce major changes and improvements to this model (as opposed to future work being oriented towards making only minor modifications to the model). If future research is intended to produce major changes and improvements, then the fact that there are now significant limitations to the model is not surprising, and the ideas discussed in this report may be useful in that research.

ANNEX 4

SOME PROBABILITIES RELATED TO PLATFORM RISK AND FLEET RISK

SOME PROBABILITIES RELATED TO PLATFORM RISK AND FLEET RISK

The following formulas were written with the assistance of Dr. Jeffrey H. Grotte, IDA. These formulas are based on Volume IV of the NNOR, and the notation of that volume is used where possible.

Let $U(n,r,\beta,p,\infty;\ell)$ be the probability that any particular (randomly selected) platform has enough ordnance given that each platform starts with ℓ salvos-worth of ordnance, that n platforms are attacked by r targets with concentration parameter β, that each salvo has a probability of p of killing the target it is fired at, and that a platform can fire an unlimited number of salvos at each target (in a shoot-look-shoot-mode). Let $U(n,r,\beta,p,d;\ell)$ be the same probability under the assumption that a platform can fire at most d salvos at any one target. Let $W(n,r,\beta,p,\infty;\ell)$ be the probability that all platforms have enough ordnance given that each platform starts with ℓ salvos-worth of ordnance, that n platforms are attacked by r targets with concentration parameter β, that each salvo has a probability of p killing the target it is fired at, and that a platform can fire an unlimited number of salvos at each target (in a shoot-look-shoot mode). Let $W(n,r,\beta,p,d;\ell)$ be the same probability under the assumption that a platform can fire at most d salvos at any one target. In terms of platform and fleet risk as discussed in Appendix A, U gives a measure of platform risk and W gives a measure of fleet risk. In terms of the NNOR, $U(n,r,\beta,p,\infty;\ell)$ corresponds to $U(\ell)$ as defined on page 16 of Volume IV of [2]; no term comparable to W is defined or discussed in the NNOR.

These probabilities are given by the following formulas:

$$U(n,r,\beta,p,\infty;\ell) = \begin{cases} \displaystyle\sum_{k=1}^{\ell} \frac{\binom{-\beta}{k}\binom{-(n-1)\beta}{r-k}}{\binom{-n\beta}{r}} \binom{\ell-1}{k-1} p^k (1-p)^{\ell-k} & \ell > 0 \\ \binom{-(n-1)\beta}{r} \Big/ \binom{-n\beta}{r} & \ell = 0 \end{cases}$$

$$\underset{\substack{r,n\to\infty \\ r/n\equiv\alpha}}{\approx} \begin{cases} \displaystyle\sum_{k=1}^{\ell} \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} \left(\frac{-\alpha}{\alpha+\beta}\right)^{k} \binom{-\beta}{k}\binom{\ell-1}{k-1} p^k (1-p)^{\ell-k} & \ell > 0 \\ \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} & \ell = 0\,, \end{cases}$$

$$W(n,r,\beta,p,\infty;\ell) = \begin{cases} \displaystyle\sum_{\substack{k_1,\ldots,k_n \\ \sum_1^n k_i = r \\ 0\le k_i \le \ell}} \frac{\binom{-\beta}{k_1}\binom{-\beta}{k_2}\cdots\binom{-\beta}{k_n}}{\binom{-n\beta}{r}} \prod_{j=1}^{n} \sum_{m=k_j}^{\ell} \binom{m-1}{k_j-1} p^{k_j}(1-p)^{\ell-k_j} & r \le \ell n \\ 0 & r > \ell n\,. \end{cases}$$

To write the formulas for $U(n,r,\beta,p,d;\ell)$ and $W(n,r,\beta,p,d;\ell)$, it is useful to define the following function. Let

$$f_{pd}(m) = \begin{cases} (1-p)^{m-1}p & m < d \\ (1-p)^{d-1} & m = d \\ 0 & m > d \end{cases} .$$

Then

$$U(n,r,\beta,p,d;\ell) = \begin{cases} \displaystyle\sum_{k=1}^{\ell} \frac{\binom{-\beta}{k}\binom{-(n-1)\beta}{r-k}}{\binom{-n\beta}{r}} \sum_{\substack{m_1,\ldots,m_k \\ \sum_1^k m_i \le \ell \\ 0 \le m_i \le d}} \prod_{i=1}^{k} f_{pd}(m_i) & \ell > 0 \\[2ex] \binom{-(n-1)\beta}{r} \Big/ \binom{-n\beta}{r} & \ell = 0 \end{cases}$$

$$\underset{\substack{r,n\to\infty \\ r/n\equiv\alpha}}{\simeq} \begin{cases} \displaystyle\sum_{k=1}^{\ell} \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} \left(\frac{-\alpha}{\alpha+\beta}\right)^{k} \binom{-\beta}{k} \sum_{\substack{m_1,\ldots,m_k \\ \sum_1^k m_i \le \ell \\ 0 \le m_i \le d}} \prod_{i=1}^{k} f_{pd}(m_i) & \ell > 0 \\[2ex] \left(\frac{\beta}{\alpha+\beta}\right)^{\beta} & \ell = 0 \end{cases} ,$$

$$
W(n,r,\beta,p,d;\ell) = \begin{cases} \displaystyle\sum_{\substack{k_1,\ldots,k_n \\ \sum_1^n k_i = r \\ 0 \le k_i \le \ell}} \frac{\binom{-\beta}{k_1}\binom{-\beta}{k_2}\cdots\binom{-\beta}{k_n}}{\binom{-n\beta}{r}} \prod_{j=1}^{n} \sum_{\substack{m_1,\ldots,m_{k_j} \\ \sum_1^{k} m_i \le \ell \\ 0 \le m_i \le d}} \prod_{i=1}^{k_j} f_{pd}(m_i) & r \le \ell n \\ 0 & r > \ell n . \end{cases}
$$

To see that U and W can differ significantly for some values of their arguments, note that if $r = n$ and $\beta = 1$ then both $U(n,r,\beta,p,\infty;0)$ and $U(n,r,\beta,p,d;0)$ approach 0.5 as r and n approach infinity, while $W(n,r,\beta,p,\infty;0) = W(n,r,\beta,p,d;0) = 0$ for all positive r.

It should also be noted that these formulas largely just enumerate the various possible outcomes and the associated probabilities of these outcomes. Therefore, it is possible that computer programs developed directly from these formulas could be very time consuming, especially for large n, r, d, and ℓ. Of course, additional research (perhaps based on the methods presented in Volume IV of the NNOR) might provide more computationally efficient formulas.

As a reminder, the definition of the expression for binomial coefficients is as follows:

$$\binom{x}{r} \equiv \begin{cases} \dfrac{x(x-1)\dots(x-r+1)}{r!} & r \text{ a positive integer} \\ 1 & r = 0 \\ 0 & r \text{ a negative integer} \\ \text{undefined} & r \text{ not an integer,} \end{cases}$$

here $r! \equiv 1\cdot 2\dots(r-1)\cdot r$ when r is a positive integer.

Two relevant formulas concerning binomial coefficients are:

If x and r are integers and $0 \le r \le x$, then

$$\binom{x}{r} = \frac{x!}{r!(x-r)!} \tag{1}$$

where $0! \equiv 1$.

If x is any positive number and r is a nonnegative integer, then

$$\binom{-x}{r} = (-1)^r\binom{x+r-1}{r} = \frac{(-1)^r x(x+1)\dots(x+r-1)}{r!} \tag{2}$$

and so, in particular,

$$\binom{-1}{r} = (-1)^r$$

REFERENCES

[1] *Sustainability Study Final Report* (U) (in 5 vols), Office of the Secretary of Defense, Vol. 1: June 1979; Vols. 2 through 5; March 1979. SECRET.

[2] *U.S. Navy (Including Marine Air) Non-Nuclear Ordnance Requirements (NNOR) POM 80 Update* (U) (in 4 vols), Volume I: *Surface-to-Surface Warfare* (U) CONFIDENTIAL; Volume II: *Air-to-Surface Warfare* (U) CONFIDENTIAL; Volume III: *Threat-Oriented Ordnance* (U) CONFIDENTIAL; and Volume IV: *Methodology for Estimating Combat Requirements for Threat-Oriented Ordnance* (U) UNCLASSIFIED, OPNAVNOTE C8000, Office of the Chief of Naval Operations, December 28, 1978.

[3] Miller, G., ed., *The VECTOR-2 Theater-Level Combat Model* (in 2 vols), Volume I: *Users' Manual;* and Volume II: *Program Maintenance Manual,* VRI WSEG-4,5 FR77-1(R), Vector Research, Inc., 1977. See also Miller, G., *et al., VECTOR-2 System for Simulation of Theater-Level Combat, Parts I and II.* VRI CCTC-1 FR77-1, Vector Research, Inc., 1978.

[4] Karr, Alan F., *Review and Critique of the Vector-2 Combat Model,* IDA Paper P-1315, Institute for Defense Analyses, Arlington, VA., December 1977.

[5] Anderson, L.B., J. Bracken, J.G. Healy, M.J. Hutzler, E.P. Kerlin, *IDA Ground-Air Model I (IDAGAM I)* (in 5 vols), Volume 1: *Comprehensive Description;* Volume 2: *Definitions of Variables;* Volume 3: *Detailed Description of Selected Portions;* Volume 4: *Documentation;* and Volume 5: *Testing* (U) SECRET; IDA Report R-199, Institute for Defense Analyses, Arlington, VA., October 1974.

[6] Anderson, L.B., D. Bennett, M.J. Hutzler, *Modifications to IDAGAM I,* IDA Paper P-1034, Institute for Defense Analyses, Arlington, VA., October 1974.

(Cont'd)

[7] Anderson, L.B., *Attrition Papers Referenced in IDAGAM I*, IDA Note N-846, Institute for Defense Analyses, Arlington, VA., April 1979.
See also Anderson, L.B., *Two Improvements to IDAGAM I*, IDA Note N-848, Institute for Defense Analyses, Arlington, VA., April 1979.

[8] Karr, Alan F., *On the IDAGAM I Combat Model*, IDA Paper P-1265, Institute for Defense Analyses, Arlington, VA., June 1977.

[9] Karr, Alan F., *On the CONAF Evaluation Model*, IDA Paper P-1210, Institute for Defense Analyses, Arlington, VA., August 1976.
See also Karr, Alan F., *On the Lulejian-I Combat Model*, IDA Paper P-1182, Institute for Defense Analyses, Arlington, VA., August 1976.

[10] *Methodology for Use in Measuring the Effectiveness of General Purpose Forces, (An Algorithm for Approximating the Game Theoretic Value of N-Staged Games) SABER GRAND (ALPHA)*, United States Air Force, Assistant Chief of Staff, Studies and Analysis, March 1971.

[11] *TAC WARRIOR Users Manual*, Control Analysis Corporation, Palo Alto, CA., June 1978.
TAC WARRIOR Analysts Manual, Control Analysis Corporation, Palo Alto, CA., June 1978.
TAC WARRIOR Programmers Manual, Control Analysis Corporation, Palo Alto, CA., June 1978.

[12] *Air Defense Requirements Study* (U), Appendix N: *Some Effects of Different Assignments of NATO Multipurpose Aircraft* (U), IDA Report R-229, Institute for Defense Analyses, Arlington, VA., June 1977, SECRET.

[13] Anderson, L.B., *Decision Modeling in Large Scale Conflict Simulations*, IDA Paper P-1355, Institute for Defense Analyses, Arlington, VA., October 1978.

[14] *Nonnuclear Consummables Annual Analyses* (U), Department of the Air Force, Headquarters United States Air Force, August 31, 1978, SECRET.

[15] Anderson, L.B., P.A. Frazier, M.J. Hutzler, F.J. Smoot, *Documentation of the IDA Tactical Air Model (IDATAM) Computer Program*, IDA Paper P-1409, Institute for Defense Analyses, Arlington, VA., February 1979.

(Cont'd)

[16] Lansdowne, Z.F., G.B. Dantzig, R.P. Harvey, R.D. McKnight, *Development of an Algorithm to Solve Multi-Stage Games*, Control Analysis Corporation, Palo Alto, CA., May 1973.
See also *Approximate Solutions of Multi-Stage Network Games*, Control Analysis Corporation, Palo Alto, CA., August 1972.

[17] Anderson, L.B., J. Bracken, E.L. Schwartz, *Revised OPTSA Model* (in 3 vols), Volume 1: *Methodology;* Volume 2: *Computer Program Documentation;* Volume 3: *The OPTSA Print-Run Program*, IDA Paper P-1111, Institute for Defense Analyses, Arlington, VA., October 1974.
See also Bracken, Jerome, *Two Optimal Sortie Allocation Models* (in 2 vols), Volume I: *Methodology and Sample Results;* and Volume II: *Computer Program Documentation*, IDA Paper P-992, Institute for Defense Analyses, Arlington, VA., December 1973.

[18] Fish, J.R., *ATACM: ACDA Tactical Air Campaign Model*, ACDA/PAB-249, Ketron, Inc., Arlington, VA., October 1975.
See also Galiano, R.J., and F.A. Miercort, *Results of a Survey of Tactical Air Campaign Models*, Ketron, Inc., Arlington, VA., November 1974.

[19] Anderson, L.B., J. Bracken, J.E. Falk, J.H. Grotte, E.L. Schwartz, *On MaxMin and MinMax Strategies in Multi-Stage Games and ATACM*, IDA Paper P-1197, Institute for Defense Analyses, Arlington, VA., August 1976.

[20] Goheen, Lola C., *On the Solution of a Three-Stage Game Representing an Aggregated Air and Ground War*, Naval Warfare Research Center Technical Note NWRC-TN-71, Stanford Research Institute, Menlo Park, CA., March 1977.
See also Goheen, Lola C., *Selection of a Method to Solve the N-Stage Game in BALFRAM*, Naval Warfare Research Center Technical Note NWRC-TN-59, Stanford Research Institute, Menlo Park, CA., August 1975.

[21] Lorentzen, R., *AMEGAME: A Tool for Analysing the Contribution to Battle of Air-Delivered Munitions*, Study Note STC SN 1979/OR/8, SHAPE Technical Centre, The Hague, January 1980.

(Cont'd)

[22] Deitchman, Seymour J., "Designing the Fleet and Its Air Arm," *Astronautics and Aeronautics*, Vol. 16, No. 11, November 1978.

[23] Bugenhagen, T.G., L.B. Carpenter, W.L. Deemer, W. Grodowitz, *A Model for Estimating Naval Surface-to-Air Missile Procurement Requirements and a Comparison With Other Models*, Technical Memorandum TG 1297A, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD., September 1976. Bugenhagen, T.G., L.B. Carpenter, W.L. Deemer, W. Grodowitz, *Addendum to a Model for Estimating Naval Surface-to-Air Missile Procurement Requirements and a Comparison With Other Models* (U), Technical Memorandum TG 1297B, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD., September 1976, CONFIDENTIAL.

APPENDIX B

INFORMAL COMMENTS

by

John R. Bode

Note: This appendix presents informal comments by John R. Bode. The comments were dated 16 October 1979.

CONTENTS

INFORMAL COMMENTS BY JOHN R. BODE

Here is a rough first draft of my impressions from our first meeting. The memo is organized in the following order: First, a quick statement of my understanding of what the focus of the panel is. Second, a discussion of the general technical problems relating to improved sustainability estimates. Third, an opinion on practical limitations of implementation. Fourth, what can be done and how the panel could help. Fifth, some abbreviated comments on the specific models and approaches used in the study; and sixth, some comments on the limitations of the Sustainability Study.

A. UNDERSTANDING OUR FOCUS

As I understand it, the focus of the panel is on the processes by which expected munitions, material and human resources expenditures are estimated; and hence requirements generated and justified. This is contrasted to a critique of the recently completed Sustainability Study. Apparently then, our purpose is to contribute to the objective implied by the slide provided to us; "OSD should develop a framework and long-range plan for improvement of Service methodologies". My interpretation of this is that our efforts should be toward enjoining and constraining the Services to produce results which are credible in content, transparent in assumption, and which illuminate the major drivers, so that the Service inputs are helpful to OSD in their management efforts. (We must focus on the Services because I don't believe OSD has or is likely to get either the staff resources or data needed to exercise these consumption-estimating methodologies.)

B. SOME GENERAL TECHNICAL PROBLEMS AND BARRIERS

The long term objective of the framework and methodologies was stated by Doctor Pirie. This is to relate consumption to the military situation and to the outcome of the military situation and to show how the outcome varies as consumption constraints vary. This is a goal toward which meaningful progress can be made, but I think we should all realize that it cannot be totally achieved in the near future. Instead, we have to think of making progress while bearing in mind that there are fundamental limits to our understanding of some of the basic processes involved, and even in our ability to model (and in particular, execute) some of the processes that we do understand. Therefore, it is necessary to implement this imperfect process within specifications which are constrained on the one hand by properties that we know we should include and on the other hand by the computations that we are able to implement. These two constraint families are not always compatible.

While the members of the panel and Mr. Culosi and Dr. Kneece are all too familiar with this general problem, I think that it would be useful for the record of the panel to state some of the major limitations that are likely to persist for the immediate future. Here, for example, is a strawman on one major barrier, discussed at three hierarchical levels.

The primary barrier could be called the "Elusive Absolute". The simplest manifestation of this is absolute versus relative analysis. One place this shows up in the Sustainability Study area is in the desire to trade readiness and sustainability. This is essentially a trade of fixed and variable costs. In principle this trade cannot be made rigorously unless the required level of readiness can be established, and to do this requires an absolute judgment (calculation) on the outcome of the conflict over some time period. Sustainability is moot unless the readiness is adequate and hence, without an absolute judgment these two quantities are incommensurable. This problem of the "Elusive Absolute" is rife in air-ground operations, where there is a need for air/land force trades, but no capability to make the trades on a solid basis. This has been an exceptionally difficult problem to deal with. A real solution may be several years away because the amount of detail required to provide credible absolute estimates far exceeds the computational capacity of any known facility and could very well be beyond the comprehension of any individual analyst. Thus, I don't propose that we solve this problem in our unified methodologies, but I do propose that we face it explicitly.

In a hierarchical sense, several problems contribute to the "Elusive Absolute" barrier. One of these I will call "nonlinearity". One nonlinearity raised in the panel meeting is the relationship of supply and demand. This process is nonlinear and unstable. As supply falls short of demand, demand increases, causing the supply to fall further short, thus further exacerbating demand. Another nonlinearity, and a particularly troublesome one, is the effective exchange ratio in the M-on-N combat case. The results of small unit combat depend as much on the relative number of individuals involved as they do on the properties of the weapon system. However, number of individuals involved is controlled by resource allocation decisions which are made on the basis of expected and measured outcome. These resource allocation decisions require intelligence and real time feed back through observation and communications. It is believed by many that these command control and communication loop nonlinearities have a greater effect on the battle outcome than the weapon effectiveness parameters. These processes and attendant decisions have been most difficult to handle. The most successful treatments to date have been with man-in-the loop models. In any case until the problem of dynamic nonlinearities can be treated, it's not reasonable to expect credible absolute results.

At the next lower hierarchical level is the difficulty of calculating high-leverage factors such as attrition probabilities. Here at the individual tactical level there is so much uncertainty in the process that the Air Force, for example, has never been able to calculate believable exchange ratios. In fact, in the panel review they justified their estimates on the basis of history, and they suggested that the calculations should be credible because they agree with history. I don't believe the Air Force claims that the models capture sufficient details to enable them to calculate absolute results.

C. PRACTICAL LIMITATIONS OF IMPLEMENTATION

It comes to mind that it would be ideal if OSD were to design an overall integrated framework within which the Services would develop their respective methodologies. These Service methodologies would be consistent, transparent and would readily communicate among themselves.

This approach is probably not implementable. The Services have invested a great deal of time, and developed extensive data sets for their methodologies. I do not believe it is feasible for OSD to direct the Services to abandon their present methodologies in general. However, some modifications and extensions should be achievable.

D. WHAT CAN BE DONE AND HOW THE PANEL CAN HELP

If it's unrealistic to begin from scratch to design and implement a coherent top down structured OSD sustainability methodology, what can OSD do, and how can the panel help? OSD is in the position of trying to make a highly imperfect system somewhat less imperfect. Is this worth doing? I think it is.

I recommend that OSD--or a designated agent--attempt to produce a systematic description of a "composite" methodology which is based primarily on present Service methodologies. By "composite" I mean that the logical relationship among the models (intra and inter service) are defined and data flows are mapped. This overview, with input/output/data source descriptions for each model, could then be used as a tool for selecting those models that should be analyzed for consistency relationships (in data, format and assumptions). Through such an analytical process, it should be possible to specify certain high interest modifications designed in certain models. Also, format changes, assumption illumination, and rationale and data needs should be identified.

If it's not possible to specify a reasonably economical set of modifications and enumerations of assumptions, then the systematic description developed in the above process should serve to prove that the collection of Service methodologies has no logical use at OSD composite level.

Obviously, the systematic composition-decomposition of Service methodologies is beyond the scope of the panel. However, it should be done by a small group--2 to 4 persons. I recommend IDA for this. The panel would probably be useful to oversee the process, although I would expand the panel to include one Service member each. The expanded panel could help resolve the major issues of sufficiency and implementability that would arise in determining which modifications to direct the Services to make.

E. GENERAL COMMENTS ON MODELS AND APPROACHES

This section is brief and illustrative of major factors that the "improved" methodologies must handle better. I think most of the problems with these models and methodologies are well known. Overall treatment of the diversity of the NATO nations is inadequate for OSD purposes. NATO weapons system effectiveness, NATO doctrine and tactics, and NATO command and control are not treated at a level consistent with the impact of these factors on the outcome of the conflict and on the U.S. consumption rates.

Furthermore, the dynamic mobility expected in a European conflict is not captured by the models used in sustainability estimates. Hence, there is no treatment of the important cases of failure of NATO forces, which would likely result in Warsaw Pact attempts to penetrate and envelop U.S. forces. These factors alone make the results of the study exceptionally speculative, and for all practical purposes probably no better than simple hand calculations.

None of the models account for NATO casualties. Furthermore, I don't believe any of the Services specifically include NATO casualties in their planning factors. Consequently, to the extent that casualty rates effect the combat operations of the forces, and the ability of both sides to effectively evacuate casualties and integrate replacements, the results of the models are suspect.

As widely recognized, the tactical air models are not integrated with the ground combat models. In addition, there is little attempt made to examine the sensitivities of air calculations (air-to-air and air-to-ground) to variations of the Soviet air threat and targeting.

F. COMMENTS ON STUDY

One major comment is that we have to understand that the study has been threat-centered. By this I mean the level of the threat is such that the models are able to show the conflict lasting for a time period on the order of months. I'm not suggesting that this threat is high or low. I'm saying that the results are largely predictable on the basis of the initial threat size and temporal development; and in that sense the overall results can be thought of as biased. Since the outcome is a strong function of the threat, fairly wide threat variations should be considered in the study. Otherwise the results should be stated in terms such as: "If we can last at least "Y" days then we will probably consume "X" amount of resources."

Another concern with the study relates to implied training requirements and the ability of the forces to sustain such a huge turnover in man power. What have we done to provide capabilities for the Army to accommodate and train a force roughly the size of our standing Army? If we don't have this capability, are the study results valid?

As I said in the meeting, the fact that we did not treat a potential nuclear conflict seems inconsistent with Soviet writings and DOD policies. I don't think this invalidates the usefulness of the study, because I think it is useful to estimate the munitions, material and replacements needed if we were to fight conventionally for 90 days. However, it is one more reason why the study shouldn't be used to argue that if we had these supplies, we could likely enforce a war of at least 90 days.

APPENDIX C

INFORMAL COMMENTS

by

Seth Bonder

Note: This appendix presents informal comments by Seth Bonder on planning for sustainability. The comments were dated 25 October 1979, and revised 15 January 1980.

CONTENTS

INFORMAL COMMENTS BY SETH BONDER

As requested during the panel working session, I am writing to communicate my thoughts regarding the study, using principally my notes from the three-day meeting as basic facts. To the extent I heard incorrectly, my observations may be in error. I hasten to add that my comments in this letter are intended to highlight potential deficiencies and not the activities which were performed well and require little or no remedial actions.

The letter is organized into two main parts: the first discusses some apparent problem areas. Following this is a sketchy description of an alternative approach for a sustainability study process.

A. SOME APPARENT PROBLEM AREAS

The following is a list of problem areas extracted from my notes. They generally relate to overall methodology, the models employed, and to a lesser extent the study proper, although it may be difficult to categorize a particular problem area. They are not given in any order of priority or importance. Time constraints precluded my reviewing detailed model structures, but the briefings suggested that many of them have technical problems. Finally, I have not taken the time to cull out the problems noted by OSD(MRA&L) and the panel, so much of the list will probably be redundant with those already identified. (The total list influenced my thoughts on an alternative approach.)

- The definition of sustainability for level of effort items as the percent demand supportable over time is somewhat vacuous in that it does not directly indicate what you buy for increased sustainability in terms of war fighting capability.

- Treating demand as independent of supply is obviously erroneous and probably results in significant misunderstanding of actual demand requirements, especially in the early intense part of the campaign. It is obvious that engagement decisions and the results of engagements are strongly affected by the availability of munitions.

- There exist a large number of inconsistencies in methodology and models employed (especially level of effort items) throughout which give rise to inconsistent study results. These inconsistencies include:

  (1) The manner in which munitions, equipment and personnel demands are determined within a service (e.g., use of CEM, WARF, theater rates, and FASTALS in the Army; CEM and WARF produce different combat intensities; use of apparently different attrition rates in analyzing ordnance and personnel requirements by the Air Force). The procedures used prohibit examination of trade-off among munitions, equipment, and personnel for balanced sustainability.

  (2) Different methods and results across services (e.g., Army's CEM versus Air Force's TAC Weapons, Survivor, Selector, and Heavy Attack; large disparity between amounts of threat armor kills attributed to the Air Force and Army; failure of the Air Force to consider Army air defense assets). The methods used do not consider the synergism between CAS and land antiarmor systems which likely would result in reduced munitions requirements.

  (3) The different means of analyzing level of effort and mission items. The distinction between threat limited (mission) items and delivery platform limited (level of effort) items is artificial and probably not necessary. The mission item analyses appear to require that the total threat be destroyed which is an over estimate of actual requirements if a time-dependent analysis were conducted.

- The use of programming procedures to determine minimum cost munitions mixes within a service seems inappropriate for planning since it leads to smaller numbers of expensive ordnance. During actual operations it is highly unlikely that these optimal allocations will be realized.

- The personnel requirements analyses for all the services, especially the Navy and Air Force, are very subjective and not a sound analytic basis.

- The requirement to replace 100 percent of Army and Marine Corps materiel losses is obviously an upper bound. The effect of lesser replacements should be examined.
- The CEM model has a large number of well known deficiencies, all of which cannot be noted here. (A forthcoming GAO report highlights many of them.) Most important deficiencies include the firepower score attrition equations which are highly questionable, the subjective nature of the inverse transformations required to determine which friendly systems caused the attrition (required to ascertain the ammunition requirements), explicit consideration of unit deployments only at the FEBA, and use of a host of "adjustment" factors.
- CEM (TRM) assessments of ammunition expended, casualties, armor kills, etc., for a division engagement are input from a high resolution model for a stylized 24-hour day and *for a particular initial status of the division.* These results are extrapolated for other initial statuses throughout the campaign in some unstated fashion which clearly can have a major impact on ammunition requirements.
- The WARF methodology can result in killing more combat assets than exist in a unit.
- The Navy methodology for determining mission (threat) munitions over specifies requirements since *each* ship carries sufficient initial supplies to defeat a large share of the threat rather than consider the possibility of resupply. The level of effort munitions requirements is very sensitive to the Delphi procedures used and the many adjustment factors in the attrition model.
- The study focusses heavily on force capability impacts (sustainable campaign days) and cost impacts to arrive at sustainability options without adequate considerations to the many risks and contingent events that could significantly alter the impacts. Much more consideration should be given to the risks, flexibility to adapt the sustainability plans if contingent events occur (e.g., significant budget variations), and flexibility of the resultant force capabilities when a plan is realized. Sustainability studies should consider the use of multiple scenarios (rather than the one improbable scenario used in the study), alternative five-year budgets, no strategic and tactical mobility improvements, etc.

Considering the broad spectrum of methodology deficiencies, model problems, inconsistencies, adjustment factors, inadequate treatment of risk, etc., noted above and elsewhere, I do not believe the study results should be used to make *long term* commitments to the Services for sustainability resources. It is not unreasonable to expect that improvements in the sustainability study process would likely result in significant changes in sustainability requirements.

B. AN ALTERNATIVE METHODOLOGY

This section of the letter presents a sketchy description of an alternative approach for a sustainability study process which might alleviate (more likely reduce) *some* of the noted problem areas. It is intended as one possible means of providing OSD(MRA&L) with tools to generate guidance to the Services and a means of reviewing the results of Service analyses. As with any quickly conceived structure of a study process, it will require significant enrichment, modification, and detailed expansion when developed and implemented to insure both feasibility and utility of the approach.

Exhibit 1 is an overview schematic of the methodology components and information flows. Conceptually, the approach is structured as a three step process:

(1) Determination of *operational demands* that relate to campaign success measures.

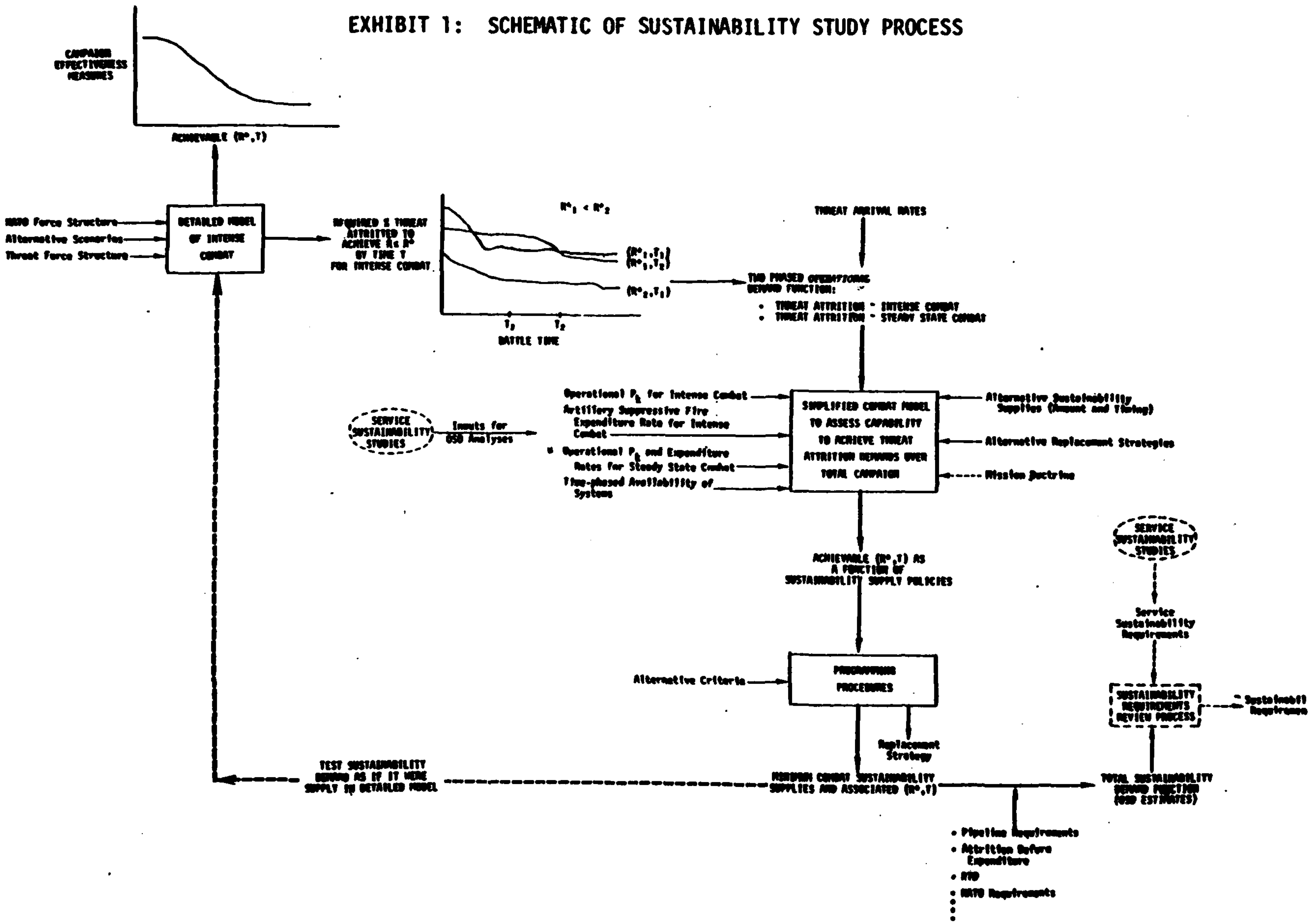
(2) Determination of *feasible combat sustainability demands* necessary to achieve the operational demands (and thus campaign effectiveness measures).

(3) Determination of minimum combat sustainability demands to accomplish specified criteria. These are added to other necessary supplies (e.g., pipeline) to arrive at *total sustainability demands*.

Ignoring for the moment who performs the activities, a brief description of the components and information is given below:

- A detailed dynamic model of theater-level campaigns such as IDAGAM-2, VECTOR-2, CEM-IV, is used to determine the percentage of the threat, by system type,

EXHIBIT 1: SCHEMATIC OF SUSTAINABILITY STUDY PROCESS



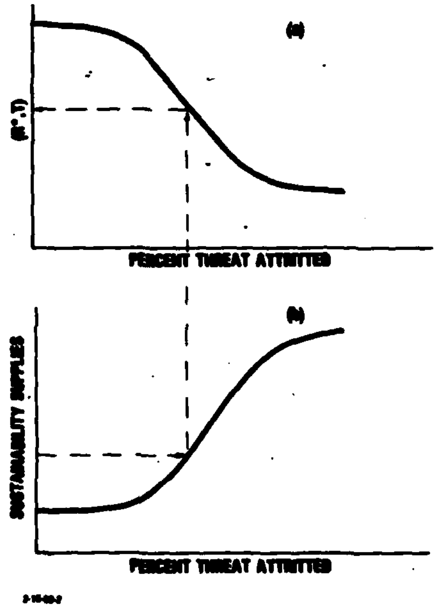
that must be attritted over time during the *intense* or transient part (initial 10-20 days) of a long campaign in order to reduce the force ratio, R, (e.g., threat armor strength/NATO armor strength) below a desired level, R*, by time T in the campaign. Example curves of required percent threat attrition as a function of (R*,T) are shown on the schematic. Obviously, the curves depend on the amount and replacement rates of sustainability supplies. However, it is intended that these curves be generated using the detailed model in a *requirements* mode assuming a large inventory of supplies which are provided at feasible rates. The curves are generated for (1) different values of (R*,T) and (2) alternative scenarios, and perhaps different US system replacement *amounts* (at feasible replacement rates) since they are a component of R. It is important to recognize that these operational demand curves (required percent threat attrition) need be developed by the detail combat model only once for use in a continuing sustainability study process. These operational demand functions become input to more simplified procedures to determine combat sustainability demands.

- Another output of the detailed model of intense combat are results which can be used to relate (R*,T) to other campaign effectiveness measures such as average FEBA location, maximum penetration, etc.

- Given that the force ratio has been reduced to $R \leq R^*$ during the intense or transient part of the campaign, it is conjectured that the percent threat attritted during the steady state part of the campaign must be proportional to the threat arrival rate (the proportionality factor depending on the US replacement rate) in order to maintain $R \leq R^*$. Prudency would suggest it be equal to the threat arrival rate. Therefore, an estimate of the operational demand (required percent threat attrition) over the total campaign to achieve and maintain $R \leq R^*$ is obtained by adding the transient and steady state demands.

- The family of operational demand functions (required percent attrition over time) to obtain different force ratio results are used as input to a simplified, fast running combat model. This model is used to assess the capability of accomplishing the operational demands considering different sustainability supply policies (amounts and timing of supplies, equipment replacement strategies) and other operational data. (Depending on the model structure, mission doctrine may also be required as input.) The other operational inputs (operational P_k and expenditure rates when

- munitions are available, time-phased availability of systems) would be obtained from the results of the service sustainability studies.
- Output of the simplified combat model are functions that relate achievable (R*,T) to feasible sustainability supply policies. The conceptual process of obtaining these results is depicted in the following paragraphs:



Given available forces and capabilities, the simplified model is used to determine the percent threat that can be attritted (actually the profile over time) as a function of the sustainability supplies (graph b). The relationship between percent threat attritted (profiles) and (R*,T) for the overall campaign is available from the detailed model runs (for the intense battle) and the conjecture on required attrition of threat arrivals during the steady state part of the campaign.

- The achievable (R*,T) as a function of sustainability supply policies is then used in a programming procedure to determine minimum combat sustainability supplies and their allocation to the Services for different criteria and associated (R*,T). Many criteria exist that can be considered including:

(1) minimize deviation from a time-phased budget profile subject to force ratio, risk, etc., constraints;

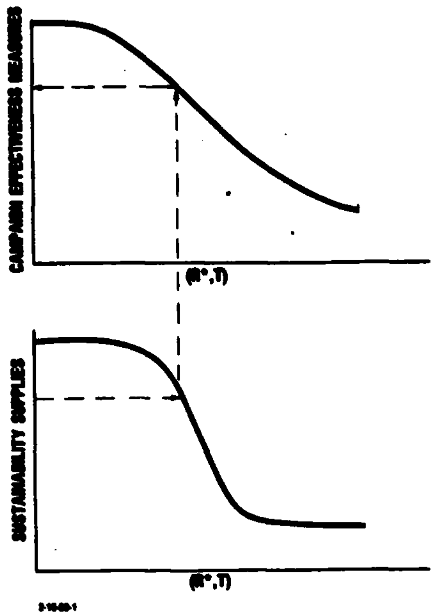
(2) minimize (R*,T), subject to cost, risk, etc. constraints; and

(3) maximize flexibility of force capability (R*,T) across different scenarios subject to cost, risk, etc. constraints.

The multiple criteria can be accommodated using various goal programming of multi-attribute objective procedures.

- The total sustainability demand function is obtained by adding (or subtracting) various other supply requirements (or sources) determined outside the approach outlined here. These include pipeline requirements, attrition of supplies before expenditure[1] (i.e., attrition of systems with their remaining munitions, supply depots, supply transports), NATO requirements,[1] and medical returns to duty (RTD).
- The total sustainability demand function developed by OSD can then be used in the process of reviewing the Service-developed sustainability requirements and provide a basis of dialogue with the Services to arrive at DoD recommended sustainability requirements.
- Initially (and perhaps periodically) the total sustainability demand should be used in the detailed combat model as supplies to test the reliability of the simplified model and procedures to estimate the percent attrition achieved and the related (R*,T).
- Given the information generated by this approach, it is also possible to relate the total sustainability demand to overall campaign effectiveness measures as indicated conceptually below:

[1]These might be determinable directly within the approach.



Depending on the degree of analysis resources available at (to) OSD(MRA&L), there exist many ways of implementing this structure to create a sustainability planning process. Since I am not aware of the analysis capability at OSD(MRA&L), let me briefly describe an implementation that is at least logical if not practical from the OSD perspective.

As noted earlier, I believe the operational demand (required percent threat attrition) need be determined only once as part of the process. This information can be developed by another organization such as IDA (using IDAGAM-2) or CCTC (using IDAGAM-2 or VECTOR-2) in conjunction with an intelligence agency for the threat arrival rates, and OSD(MRA&L) need not become involved with the detail campaign models. OSD would work with the simplified combat model and the programming procedures.

In the initial application, the Services would perform their sustainability studies to provide OSD with (1) their sustainability requirements, and, from the same studies

(2) inputs to the simplified combat model such as operational P_k, expenditure rates, and time-phased weapon system availabilities. OSD(MRA&L) would then use the simplified combat model and programming procedures, along with other information shown on the schematic, to develop their own estimates of total sustainability demands for each Service. These would be used to review the Service requests and provide a basis for dialogue between OSD and the Services. The Service operational information developed in the first year could be used by OSD(MRA&L) to develop initial guidance for the Service studies in the next cycle.

Clearly, some method developments will be required to implement this approach. Depending on the specific implementation, I would estimate that the developments would require approximately four man years of (IDA caliber) effort over a 9-12 month period.

I think this approach has the potential of alleviating (more likely reducing) a number of the problem areas identified by OSD(MRA&L) and the panel. Some of the potential benefits are noted below:

- Provides a structure for a top-down sustainability planning process in which OSD(MRA&L) can provide guidance to the Services and review the Service requests for resources.
- Provides a means of relating resources expended for sustainability to operational impacts--the (R^*,T) and perhaps measures of campaign effectiveness.
- Provides a means of considering the effect of sustainability supply on demand.
- Can examine impact of policies other than 100 percent replacement.
- Can examine the trade-off between munitions and equipment replacement (and perhaps personnel) and different allocations among the Services to develop an efficient and effective sustainability program.

- Can examine the impact of different criteria (cost, force capability, risk, etc.) as a basis for decisions on sustainability resources.
- Can examine the impact of different assumptions regarding the length of war.
- Provides a means of considering level of effort and mission items together in a consistent fashion. (I believe the approach can include most items listed in Appendix B of the Sustainability Report.)
- Continued annual use of the process and feedback to the Services may provide a degree of consistency among the Services. At least it will provide a motivation for identifying why OSD and Service estimates of needs differ (assumptions, data, methods, etc.) and perhaps a means of logically resolving the differences.

APPENDIX D

INFORMAL COMMENTS

by

Hugh M. Cole

Note: This appendix presents informal comments by Hugh M. Cole. The comments were dated 12 October 1979.

CONTENTS

INFORMAL COMMENTS BY HUGH M. COLE

A. PREFACE

The following brief comments are based on my readings in The Sustainability Study [hereafter the Study] and the briefings and Panel discussions of 25-27 September. In the main, my comments were outlined in writing prior to the final Panel session and so do not necessarily reflect the elements of consensus obtained in that session. You will note that I have, in the terms of the Tasking laid on by the Assistant Secretary of Defense (MRA&L), given more attention to the stated problem of developing a plan "for improvements in methodology supporting planning and programming for sustainability of combat forces" than to the search after improvements in "analytical techniques for prediction of wartime consumption." Note, also, that my comments are accompanied by parenthetical examples or explication designed to assist the reader in following the reasoning in the separate comments.

B. THE STUDY PROBLEM

The definition of "sustainability", contained in the Study and elaborated in the OASD comments and briefings, is unclear and imprecise. [I set aside the perverted use of the term itself, as in "90 days of sustainability" but strongly urge that a grammarian be consulted.] As a result the Panel found itself debating as to whether we were considering a "procurement study" or a "capability study"; and whether we were debarred from considering the problem of "readiness" or might treat the same as a factor in the ability to sustain successful operations in war-time. [I recommend that in future studies the problem be stated simply, i.e., to determine the major actions required to support and maintain the armed forces of the United States in successfully carrying out their assigned mission either in the face of an enemy or in combat with the same. Such a statement would coincide with the mission prescribed by the President when, under our system, he assigns national military goals and establishes a theater of operations. More importantly, such a simplified statement would avoid an artificial separation of (a) "combat readiness" and (b) "the ability to sustain combat operations". A statement of this nature also would recognize that "procurement" and "military capabilities" cannot--or at least should not--be treated singly and in isolation.]

C. SCOPE AND CONTENT

The limits of scope and of content accepted in the <u>Study</u> have a critical bearing on both (a) the improvements sought in planning and programming to ensure that national forces will be sustained and supported in combat, and (b) the design of analytical tools and techniques.

In the <u>Study</u>, the conscious deletion of entire areas of major importance in the conduct of warfare has resulted in a set of conclusions which neglect the interactions between the armed Services, modes of military operation, and the major aspects of success in large scale combat. The absence of these interactions results in single factors which are dangerous and inappropriate when used in <u>planning</u> for the support of large scale multi-Service operations in some future war. Admittedly, the problems addressed by the <u>Study</u> become simplistic, mechanistic and more manageable if their solution is based on the application of only those methods and analytical techniques which are presently available and more or less generally understood. Nonetheless, one must have reservations about the validity of the Study assumption that the deletion of critical areas of combat and combat support for reasons of cost, or lack of cost, will "not bias the policy decisions" derived from the Study. Examples follow:

1. Transportation

Perhaps the acceptance of the schematic Supply/Demand Data Curves paraded in the Study (curves called "nonsense" by the Panel) led to the extreme emphasis on consumption factors and the general disregard of supply or the ability to carry out this essential military function. Since the supply of ammunition, etc., is a function of transportation, both inter-theater and intra-theater, the disregard of transport means and capabilities forces the decision-maker to accept a dangerous assumption which has been disproved in all modern wars; that is, that every lot of artillery ammunition and every missile which has been procured for a specific enemy threat will arrive at the battery site, on the launching platform or in the ammunition racks of the using weapons, and will not only arrive at the weapon site or on the launching vehicle but will do so at the precise time for the most effective use against the enemy. The tactics implications should be obvious. The failure to provide transport to resupply the main battle tank which has fired its ammo load means that the tank as a weapon must be withdrawn from combat or abandoned to enemy action. Furthermore, the implicit assumption that because artillery ammunition or tactical missiles have been pre-stocked somewhere in the putative theater of operations they then will be available to the using weapons crews, has no basis in modern military history. [Example. In October 1944 (in the European Theater) and in the Korean War (during McLain's command of the U.N. forces) the supply of artillery ammunition fell far below tactical requirements, so the U.S. Congress initiated investigations of the production base in the CONUS and the procurement decision earlier made at high levels. In both cases it was determined that adequate stocks of artillery ammo were in the theater of operations but that these still were on ships awaiting off-loading, this because of the lack of trucks and off-loading or dock-clearing facilities. Note that in both these cases the intervention of enemy air was not a factor.]

2. Two Critical "Secondary Items"

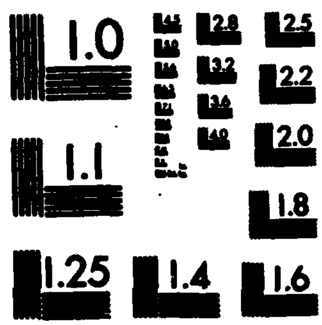
The deletion of "secondary items" because of their relatively low cost [i.e., they are not "big ticket" budget items] dismisses two items as of secondary importance which, in the historic record, are of primary importance in the conduct of mobile operations on a continental land mass, in the temperate zone, against a numerically superior enemy equipped with weapons and materiel representing "the state of the art" in military technology. These two items--both referenced in the Study and summarily dismissed--are Spare Parts and POL.

a. Spare Parts

The importance of spare parts (repair parts) probably is greater in the Army than in the other Services, this because of the extremely large number and variety of end items of equipment fielded in combat by the Army. Nonetheless, the procurement and distribution of spare parts in the Air Force, for example, becomes of critical military significance when the major end item--the first line combat plane--is not backed up in the theater supply line by an equivalent replacement weapon (a condition accepted as basic to the Study). The situation in the ground forces is aggravated by the short interval (either in using hours or distance travelled) between failures when army equipment is introduced to combat and peace-time maintenance perforce is abandoned. It must be added that the spare

AD-A091 882 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA PROGRAM --ETC F/G 15/3 3/3
REPORT OF COMBAT CONSUMPTION MODELING IMPROVEMENT PANEL.(U)
JUL 80 J BRACKEN, J R BODE, S BONDER MDA903-79-C-0320
UNCLASSIFIED IDA-P-1455 IDA/HQ-79-21815 NL

END
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

parts problem has in our past three wars, reached back as far as the CONUS industrial base because of the need to reopen industrial lines for the production of military spare parts as an emergency measure when time was too short for renewed production of the major end item (i.e., main battle tanks, heavy trucks, ground radar, etc.). In sum, the analyses contributing to the Study which provide figures on the requirements for main battle tanks will prove in error if the individual tank is pitted sequentially against more than one enemy weapon and if (a) adequate tanks are not available as replacements on a one-to-one basis, or (b) repair parts are not available as required and where required. Logically, if the procurement and distribution of tank repair parts is put to one side, then the procurement requirement for U.S. tanks probably should be increased by a factor of something like fifty percent. [I suggest this figure because it was used by the U.S. Army in WWII--until it was found that tanks could not be replaced in periods of severe combat but had to be repaired instead.]

b. POL

This class of items is deleted by name from the Study as "secondary". What has been said above about transport applies, obviously, to the supply of gasoline in modern combat--particularly on the European Continent. The leading authorities on the world gasoline market seem to have agreed that a crisis of production and distribution will appear in the mid-80's, i.e., the end of the procurement period in the Study. It would seem reasonable and, indeed, necessary to conduct analyses which would consider the procurement and combat value of each plane, tank, APC, etc., in terms of the POL required and available to support the separate weapon in combat, or at least until the predicted mission (number of sorties, number of enemy tank kills, etc.) has been accomplished. [Numerous studies in-country in the 1950's-1960's showed rather dramatically that even in those pre-OPEC days the gasoline stored in NATO countries could not support large scale mobile operations. Some idea of the size of the procurement problem--if the U.S. must provide POL from outside Europe--is shown by the fact that one-quarter of all tonnage moved by the U.S. forces to the European Continent in 1944-1945 was POL.]

3. Medical Support

The Study (and numerous Panel briefings) indicates that although deleted from the Study attention is being given elsewhere to the problem of calculating personnel loss rates and medical support factors. Apparently the Services and DOD agree that techniques are available which can determine--with a high level of confidence--an optimum evacuation policy which will provide the greatest number of "returns to duty" and so diminish the required reserve of trained replacement manpower. But again, the analytical techniques which produce these personnel replacement factors under optimal theater evacuation policies are liable to extremes of error unless they introduce and measure the availability--or nonavailability--of transport vehicles and POL set against the selected theater evacuation policy.

D. QUESTION OF CRITICAL ASSUMPTIONS

Implicit or explicit, there are a few major assumptions in the Study and in the analyses supporting the same which brutally bias both the output of the models and the conclusions of the Study. These are listed below.

(1) The war in Europe, sketched in the Study and supporting analyses, assumes no transition to an atomic exchange. Therefore, there is no requirement of procurement and preparations to place the NATO forces in a posture permitting tactical and strategic transition to the nuclear battlefield. [Note that our recent Presidents and National Security Councils have continuously addressed this requirement.]

(2) The Study, and most of the supporting analyses briefed to the Panel, assumes that the techniques used and the factors derived are so precise and of such high confidence levels that the U.S. armed forces can be equipped with the precisely measured numbers of weapons and munitions which will bring NATO to those "end of the war conditions" desired, this without either shortages or surpluses of major equipments and munitions. [This assumption might well be compared with one made by the top U.S. military and civilian decision-makers early in World War II: That the winner in modern warfare always is the power with a surplus of equipment and ammunition at the end of the war.]

(3) The Study and more particularly the supporting analyses assume that requirements can be rationally generated without more than passing reference to some specific and clearly designated mission. [I note that requirements are tied to specific missions and well-defined tasks only when a single item of NATO equipment faces an assumed Soviet target and attempts to "kill" that target.] This entire Study effort once again raises the question as to whether the freedom in analysis gained by divorcement from a given scenario is worth the resultant loss of battlefield realism.

(4) A number of briefers--and their models--stressed attention to real time and distance factors. But in general, such references were to weapon exchanges, target appearances and kill probabilities--plus calculated times in hospital. In matters of supply and equipment, however, it is assumed that all resupply and re-equipment is instantaneous. This condition it must be said, does not obtain even in regard to unit loads and reserve equipment within a combat division area--particularly under conditions of close combat. Time in the pipeline is one of the major "bugger-factors" of modern warfare and should not be assumed away; nor should the "overages" of ammunition and major equipment required to maintain flow through the pipeline be deleted from the procurement, consumption and supply factors employed by DOD decision-makers. [If the Study had veered toward supply rather than consumption, the evaluation of time and amounts in the "pipe-line" might well have changed the Study conclusions as to the Production Base.]

E. SPECIFIC ITEMS OF METHODOLOGY AND TECHNIQUES

[I assume that the attention of the Panel in its final meeting will be directed to specific items and models as was the case in the meeting of 27 September. Therefore, I suggest a series of questions which the Panel might consider.]

(1) Are the current techniques for the establishment of "the historical data base" and the analytical applications of the same being subjected to critical scrutiny at least as severe as that given to the using models and formulae themselves?

(2) Does the current emphasis on "Cost-per-Kill" bias the Study toward a devaluation of the combat worth of ground artillery ammunition when employed in the anti-personnel role? In neutralization? In immobilizing enemy equipment (tanks and APC's)?

(3) Does the emphasis on formulae which direct a single missile or salvo against a single designated target result in untenable sub-optimization? Do these formulae comprehend and accept the tactical and organizational concept of "the combined arms" (this being paramount in the doctrine and practice of both the U.S. and Soviet ground forces)?

(4) Is there general agreement that dynamic modeling of highly mobile combat is presently beyond the state of the art (particularly in reproducing the "break-in" and the "breakthrough")?

(5) Is there general agreement that there is no form of net-work analysis (or equivalent technique) which will permit useful analysis of supply line and transport movement, or the interdiction of the same?

(6) The Study and supporting analyses seem to accept a steady-state of combat intensity from H-hour to "end of the war conditions." [Some exception is made in the case of personnel casualty rates.] Should not greatly varying conditions of combat intensity be routinely introduced--and these for measurable periods of time?

(7) Have the Study and supporting analyses critically scrutinized the "manufacturer's" or "designer's" claims for predicted capabilities of new and untried munitions and equipment which are "big ticket" items? Should a percentage degradation of such "predicted" capabilities be routinely introduced? Should such degradation be "directed"?

APPENDIX E

INFORMAL COMMENTS

by

Milton G. Weiner

Note: This appendix presents informal comments by Milton G. Weiner. The comments were received approximately 15 October 1979.

CONTENTS

INFORMAL COMMENTS BY MILTON G. WEINER

The Combat Consumption Modeling Improvement Panel was convened with the objective of recommending "mid-term and long-term improvements to analytic techniques for prediction of war-time consumption." The initial meeting of the panel was held at the Institute for Defense Analyses (IDA), 25-27 September, under the chairmanship of Jerome Bracken. The panel received briefings on the Department of Defense "Sustainability Study" from representatives of the Office of the Secretary of Defense, the Departments of the Air Force, Army, and Navy. Based on these presentations and the subsequent discussions, the members of the panel requested a number of relevant publications and agreed to submit some initial views prior to another meeting. The views expressed below represent my initial reactions and do not incorporate material from the follow-up publications.

A. COMBAT CONSUMPTION MODELING AND SUSTAINABILITY

The charter of the panel focuses on combat consumption modeling, but has to be viewed in the context of sustainability, for which I will accept the working definition, "maintaining effective military capability against a range of feasible enemy options." Under this definition, sustainability is considerably more than:

(1) the availability of selected weapons, munitions, and personnel, and

(2) the examination of consumption under a narrow set of enemy options.

In reference to the first point, sustainability involves a complex of factors that contribute to "military capability." The various volumes of the Sustainability Study reflect the recognition that such factors as CONUS distribution capability, inter- and intra-theater transport capability, port and air terminal thoroughoutput capacity, POL availability, command-control-communications capabilities, maintenance capabilities, as well as the vulnerability of forces, installations, communications, the capacity to regenerate forces, and a host of other aspects, are important in assessing "sustainability." While it is appropriate to focus on the "big money" items of major equipments, munitions, and personnel as the initial focus of the study effort, any consideration of overall capability to maintain military effectiveness should provide a context in which the sensitivity of the conclusions to many of the other factors can be examined. Thus, the initial issue for consumption modeling is whether this type of study is a one-shot effort or whether it is to be a recurring effort. In the latter, it is important that "long-term" improvements in modeling be viewed in a broader context. And this context will require the development of an architecture for analysis, a research strategy, and an identification of the factors that are to be incorporated in the analysis.

In reference to the second point, i.e., a range of feasible enemy options, it is generally accepted that the attacker has the initiative in choosing the time, place, and means of his attack, as well as many options in the way in which he prosecutes his offensive (or defensive) operations. On this basis, the amount of warning time, the degree of preparedness, the size of the initial attack force, the initial attack disposition of forces, the types of weapons (conventional, chemical, nuclear, airborne, sabotage, etc.), the allocation of assets to different types of targets, as well as changes in his axes of advance, commitment of additional echelons exploitation of breakthrough opportunities, and a host of other items are considerations in the full array of initial and intra-conflict options available to the enemy. This implies that an examination of only a limited set of enemy options is justified where there is some means of establishing the dominance (or priority) of that limited set over others in terms of their consequences of sustainability, or its surrogate, combat consumption. In the absences of analytic investigation of a broader range of enemy options, it seems useful to at least develop a structured rationale for comparing the limited set to the broader set. Again, this view presumes that sustainability will be a recurring issue, and that a planning effort to define a broader range of enemy options is therefore justified for a long-term analytic strategy.

B. SUSTAINABILITY, CONSUMPTION, AND REQUIREMENTS

The preceding topic raises the question of whether a focus on three aspects of sustainability, i.e., major equipment, munitions, and personnel consumption, provides an adequate basis for assessing sustainability even against a narrow set of enemy options. A second question is the relationship between "requirements" computations and demand. The various models and methods presented to the panel indicate very different approaches in this area. Excluding for all the Services the differences between "level of effort" and "threat/mission oriented" items, the U.S. Army approach emphasized the generation of requirements as an output of a dynamic combat simulation. By contrast, the U.S. Air Force emphasized generation of requirements as an output of a semi-dynamic, or at least a non-static, calculation procedure, in the sense that the U.S. Air Force effort recognized phases of conflict and changes within these phases in the allocation of effort. The conceptual limitation of the Army approach lies in the adequacy with which combat can be modeled for a spectrum of threats. The conceptual limitation of the Air Force approach is in the magnitude and priorities associated with the target structure. But (peacetime) requirements are not (wartime) consumptions; they are estimates that incorporate many different factors.

In fact, given the nature of the approaches used by the two Services, it is probably easier to be comfortable with the Air Force approach because it provides an explicit formulation in which the degree of "safe-siding" could be analyzed by making different assumptions about the target structure and priorities. By contrast, the Army formulation involves such a host of factors that there is no clearly evident means of identifying the extent, if any, of safe-siding, particularly since policy, tactical, and other considerations can probably swing the results considerably. This does not imply praise of the Air Force methodology, since there are several issues regarding the use of allocation priorities, pay-off criteria, attrition estimates, etc., that we have already noted, nor criticism of the Army approach since the ground combat situation inherently has such a large number of attributes in dynamic interaction. It does, however, imply that the computations, at least for level-of-effort items, should distinguish between those that are based on sustainability considerations (a broad and dynamic or quasi-dynamic context); those that are based on consumption considerations (an actual scenario or scenario set); and those that are based on requirements considerations (an assumed target set against which specific capabilities are employed).

C. UNCERTAINTY, RISK AND CONFIDENCE LEVEL

The one virtually unchallengeable characteristic of efforts to assess sustainability, the demands of combat, or the requirements of an "adequate" military capability, is the uncertainty that surrounds so many aspects of these efforts. From the highest level of how a conflict may be initiated and prosecuted to the level of the performance of specific systems and munitions, there are open questions about the rigor or reliability of the data. Given this uncertainty, the assessment of risks of choosing one course of action, such as a particular "buy" of systems, munitions, or personnel, is recognized as one involving some (often unquantifiable) risks. One of the overriding impressions from the presentations and discussions was that specific questions and issues were raised, often in isolation from one type, with inadequate recognition of the uncertainties involved. Previously, I have found it convenient to categorize "data" in three ways, which for simplicity purposes, I abbreviate here:

- Type I data is essentially nominal or technical data with which the uncertainties are limited. For example, the Table of Organization of a unit, the maximum range of a weapon, the PRF of a radar, etc.
- Type II data is essentially probabilistic data reflecting the interaction of a number of factors not all of which can be controlled (or understood) in a specific situation. For example, weather conditions, target acquisition, weapon effects, etc.
- Type III data is essentially data that is based on assumptions about activities or events. For example, where the enemy will attack, when a unit will "break," how tactics will change, etc.

My purpose in describing this crude categorization is to note that all three types of data were used in all of the models. Ignoring the issue of the adequacy of the Type I data, the single data point assumptions about the Type III data in the models is troublesome, as indicated in Point 1 above. I find the arguments about the cost of multiple runs of the models, particularly the Army CEM model, to explore a wider range of conditions only partially satisfying. I suspect that the model results are largely "driven" by a relatively few factors and that a series excursions could identify those factors and lead to a simpler and more analytically satisfying model. Similarly, in the case of Air Force computations, I suspect that a series of cases in which some parameters are "zeroed-out" would yield essentially the same results as the full procedure. Given that this premise holds, and only a detailed look at the model would indicate whether it is a valid premise, I suggest that concentrating on the smaller number of factors would result in a more comprehensive understanding of how large the uncertainties are and what the range of risks for certain decisions is.

For the Type II data, a different condition holds. For these data some aspects that should be considered as interdependent (and probabilistic) are not, some data that are treated as probabilistic are not subjected to a sampling (Monte Carlo or other) technique, and some data are used without clear understanding of the shape of the distribution from which it is (presumably) drawn. Here again, specific examples would depend on a more detailed examination of the individual models. The main point is *not* that these conditions exist. They do for all models of combat. The point is that it would be both clearer and more illuminating if the major factors, inputs, etc., of the models were explicitly identified in terms of their recognized uncertainties so that the results could be treated in terms of risks and confidence, even if the overall results--for decision making purposes--were unchanged.

D. MODEL LIMITATIONS AND IMPROVEMENTS

The preceding points have stressed "approach" to the assessment of sustainability and modeling. As such, it would be inappropriate for me to assume that such issues as a broader representation of enemy options, recognition of the interaction between sustainability, consumption, and requirements, and the recognition of the types of data and their implications for uncertainty and risk assessment, were not fully considered by the participants in the sustainability study. Similarly, it would be inappropriate to list the shortcomings or limitations of the models or computational procedures. The study report, if nothing else, cannot be faulted for its specific recognition of these limitations and of caveats in the use of the outputs. At this point, I find it neither challenging nor instructive to relist these, based on reading the study or on the panel session. Nor do I find it useful to search for other items to add to the list or to discuss/describe the merits of one analytic formulation over another. I concur with the study view that the initial phase(s) were so constrained that available tools or procedures had to be used. The more interesting questions are:

(1) whether the "sustainability" question deserves more effort?

(2) if so, whether "improvements" to existing models or procedures is the way to go?

(3) to what extent should models or procedures be consistent?

(4) what "costs" are involved?

At this point, I can only reflect my own views on these subjects, which I will abbreviate in the interests of economy.

1. Does "Sustainability" Deserve More Effort?

My reaction is that it does. However, I base this less on the view that there are significant decisions to be made, than on the view that sustainability is a topic that forces us (the defense community) into a clearer explication of modern combat. Any reasonable endeavor that requires us to look in detail at *how* we will fight, that requires us to understand the limitation of our analytic techniques, that provides us with an increased comprehension of the areas of uncertainty and of risks, etc., is useful. "Sustainability" has the immediate virtue of being an integrating concept for such endeavor(s) as opposed to many other uses of analytic techniques which use large-scale combat simulations/models for sub-issues rather than total force issues.

One area of concern in this regard would be to continue to examine "sustainability," but to tie the continuing examination to a time-scale (every year?) so that only marginal improvements could be made to current methods or procedures in order to meet an annual deadline. It is not clear to me that, if "sustainability" is to be considered a continuing effort, that either a hiatus on "results" for a few years, or a separate but parallel effort on development of an overall architecture, research strategy, and methodology would not be worthwhile.

2. Are "Improvements" to Existing Models or Procedures the Way to Go?

My reaction is that the large number of limitations in the current methods--even if one considers only those cited in the Study Report--is so substantial that trying to identify a few key items and suggesting improvements on these is of very marginal utility. Nevertheless, I am open to panel views that there are such improvements that can be made and that their utility is greater than I believe. But, in line with the previous item on the importance of "sustainability" as a vehicle for examining our military capabilities for modern combat, I am inclined toward the construction of a new model structure with several characteristics:

1. a more explicit research objective than "modeling combat,"
2. a research strategy for guiding the development/construction of the new model structure,
3. the utilization of a "modular" construction that takes advantage of some of the more recent combat modeling formulations, and
4. the use of the growing body of new techniques in the information processing area that promise enormous increases in flexibility and computing power through software.

There are at least three aspects of any new model structure that require consideration before any significant effort is devoted to it. One is whether the ability to overcome some of the identified limitations in the current models and computations is used for the Sustainability Study would substantially influence the output of the study, either in terms of the specific quantitative results or in terms of the resulting decision options such as those generated in the study. Since one must accept the position that even extensive efforts on a new model structure will leave many questions unanswered, there will always be reservations and criticisms of the outputs. The issue is whether a broader and more robust set of outputs will have an impact, or whether they will be subordinated to other considerations, particularly those related to overall defense policy. A second is whether a new model structure is feasible. Obviously, a different model structure can be developed, but would it be a significant improvement over the current models and computations? My view is that it would, but a non-trivial amount of conceptualization of a possible new structure would have to be done before a definite answer can be given. A third aspect is whether the major consumer, OSD, would be willing and able to provide the necessary guidelines for such a development. If OSD were not a major player in the development, it is questionable whether the effort would be justified.

3. <u>To What Extent Should Consistency Be Emphasized?</u>

A new model structure would presumably be designed in a manner that would incorporate many elements of at least Air Force and Army capabilities so that the two Services would be utilizing the same combat simulation and the results would reflect a common spectrum of conflict situations. Nevertheless, this would cover only a portion of the total picture for level-of-effort requirements because of the unique responsibilities of the two Services. So that even a new model structure would be limited to terms of many aspects of sustainability.

The question of consistency under circumstances where a new model structure is *not* developed is one of a different nature. For this situation, at least two alternative methodological approaches are evident. One is the matching of the results of the Air Force and Army to identify and then examine areas of inconsistency. These seem to center mainly on such items as allocation of effort, target structure, sources of attrition, and relative contributions of different weapon systems. Some gross matching of these might be accomplished by utilization of the results of the Army CEM model with a modified Air Force NCAA procedure, at least as one way of identifying differences in assumptions and treatment of the use of air power. A second and much more demanding alternative would be to apply the Air Force NCAA methodology to the Army situation, i.e., use the underlying structure of targets, allocation of effort, time phasing, attrition, etc., but apply it to the ground situation. This would undoubtedly involve a number of accommodations in the use of an NCAA-type method. It might require using CEM-derived data on the target structure for much finer time phases than represented in the NCAA approach. The way in which this alternative could be implemented would require some effort in adapting the NCAA-type methodology to the weapons capabilities, target structures, time-phased dynamics, and attrition outcomes of ground combat, but at least, initially, this appears to be feasible.

4. What Costs Are Involved?

The magnitude of the costs for changing the present level of analysis of sustainability are a function of the particular choice made. While I would not venture anything more than a "ball-park" guess, there seems to be three levels of change with substantially different levels of costs. The first is moderate improvement to current methods, many of which appear to be already incorporated in the individual Service effort, and for which the costs are largely incorporated in current activities. The second level is a more integrated Air Force-Army approach involving extensions, primarily of the Army methods, in the form of improvements in the CEM/TRM/WARF/WARRAMP activities. Considering the large number of improvements both in what aspects are incorporated and in what level of detail, the costs could be moderately high. Incorporating a fuller set of capabilities for integrating air and ground actions, plus incorporating many new aspects such as transport, supply, support, command-control-communications, etc., would require extensive revisions or additions over a period of years. The most elaborate changes, the development of a new model structure, new formulations of ground and air combat operations, introducing advanced software programs, etc., could easily require a multi-million dollar, multi-year program involving extensive participation of OSD, the Army, the Air Force, and (very likely) the Navy in the formulation of the research architecture, the model structure, the establishment of adequate data bases, and in the actual programs and validations of the new structure.

E. CONCLUDING REMARKS

It is clear from all of the above that my initial views on the study and the panel meeting extend well beyond the more limited issues of consumption model improvements. I trust that my comments and references are not too cryptic in this initial paper. Obviously these views may not be shared by other panel members, and I look forward to discussions of their initial views.