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MODELS, DATA, AND WAR: A CRITIQUE OF THE STUDY OF CONVENTIONAL FORCES

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Many combat models exist which simulate phases of conventional war. These models must employ data inputs to provide quantitative estimates of effectiveness useful for decisionmaking. This Report surveys the quality of both the data and the combat models. Attention is given to the concepts of firepower scores and indexes, estimates of terminal ordnance effects, and estimates of ammunition expenditure which are used in most models. It is shown that major deficiencies exist in both the quality and kinds of empirical data necessary for adequate analysis of combat operations. There is inadequate testing of most of the behavior relationships embedded in models. Combat modeling appears structured to accomodate the inadequate data base, with much of the available data being of either unknown relevance or obscure empirical foundation. The structural inadequancies of combat models and the poor data quality appear to be mutually reinforcing. Attention is given to how this situation can be improved by appropriate operational testing or field experimentation. Bibliog. (Author)

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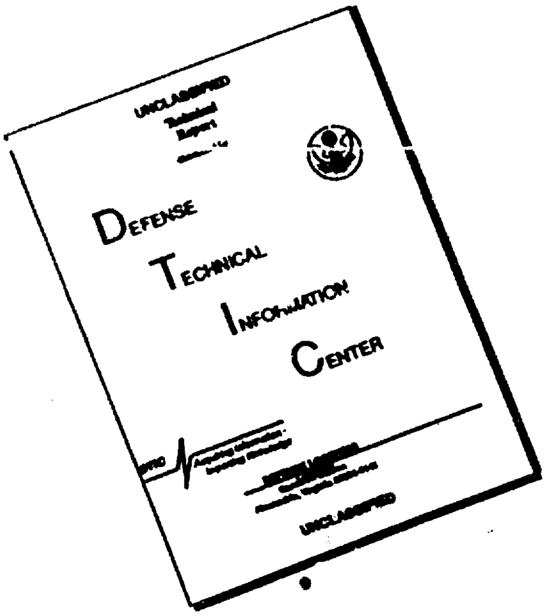

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PREFACE

This Report, prepared as part of a Rand study of improved air-ground warfare analysis methods, addresses the problems of data and models used in the management of conventional armed forces. It was motivated by concern about the quality of information provided by the methods employed during the recent past.

A prominent feature of Department of Defense study and planning is the extent to which it has supported modern quantitative methodology as an aspect of decisionmaking: operations research, cost-effectiveness analysis, gaming and simulation, and so on. Much of this activity consists of setting up mathematical models that are used to simulate phases of combat, including campaigns involving the use of diverse combat specialties such as armor, infantry, artillery, and tactical aircraft.

The use of combat models to simulate combat and campaigns requires data, which are inputs for the models. The quality or worth of the findings of any model is a function of both the model's structure and the quality, or relevance, of its data inputs. This Report critically surveys both of these components.

The major positive recommendation of the Report, aimed at armed forces decisionmakers -- specifically, those involved with weapon-system development, evaluation, and testing, as well as force planning -- is that relatively more emphasis must be placed on empirical work, and particularly on operational testing. The Report does not suggest that quantitative methodology can handle all problems of choice that are encountered in military affairs. It merely argues that the application of quantitative methodology can be of great help and, further, that it likely has not achieved its fullest potential.

The shortcomings of the data and models encountered in DoD-sponsored study and analysis result from institutional, political, and bureaucratic pressures. But the fault does not lie exclusively with the suppliers of that study and analysis, for it is the *demanders* -- that is, the decisionmakers -- who, in large part, create the institutional pressures and incentives. Their role will be the subject of a future Report.

SUMMARY

This Report surveys the effort to analyze and study conventional military forces by mathematical-statistical methods. A combat *model* is one necessary part of this activity. Empirical data, or statistics, are the other necessary part. This Report treats both subjects.

For general-purpose forces and conventional war, combat models fall into two categories: (1) those that treat specific combat actions, e.g., a small unit infantry firefight or tank engagement, in detail; and (2) those that analyze large confrontations of force aggregations in a campaign. We label these *detailed* and *aggregative* models, respectively.

Detailed models that simulate two-sided engagements usually employ hit probability functions, P(H)s, of weapons against target systems. By means of conditional kill probabilities, P(K/H)s, which describe terminal ordnance effects, kill probabilities, P(K)s, and kill ratios are estimated. Detailed models have been used to evaluate weapon-design objectives and to advocate specific weapon concepts.

Aggregative models have thus far mainly relied on firepower scores and indexes to measure force ratios. Manipulation of a model (usually by a computer simulation) generates numerical estimates of *effectiveness*, such as Red and Blue casualties and derived exchange rates, movement from a defense line, etc. In some instances, the firepower index has been taken as a measure of relative force strengths and even advanced as a measure of relative effectiveness.

This Report dissects both the conceptual and empirical underpinnings of the firepower-index concept to provide a case study of what is actually an admixture of a scientific methodology problem and what might be considered an organization problem. As for the substantive worth of the firepower-index concept, our conclusions are twofold:

First, the conceptual foundations of firepower indexes (due to what may be described as the weighting problem, by which relative importance is attached to different military specialties such as

infantry, armor, artillery, and aircraft) are unsound or questionable. To resolve the weighting problem requires much more knowledge about war than we currently have. To acquire this kind of knowledge at a minimum necessitates much more empirical work. To the extent that firepower indexes masked these shortcomings and concealed large elements of subjectiveness and uncertainty, their widespread use was unfortunate. Their use, therefore, detracted from the potential contribution that analytical techniques and the application of scientific inquiry could make to military force planning and weapon system evaluation.

Second, although the empirical foundation of the firepower index is logically derivable from the work done in the separate fields of ballistics research and operational testing, including operational research that explicitly tries to employ data and information generated from actual military operations, our conclusions are again twofold. First, the ballistics data employed as inputs to firepower indexes contain major uncertainties. Second, hard operational-testing data are virtually nonexistent. Given these deficiencies, the empirical foundation for existing firepower indexes (or anything that might be substituted for them) is shaky.

But, even if the relevant empirical data were greatly improved, the firepower index concept, because of the weighting problem, appears nevertheless to remain a questionable intellectual undertaking.

Increased unease about the firepower index has been evident over the last few years. Consequently, effort is under way to develop campaign models that are extensions of detailed combat models. However, the outputs or assertions of these models are of questionable worth because of inadequate empirical work, which should consist of both operational testing (i.e., controlled and instrumented field experimentation, as contrasted with engineering testing carried out by technical establishments) and empirical study of past wars. Moreover, operational testing is a way of both testing or validating detailed models themselves and gaining better insight on how these models may be structured. Without increased and definitive operational testing and empirical studies, the use of detailed models to treat larger force aggregations is probably of limited value in the analysis of conventional wars. Overall, we are left with faulty concepts, such as the firepower indexes, as empirical inputs for aggregative models, and an abundance of unverified -- or only partially verified -- detailed models.

This condition results from an imbalance between empirical and theoretical endeavor in DoD analysis and study. The image of scientific activity -- an image that depicts theories and models as being independently tested by experiment or appeal to experience, with the empirical work in turn casting up new insight that contributes to theoretical advance -- does not seem to prevail in the military establishment. One aspect of this situation is that the unverified findings of modeling conducted by one organization can be taken as fact by another organization and used as inputs for the latter's model. Another aspect is that a number or a set of numbers constituting *data* can be admixtures of subtle concepts, subjective evaluations, and limited but hard evidence based on actual physical testing. The particular testing, however, may have been undertaken for purposes remote from the use that another study makes of the data. The *lethal area* concept, as well as estimates of a tank P(K/H), embedded in firepower scores and indexes are an interesting illustration of this latter point, which is developed in this study. The case in point, incidentally, is not intended to criticize the work done in the laboratories Rather, it seeks to emphasize that research conducted by specialized subgroups in large, hierarchical organizations can have unintended consequences.

The overall conditions suggest two recommendations. The first is that any *number*, when confronted by an analyst, decisionmaker, or any other interested party, should be probed by at least the following questions: Is it the output of a model, or the result of some physical measurement? If it is the output of a model, to what extent is it an untested and therefore contestable hypothesis? That is, has the model been validated by some independent test? If not the latter, then what is the structure of the model -- i.e., what is the theory? If a model has been tested, or if a set of numbers are the result of physical testing or some other empirical source, then what was the experimental matrix and what are possible instrumentation errors, or what were the reporting methods employed? How was the data filtered and aggregated as it moved upwards (and often sideways) in the bureaucratic hierarchy? If the subjective assessments of individuals are used for certain kinds of data generation, who were these individuals and what has been their experience and institutional affiliation?

If these and similar questions were systematically asked and vigorously pursued, a second recommendation, in our view, would suggest itself: The need for better and more empirical work, including operational testing, is of such a magnitude that a major reallocating of talent from model building to fundamental empirical work is called for. This paper develops some of the benefits that an expanded experimental and empirical effort could have, and examines some of the objections to operational testirg.

It is argued that a major benefit of greater emphasis on empirical work is that insights can be gained about military production processes, or production functions relevant to the fighting end of the business. Presently, assertions about military production functions are generated a priori, by means of combat models, with technical engineering data (much of which is derived a priori from engineering equations) constituting the data inputs for the models. These images of production functions have, in turn, been advanced and employed as the underpinnings of military cost-effectiveness analyses, despite the fact that few of the assertions they embody have been empirically verified.

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I cannot truthfully say or imply that none of these persons shares responsibility for any of the views expressed in this Report. I can only assert that any errors are mine.

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I. INTRODUCTION

Much effort has been expended to analyze the subject of conventional war by techniques of quantitative methodology, including mathematical statistical methods. A combat or campaign model is often the result of this effort. A large number of models has been produced during recent years, and new ones are forthcoming.*

The end result of a model is some indication of comparative outcomes, as inputs vary, about a military operation, expressed in quantitative or numerical terms. These statements are produced by manipulating the model, usually by means of a computer simulation. The model must also take in certain numerical data or inputs. The structure of the model -- as specified by either its equations or computational routines -- transforms the selected numerical inputs into the numerical assertions that are the model's outputs.

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*For a partial indicator of the magnitude, see for example, *Combat Developments: Catalog of Computerized Models*, United States Army Combat Development Command, USACDC Pamphlet 71-11, 1 July 1969; *Air Defense Model Index*, Department of the Army, Frankford Arsenal, May 1970; and Martin Shubik and Garry D. Brewer, *Models, Simulations, and Games -- A Survey*, The Rand Corporation, R-1060-ARPA/RC, May 1972.

Shubik and Brewer identified about "450 active military models, simulations, and games ... in catalogs and inventories" (p. 11), and undertook a questionnaire survey of 150 of them, most of which were of the type we would label *combat* models. (Some of the 450 may have been logistics or cost models.) However, the 450 that they catalogued were only a portion of the total formal modeling effort. For example, much modeling is undertaken by weapons developers and suppliers. Also, considerable effort is expended modifying or refining selected existing models to address specific problems.

The catalogs cited above and the Shubik-Brewer survey predate the emergence of a number of newer models designed to address the problems associated with large aggregations of general-purpose forces. It is not inaccurate to state that there is an *old* and a forthcoming *new* generation of models, and that we may currently be in a state of transition. Aspects of this transition is one of the subjects of this study.

The assertions, or outputs, of combat models have been advanced to assist analysis and decisionmaking that bear upon a wide range of resource-allocation issues that arise in the management of armed forces. Among these issues are:

- How do we assess a possible opponent's military capability, and how large should our military forces be to meet the perceived threat?
- How should the total force be structured between major services, such as land forces and tactical air forces?
- How should the land forces be structured with respect to (1) combat branches, such as infantry and tanks, and (2) service specialties that provide logistic and personnel support?
- What should be the technical performance and physical specifications of new weapons that will be the object of engineering development programs? Given the availability of new weapons, what should be their tactical usage, how many of them should be procured, and in what organizational and command context should they be employed?

Each of these and related questions entails many complexities for which information is uncertain. The totality of these questions poses staggering information demands, and the even more difficult problem of assimilating widely diverse kinds of knowledge and information. One view of the extensive use of combat models employing quantitative methodology is that they provide help by way of assimilating diverse information and organizing it in ways that are helpful for decision-making. Indeed, science -- based, of course, on mathematical models -- has been characterized as an information-economizing device. Thus, a formula, a set of equations, or a computer algorithm treating aspects of military operations would seem to have similar potential, and thereby be helpful. But is it? This is a major question. Any answer to it will be mixed because the subject possesses many complex phases. The purpose of this Report is to offer some critical assessment of the current state of combat modeling of general purpose forces and conventional war and the use of such models in the decisionmaking process.

II. THE MAJOR ISSUES AND PROBLEMS

The modeling activity that this study examines has grown in response to the needs of the Defense Department decisionmaking process. The design specification and selection of new weapons, the allocation of resources between air and land forces and, within land forces, between infantry and artillery, how tactical air capability might be allocated among diverse missions, the amount of logistic support that the combat elements of field forces should have, the rate at which forces might be mobilized and deployed, and finally, the issue of how large the forces should be are the major subjects that analysts have attempted to study by means of analytical models and associated computerized simulations of systems behavior.* The kinds of decisions mentioned have long appeared to be critical to effectiveness in war and, by implication, to war's deterrence.

A. ANALYSIS VERSUS JUDGMENT

It should be acknowledged that men, through their political and military institutions, have always made these kinds of resource-allocation decisions -- even before the application of modern quantitative methodology to military affairs. Today, the idea is often advanced that the use of quantitative methodology possesses advantages over the traditional approach to decisionmaking, which relies on professional judgment. The achievements of scientific endeavor in technical fields lends at least superficial support to this view. The accomplishments of World War II operations research, along with the notion that war and armed forces possess a high technical content due to the application of technological change to weapons, add weight to this idea. It is also argued that quantitative methodology has the virtue of making the assumptions of an analysis explicit and that

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*For a precise discussion of some of the key terms used here, specifically, *model* and *simulation*, see George Evans II, Graham F. Wallace, and Georgia L. Sutherland, *Simulation Using Digital Computers*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1967, pp. 3-15.

the analytical process by which conclusions are deduced is transparent. Although these interrelated arguments possess merit in certain contexts, they can mask a fundamental difficulty, if not confusion.

A practitioner of quantitative methodology, such as a physicist, or an engineer well-grounded in physics, can -- by extending his technical expertise to, say, the terminal ballistics aspects of weapon design -- offer much suggestive insight to assist military decisionmakers.* The same physicist, pondering the less technical or the unfamiliar phases of the broader subject, however, might try to extend models or concepts known to him -- e.g., the Newtonian paradigm -- to the less well understood subject matter. Similarly, an economist versed in the neoclassical economic theory of production and the associated production-function concept, with its well-behaved, negative second partial derivatives, seeks to extend this particular construction to aspects of military affairs.

Such extensions of diverse theoretical constructions (or models) to military affairs can provide insights. But the core subject -- combat and associated military operations -- can possess elements that are obscure and uncertain and therefore discomforting to the analyst. The challenge of this condition, in turn, stimulates attempts to model the actual combat operations, one striking result of which has been the proliferation of combat models. But the proliferation suggests a degree

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*Perhaps the best example of this point is provided by F. W. Lanchester, *Aircraft in Warfare: The Dawn of the Fourth Arm*, Constable and Company, London, 1916. This book brims over with what were at the time it was written fruitful leads, suggestions, insights, and testable propositions pertaining to numerous technical and tactical possibilities bearing upon the use of aircraft in war. The overall effect of the book is to illustrate how an imaginative engineer or technician can contribute to military planning and study. However, Lanchester is presently esteemed for his "combat model," and specifically his "N-square law" of combat, which is nothing more than a mathematical formulation of the age-old military principle of force concentration. That there is no clear empirical verification of this law, or that Lanchester's model or present versions of it may in fact be incapable of verification, have not detracted from this source of his luster.

of immaturity* with regard either to understanding the subject addressed, or to how the analytical techniques are to be applied. It also gives rise to the methodological question of just how inquiry should be carried out.

There also exists a body of knowledge relevant to military operations, which is possessed by the Officer Corps and is the product of both experience and intensive study. This body of knowledge is often referred to as military judgment. That expression is unfortunate whenever the context suggests that the kind of information it incorporates is either inferior or superior to knowledge that is produced by application of scientific quantitative methodology. Particularly misleading is the idea that knowledge produced by the application of quantitative methodology is objective, whereas military judgment is subjective. Assertions or beliefs along these lines may not even be meaningful hypotheses that can be tested or resolved in any satisfactory way.** This Report develops aspects of this point.

B. THE FIREPOWER INDEX AND THE AGGREGATION PROBLEM

Any study endeavor possesses both a theoretical and an empirical side, and these two elements are related and critically connected. It is the purpose of this Report to demonstrate that the analysis of conventional military affairs presently suffers from an inadequate empirical endeavor, an apparent misuse of what empirical data there are, and a large-scale production of "pseudodata." Further there appears to be a widespread practice of using "data" generated from

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*The word *immaturity* should not be interpreted to have a pejorative connotation. Rather, it describes a situation in which the subject matter is poorly understood and, more specifically, the correspondence between *theory* and the *reality* treated by the discipline is poorly developed. An example of a mature discipline is classical physics where, in many if not most applications, the distinction between theory and fact (or reality) is scarcely apparent. In such a discipline, practitioners are seldom concerned with methodology in the sense that the word is used here. Thus, it is primarily in immature disciplines that discourse on methodology frequently becomes relevant.

**For a comprehensive treatment of the issue, see Ralph E. Strauch, *A Critical Assessment of Quantitative Methodology as a Policy Analysis Tool*, The Rand Corporation, P-5282, August 1974.

models, or by a priori methods, as numerical inputs for other models, which in turn, may be either unverified or inadequately tested. In some instances, the outputs of the prior model, although adequate for the questions initially addressed, may be inappropriate for subsequent refinements, formulations, or uses of the data made at a later time and, often, by a user other than the one that conceived the model or did the related empirical work. In other instances, empirical data based on historical experience may be inadequately assessed, analyzed, and modified so as to serve properly the analytical purpose at hand. Often, the basis for modifications that are made is obscure. This set of problems may be illuminated by a detailed examination of the *firepower-index*[*] concept that has been employed in military studies.

A firepower index is but one of many measures of effectiveness indexes (MEIs) that have been advanced and extensively discussed by military analysts during recent years.[**] Some of these so-called indexes, however, are not really index numbers in the strict meaning of the term. For example, the number of rounds fired per period by a

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[*]Various terms have been used. The current one is *Index(es) of Firepower Potential* (IFP): see *Theater Battle Model (TBM 68), Vol. I - Part III - Appendixes - Theater War Game Model* (U) (TWGM), Research Analysis Corporation, RAC-R-36, January 1968 (Secret). Elsewhere, *firepower potential* is used: see Ernest Heiberg et al., *Measuring Combat Effectiveness*, Vol. III, *Weapon and Unit Firepower Potentials* (U), United States Army Combat Developments Command, CCRG-M-272, September 1968 (Secret); *Measuring Combat Effectiveness*, Vol. I, *Firepower Potential Methodology* (U), United States Army Combat Developments Command, March 1967 (Confidential). The measures in question have also been called *Index(es) of Combat Effectiveness* (ICE). These concepts have an antecedent in the concept of a *firepower score*, which, very likely, is as old as military maneuvers and map (including gaming) exercises: see, for example, *Maneuver Control*, Department of the Army, FM-105-5, February 1958, pp. 69-73, which uses the term *firepower score*.

The words *score* and *index* should not be regarded as synonymous, however. It is more precise to apply the concept of a firepower score to a specific weapon, and particularly to its munition, and the concept of an index -- which is derived by summing scores -- to some aggregation of diverse weapons. Entailed in this overall subject is a classic example of the "index number problem" as it is encountered in economics; the index number problem will be discussed later.

[**]For a good brief summary and discussion of some of these, see John R. Bode, *Indices of Effectiveness in General Purpose Force Analysis*, Braddock, Dunn, and McDonald, Inc., 1974, especially pp. 2-4.

weapon is simply a *number* in that it is capable of being determined by direct empirical methods. The advancement of such a measure as an index of effectiveness really means that the proponent believes (or the context justifies) that the entity might be a good proxy measure of effectiveness. Similarly, the time of flight of an antitank missile for a tactically relevant distance may be regarded as such a proxy. This latter number may be either measured directly or deduced from physical models. Still other indexes of effectiveness are estimates deduced by analytical methods, or from models. The number of enemy killed, this figure relative to friendly losses or the resulting exchange ratio, and territory taken are examples. Finally, there are indexes per se, which are weighted aggregations of selected numbers, or of cross products, or of other arithmetic operations applied to diverse sets of data. The firepower index is of the latter kind.

The emergence of an index number concept as part of military study arises from the fact that combat usually involves the use of mixes of diverse military specialties. For example, in a company-sized engagement, one side may have two platoons of infantry, a tank platoon, plus mortar and recoilless-rifle sections. The mixes of such diverse combat elements can vary endlessly, and much of command skill is to tailor appropriate aggregations ad hoc to carry out operational tasks. This decisionmaking entails such valuations as, for example, that under some circumstances it is better to combine a platoon of tanks with the infantry than, say, a platoon of engineers, or vice versa. Similar judgments or assessments are involved in battalion, brigade, and larger operations.

Implicit in these kinds of evaluations is the idea of military capability, power, effectiveness, or utility. *Firepower* is often used as a surrogate for these -- although that word is susceptable to misunderstanding. What is central to the subject, however, is that conventional military operations involve the combined use of diverse specialties and require the evaluation of these in the context of some perceived pattern of different combat situations, or a *scenario*. These evaluations and perceptions provide the ingredients for an index number. Conversely, an index number may be viewed as a way of handling the aggregation problem that confronts military force planners.

Variations of the aggregation problem are extensive in the analysis of general purpose forces. One phase of this analysis centers on the question of just what should be counted, given opposing force arrays that can differ in their structure, or in their contemplated doctrinal usage, or both. One way to deal with this problem is to develop index numbers, or collections of indexes. The aggregation problem has posed difficulties for model builders and users, and these difficulties have given rise to a crude dichotomy that may be characterized as *aggregate* versus *detailed* models.

Aggregate models address the subject of major confrontations between forces composed of diverse combat elements, in the context of a large area like the NATO Central Front. Here the *counters* or measures of relative force size can be such entities as divisions, division forces, air wings, or index numbers representing these. When units like divisions are used, effort must be made to take account of the possibility that one side's division may possess more or different fighting capability than the other side's division. Or, these differences may be incorporated in an index number. At the outset there is an evaluation complicated by the aggregation problem.

Detailed models treat small-unit actions like the infantry firefight, tank versus antitank, aircraft versus air defense, and so on. These models generally try to deduce something about weapon effectiveness from technical performance data like rate of fire, weapon accuracy, and so on. These models are often highly detailed in terms of the data they use. However, so that they can be manageable, they abstract from the larger context of an engagement. Although they may avoid the aggregation problem, they run into a problem caused by excessive or improper abstraction. The degree of abstraction chosen involves the judgment of the model builder, which in part may be influenced by military men whose advice and insight the model builder seeks.

Thus a hierarchy of models exists. Some are analytical; others, judgmental. The outputs of some models are often inputs for other models. Campaign models have employed aggregative measures to convey something about major interdependencies that characterize the larger system. But aggregative measures can mask important distinctions. On the one hand, there is a danger from excessive abstraction; on the other hand, there is an *aggregation* problem.

The problems posed by hierarchies of models and their interrelationships is complicated by another set of difficulties that surround the word *data*. In certain settings and fields of inquiry, it is possible to resort to logical positivism or *operationalism*. Given a well-received paradigm or body of theory, the test of a model is simple: does it square with the *facts* as determined by an independent experiment or set of observations? Although this hard-nosed approach may at first glance seem to be a healthy manifestation of critical scientific spirit, it possesses difficulties. In most affairs affecting the human condition, many if not most of the facts are themselves the result of some model, or set of abstractions. In most social affairs, the analyst must take the data as he finds them -- as determined by the questions the Census Bureau asks, or the conventions of business accounting that govern financial data, or an agency's operating and reporting rules, which in turn are determined by its prevailing beliefs and procedures. Even in the physical sciences, both the structure of experiments and the design of instrumentation have been constrained, if not governed, by the prevailing paradigms.* Thus, there is not a clean distinction between data and models, especially when there is not a well-founded body of theory. The present state of analysis and data bearing upon general purpose forces -- to be discussed in this Report -- illustrates aspects of these problems.

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*See Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2d Ed., University of Chicago Press, Chicago, Illinois, 1970, passim.

III. CONTROLLING MANEUVERS AND MILITARY GAMES: THE CONCEPTS OF FIREPOWER SCORES AND INDEXES

Maneuvers, tactical exercises, and battle drills are an intrinsic part of armed forces. Their primary purpose is to train unit commanders and staff, although they serve an equally important training function for troops and crews through exposing them to many of the physical conditions encountered in military operations.

Much of the business of conducting military operations consists of moving units, selecting terrain either to be defended or from which to initiate an assault, and timing these activities so they are coordinated with the availability of supporting arms and services, including artillery and airborne fire support, as well as engineer support. Other critical activities are the gathering of local intelligence and the establishment and use of communications links between cooperating and supporting units. All combat activity, in turn, must be keyed to logistic and personnel support, including the care of wounded, the rearward processing of captured prisoners, and so on. These activities can also be simulated in a map or command-post exercise. Refinement of such a simulation -- by the use of rules, procedures, and such artifacts as ways to provide players with the imperfect information that characterizes military intelligence -- becomes a "military game."* The activities of moving, communicating, gathering intelligence, and transporting and supplying combat units are undertaken to influence the outcome of engagements, or the contacts that involve actual shooting. It is in the confrontations of the shooting elements that something called *firepower* comes into play. How might this concept be specified and assessed for purposes of carrying out exercises, including map studies, campaign planning, and so on? (Bear in mind that land forces are composed of mixes of different weapons, and these mixes can increase

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*For a good account of the evolution of military games, see John P. Young, *History and Bibliography of War Gaming*, Operations Research Office, ORO-SP-13, April 1957.

in variety as a force becomes larger.) One answer is by means of firepower scores, index numbers for combat units, and criteria for damage assessment and attrition.

A. COMBAT PLANNING FACTORS BASED ON MILITARY EXPERIENCE AND JUDGMENT

Examples of firepower scores, unit index numbers, and damage and attrition criteria are shown in Tables 1-4, which are taken from the 1973 issue of the Army Field Manual on *Maneuver Control.** Table 1 shows firepower scores assigned to selected direct-fire and fragmenting weapons. Table 2 shows scores for selected tactical units, derived by multiplying the number of weapons of a given type in a unit by scores such as those shown in Table 1, and summing the products. These and similar scores for other tactical units, in turn, can be derived for a given confrontation that may be either postulated or the result of prior maneuver or assessed damage.

These aggregations, with adjustments as determined by rules derived from experience or otherwise specified, can be rendered into indicators of relative combat power. The 1973 Field Manual on *Maneuver Control*, for example, suggests that the combat power derived from the firepower ratio between an attacker and a defender should be converted as a function of whether the defender is in the open, in a hasty defense position, or in a fortified position, and whether the attack is from the front or a flank. Thus, if the defender has a score of 1040, composed as follows:

Rifle Company	540
105-mm Howitzer battalion firing in support	500
Total	1,040

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*The expression *maneuver control* can be interpreted to encompass more than a "field maneuver in which troops and armament of both sides are present in whole or in part ... in which more than one division normally participates ...." (p. 2-3). The manual identifies nine kinds of tactical exercises, with and without troops, and including map maneuvers or exercises that may be controlled or uncontrolled and involve a sequence of command staff actions against either opposing players or umpires who represent an opponent (pp. 2-1 to 2-4).

Table 1

ILLUSTRATIVE FIREPOWER SCORES OF U.S. WEAPONS

Direct-Fire Weapons	Range (Meters)		
	300	500	1000
Rifle, 7.62 or 5.56 mm	1	0.5	-
Machinegun, 7.62 mm	6	6	6
Grenade Launcher, 40 mm	5	-	-
Tank,[a] 105-mm gun	32	32	32
Dragon	50	50	50
TOW	60	60	60

Indirect-Fire Weapons	Range (Meters)	Score
Mortar, 81 mm	100-3650	12
Mortar, 4.2 in.	777-5486	15
Howitzer, 155 mm, self-propelled	0-18,000	50
Howitzer, 8 in.	0-18,000	100
Tank, 105-mm gun	0-22,290	20

SOURCE: *Maneuver Control*, 1973, Tables E-1 and E-2, pp. E-1 and E-2.

[a]Combined score for main gun and secondary armament.

Table 2

FIREPOWER SCORES FOR SELECTED AGGRESSOR AND U.S. UNITS

Military Units	Range (Meters)		
	300	500	1000
Opponent			
Motorized Rifle Battalion	1200	700	500
Medium Tank Battalion	1200	1200	1200
Motorized Division Artillery	3800	3800	3800
U.S.			
Mechanized Infantry Battalion	3346	2426	1792
Armored Cavalry Squadron	4327	3187	3013
Tank Battalion	2843	2419	2083
Howitzer Bn., 155 mm, self-propelled	Range: 0-18,000 meters; Score: 900		

SOURCE: *Maneuver Control*, 1973, Tables F-2, F-3, G-2, and G-3, pp. F-2, F-3, G-2, and G-3.

and the attacker has:

Two infantry companies (540 each) attacking frontally	1,080
One tank company (600), attacking from the flank (600 x 2)	1,200
One 155-mm Howitzer battalion firing in support	900
Total	3,180

and if the defender is in a hasty or fortified defense position, then the ratio of combat power is

$$\frac{3180}{1040} \text{ -- or } 3.06 \text{ to } 1.$$

If the defender is in the open, the attacker's score is doubled, and the ratio of combat power is 6.1 to 1.* If the combat ratio is 3 to 1, the attacker, if mechanized, is permitted to advance in open terrain at a rate of 1100 meters per hour; if 5 to 1, the movement rate is 3300 meters per hour.**

Unit firepower scores and hence combat power is adjusted to take account of casualties. Casualty assessment is governed by factors applied to different kinds of weapons (e.g., small arms, artillery fires, air-delivered ordnance) as a function of terrain, troop posture and density, force ratio, time under fire, and so on. Table 3 shows loss assessment criteria for tank-versus-tank engagements; Table 4, for close air support strikes against selected ground combat elements. More detailed assessments of losses can be derived: for example, personnel casualties per vehicle destroyed,*** as a function of time exposed to small arms fire,**** and as a function of varying densities of artillery fire applicable to different troop postures.*****

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*See *Maneuver Control*, 1973, pp. D-10 and D-11.

**Ibid., Table H-4, p. H-3.

***Ibid., Table D-2, p. D-8.

****Ibid., p. D-12.

*****Ibid., p. D-13 and Tables H-7 and H-8, p. H-5.

Table 3

LOSS ASSESSMENT FOR TANK-VERSUS-TANK ENGAGEMENTS

Attacker-Defender Combat Ratio	Tank Losses per 5 Tanks per Hour	
	Attacker	Defender
1 to 1	2	1
2 to 1	2	1
3 to 1	1	1
4 to 1	1	2
5 to 1	1	2

SOURCE: *Maneuver Control*, 1973, p. D-15.

Table 4

GENERAL GUIDE FOR DAMAGE ASSESSMENT OF STRIKES BY TWO AIRCRAFT

Type of Target	Ordnance	Expected Damage (% immobilized)
5 tanks in column on road	Smart bombs	95
	CBU	35
4 armored personnel carriers	Smart bombs	95
	CBU	50
5 tanks in defense	Smart bombs	80
5 tanks in attack	Smart bombs	80

SOURCE: *Maneuver Control*, 1973, pp. D-14 and D-15.

It is intended, in the context of a maneuver, that the damage or casualty assessment and allowable rates of advance as evaluated by umpires take account of various relevant conditions such as visibility, available fields of fire, skill with which aircraft make their passes, and so on. Where feasible or appropriate, as in the case of tracking time for air defense weapons, which is considered to increase accuracy, the use of random numbers for damage assessment is suggested. But overall it is expected that the damage assessment and related movement rates (as determined by the umpires) be tempered by professional judgment that takes account of circumstances prevailing in the context of the activity. Guidelines like those suggested in Tables 3 and 4 are not to be applied in an arbitrary r uncritical way.

The firepower scores discussed thus far are designed to deal with detailed activities and operations. For map exercises or war games treating larger aggregations of forces, it is necessary either t aggregate or to develop computational aids, or some of both. Aggregation employed in this fashion facilitates "quick gaming." The use of computational aids has led to the development of computer-assisted "free-play," rigidly assessed games, of which the Army-sponsored TACSPIEL is a good example.*

Table 5 shows some illustrative aggregative firepower scores that might be used for a corps-level quick-war game. Here are reflected the ideas, for example, that a mechanized division -- being relatively intensive in infantry -- possesses an advantage n a defensive mode, whereas an armored division has a relatively greater offensive power. Note also that an artillery group (assigned to a corps) is judged to make a greater contribution to a defensive, as contrasted to an offensive, effort. Among the reasons for this difference are that (1) artillery elements on the offensive must move, during which time they cannot shoot and (2) a defensive posture often permits better

*See Edward W. Girard et al., *TACSPIEL War Game Procedures and Rules of Play* (U), Research Analysis Corporation, RAC-TP-111, November 1963 (Secret); and Lawrence J. Dondero et al., *TACSPIEL War-Game Procedures and Rules of Play for Guerrilla/Counterguerrilla Operations*, Research Analysis Corporation, RAC-TP-223, August 1966.

Table 5

ILLUSTRATIVE AGGREGATED FIREPOWER SCORES FOR COMMITTED UNITS: CORPS WAR GAME

Unit	Unit Strength			
	91-100 Percent		81-90 Percent	
	Offense	Defense	Offense	Defense
Mechanized Division	25	20	20	15
Armored Division	30	15	23	11
Armored Cavalry Regt.	3	6	2	4
Artillery Group	3	4	2	3

SOURCE: *Maneuver Control*, 1973, Table D-6, p. D-29.

knowledge about one's position and the reference points, a situation that permits better shooting. It is of interest that for purposes of assessing the contribution of close air support, the *Maneuver Control* manual also suggests that a close-air-support sortie increases the supported unit's firepower score by .1 when the unit is in contact. When there is no contact, the firepower score of the attacked unit is to be reduced "to a realistic level..."*

Firepower scores like those in Tables 1, 2, and 5 raise two questions: How are they derived? And just what do they mean? The answers are interrelated. The derivation of the scores generally rests on judgment derived from experience and from ordinal ranking of weapons when the weapons' technical characteristics provide plausible support for a ranking. An example of this latter kind of ranking is the larger score given to the 4.2-in. mortar, as contrasted with the 81-mm mortar, as shown in Table 1. But why is the 81-mm mortar given a score of 12, and the 4.2-in. mortar given only 15? Might not a relatively larger score be given the latter, especially in view of its 50 percent greater maximum range, or its much greater weight per round? Such questions

***Maneuver Control*, 1973, p. D-29.

were no doubt discussed extensively by those who advanced these scores. Among the points likely considered in the deliberations were (1) that the two types of mortars are complementary, especially given the fact that the 81-mm mortar has a shorter minimum range, and (2) that it can fire a larger number of rounds, given a weight constraint on infantry operations. Although these details are important in certain contexts, the precise value attached to these two weapons may not be of importance if the opposing sides have a roughly comparable mix of the weapons in their infantry units. This point is further reinforced by taking account of the analytical context in which the particular scores are to be used. And it is this context that is central to the second question of just what any particular set of scores may mean.

A good example of how the approach to analysis can and should influence the specification of numerical inputs is provided by the TACSPIEL war game. This game was initially designed to deal with division-level engagements, to be a free-play game, and to be rigidly assessed by means of a computer, eliminating assessments by umpires (random numbers are used extensively in the target acquisition and casualty assessments). Because the game treats division-level engagements and because these involve mixes of infantry and tanks, the problem existed at the outset of how to handle either predominently tank or infantry, or mixed engagements -- e.g., a tank-heavy force against an infantry defense with or without tank support. This problem was handled by assigning *effectiveness values* to the antipersonnel and antitank capabilities of opposing infantry and tank companies. Table 6 shows these values.

The rationale for determining these relative values is involved. Some of the differences between Blue (U.S.) and Red (USSR) units is accounted for by the fact that the Blue units are larger, e.g., 15 versus 9 tanks per company. The interesting parts of the assessments, however, were based on the judgment that in tank engagements the Red medium tank was about 83 percent as effective as the Blue tank, and that both tanks were equally effective against personnel. Tank antipersonnel capability was then given a nominal value of one per tank. It was judged that the antitank capability of the tank units was about

Table 6

ANTIPERSONNEL AND ANTITANK EFFECTIVENESS VALUES ASSIGNED TO OPPOSING INFANTRY AND TANK COMPANIES FOR TACSPIEL WAR GAME

Company	Capability		
	Antipersonnel	Antitank	Mixed
Blue Infantry	24	10	34
Blue Tank (medium)	15	24	24
Red Infantry	12	5	17
Red Tank (medium)	9	12	12

SOURCE: Girard, *TACSPIEL*, Appendix B.

60 percent greater than their antipersonnel capability. Each infantry unit's antitank capability was assessed and values were established. A separate assessment of the number of rifles, automatic rifles, machineguns, grenade launchers, and mortars in the respective infantry companies (and a pro rata share of battalion heavy weapons) concluded that the Blue rifle company had twice the antipersonnel capability of the Red rifle company. The judgment that an infantry company's antipersonnel capability was worth more than twice its antitank effectiveness established a value of 12 (by simultaneously solving three linear inequalities), which put the rifle company antipersonnel effectiveness values at 24 for Blue and 12 for Red, as shown in Table 6. The scores for mixed engagements reflects the point that an infantry unit's infantry elements engage opposing infantry, and its antitank sections engage tanks, whereas an attacked tank unit concentrates on opposing tanks.

The assessment of the relative effectiveness of the two infantry companies, based on a tabulation of their respective weapon mixes, including a company's share of battalion support weapons, is shown in Table 7. It was assumed that a machinegun or an automatic rifle was worth three rifles and that a U.S. 40-mm grenade launcher was worth one-sixth of an 81/82-mm mortar. Comparisons of (1) these two units with the authorized equippage of the World War II German infantry

Table 7

NUMBER OF WEAPONS IN OPPOSING INFANTRY COMPANIES AND ASSIGNED EFFECTIVENESS VALUES, 1963

Infantry Company	Blue	Red
Antipersonnel weapons		
Rifles	54	63
Machineguns and automatic rifles	24	14[a]
Grenade launchers, 40 mm	18	--
81/82-mm mortars	3	2
Effectiveness value	[illegible]	[illegible]
Antitank Weapons		
Squad antitank weapons (RP6-3)	--	9
3.5-in. rocket launchers	3[a]	--
90-mm recoilless rifles	6	--
Antitank guided missiles or 106-mm recoilless rifles	3[a]	2[a]
82-mm or 107-mm recoilless rifles	--	2[a]
57-mm self-propelled antitank gun	--	1[a]
Effectiveness value	10	5

SOURCE: Girard, *TACSPIEL*, Appendix B.

[a]Some or all of these weapons are located in Battalion Weapons or Headquarters Company. One third of these weapons are assumed allocated to each of a battalion's three rifle companies.

company and (2) U.S. World War II casualties caused by bullets versus those caused by mortars led to the conclusion that one 81/82-mm mortar had the casualty-production capability of 40 rifles. These estimates provided the justification for the relative antipersonnel effectiveness of the two units.

These and similar estimates for other types of small units, such as combat engineer and assault gun, can be aggregated to provide the opposing force ratios for whatever sequence of engagements emerges during the free play of the game. In the course of the play, a unit's effectiveness is scaled down in accordance with assessed attrition, out-of-commission vehicles, and other factors that can reduce unit combat ability.

The unit assessments developed for the TACSPIEL war game were made by experienced officers in the infantry and combat arms, engaging in a dialogue with the analysts who developed the game's model. Estimates like those in Table 6, and especially some of the judgments that provide their rationale, can be argued about and subsequently modified. For example, was the rationale for concluding that one 81/82-mm mortar is worth 40 rifles valid? Should an automatic rifle like the U.S. M14E2, then in use, be given as much weight as a machinegun, and should a machinegun be considered equivalent to three rather than, say, four or five rifles? Such debate can go on endlessly, and in certain contexts it is important; but, for purposes of developing the artifacts for a larger analytic game, some of these finer points need not be of interest.

One thing that is important about numbers such as those of Table 7, however, is that they do reflect the judgments of people who have had command (and combat) experience. They would, therefore, seem to say something about the kinds of on-the-spot assessments that would be made by unit commanders in actual combat during the initial phases of a campaign. The validity of these initial assessments would be tested, and modified. Moreover, it is likely that actual weapons mixes would themselves be modified quickly as a result of new experience. The opponent would make comparable assessments and changes. Thus, for example, if in actual operations machineguns turned out to be worth more relative to rifles than the 1 to 3 ratio employed in the Table 6 assessments, platoon and company machinegun density could quickly be increased. Such an increase is relatively simple to achieve: Inasmuch as infantry units are seldom at full authorized personnel strength due to casualties,* the weapon mix can be varied when the shortages are allocated.

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*Because of the incidence of casualties, a case can be made that the 1963 estimate for TACSPIEL of one 81/82-mm mortar's being equal to 40 rifles is perhaps excessive, and the relative worth of machineguns to rifles of 1 to 3 may be too low. Given that German infantry companies during World War II were usually understrength and that infantry squad authorized strength was one machinegun (and a three-man crew) and seven rifles, it is likely that machinegun strength was maintained to a higher degree than was rifle strength. Hence, machinegun densities were higher than suggested by authorized strength, and the ratio of

B. NEW FIREPOWER INDEXES AND SOME REACTIONS TO THEM

The analysis of general purpose forces expanded greatly during the 1960s due to debate over budgets and capability stimulated by the greater emphasis placed on conventional forces in the NATO context.* The thrust of effort was twofold: First, there emerged new models and computer simulations that simulated campaigns involving aggregations of specialized combat elements. The Research Analysis Corporation's ATLAS model can be regarded as the prototype of this family.** Other models of this kind were WSEG/IDA's GACAM,*** and Rand's TALLY/TOTEM.**** A prominent feature of these models was their use of a new firepower index concept to aggregate either all or major portions of the diverse combat specialties and to specify force ratios.***** The improved firepower index, called the *Index of Combat Effectiveness* (ICE), can be regarded as the second part of the twofold effort.

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machineguns and rifles to mortars was in fact lower, since there would be a tendency to maintain mortar strength, especially in the predominantly defensive operations that characterized German activity after 1942.

*See Alain C. Enthoven and K. Wayne Smith, *How Much Is Enough: Shaping the Defense Program, 1961-1969*, Harper and Row Publishers, Inc., New York, 1971, pp. 117-164, which provides one account of the dialogue.

**See E. P. Kerlin and R. H. Cole, *ATLAS: A Tactical, Logistical, and Air Simulation*, Research Analysis Corporation, RAC-TP-338, April 1969.

***Jerome Bracken et al, *Methodology for General Purpose Forces Planning*, Vol. II, *Ground-Air Campaign Model* (GACAM) (U), Institute for Defense Analyses, R-175, March 1971 (Secret).

****See P. M. Dadant, *Measures of Effectiveness and the TALLY/TOTEM Methodology*, The Rand Corporation, P-5062, July 1973.

*****The differences between these models are important at a certain methodological level. The ATLAS model consists of a battle routine that operates in different sectors, where the forces specified in each sector are expressed in terms of the firepower index concept. TALLY/TOTEM, in a sense, can be viewed as a ground battle model (TOTEM) and an air battle model (TALLY). TOTEM is a refinement of the ATLAS model and employs the firepower index. TALLY simulates the air battle in a more fine-grained way, and permits aircraft sorties to be allocated to different missions, including combat air support or attacks against enemy ground forces. In the latter case, damage per sortie against ground combat elements -- e.g., combat vehicles -- is postulated as a function of the type of ordnance, and the attacked ground forces are thereby attrited, as reflected by firepower index. The changing ratio of ground forces is subjected to the TOTEM routine.

The new firepower indexes, promulgated by the Army Combat Development Command,* drew upon concepts and data produced from ballistics research conducted by Army laboratories. One concept that grew out of that research was that of the *lethal area* (LA) of a fragmenting munition. For a given munition, the lethal area times the quantity fired could provide a score for a weapon using that munition. Account could then be taken of mixes of munitions, as well as quantities expended. The quantity expended was termed the *estimated expenditure of ammunition* (EEA). Similar refinements, again drawing on terminal ballistics research undertaken mainly during the 1950s, were incorporated in the firepower index concept for armor-defeating devices, with tank conditional kill probabilities, P(K/H), being the counterpart of the lethal areas. These refinements, along with the way small arms were treated, provided an alternative basis for aggregating diverse weapons and major combat arms, as well as for treating logistics capabilities and constraints affecting ammunition supply.

The resulting sums of products, roughly speaking, constituted an index number for diverse weapons and collectively formed the Index(es) of Combat Effectiveness. The precise numbers of different weapons could be determined through separate inquiry (1) by reference to organizational tables of equipment or order of battle estimates, (2) as a function of assumed or planned mobilization and deployment rates, or (3) by assumption.

When used to specify force ratios of a combined arms battle, the ICE was an input measure. If the units aggregated by the ICE are deployed and maneuvered in a map exercise or computer model, force ratios can then be generated. The logical sequence is the scenario-like campaign analysis from which new force ratios are deduced as a function of casualty exchange. From these latter force ratios, as well as initial ones, movement rates can be deduced. Here, the heart of a campaign model is the relationships postulated between force

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*See Heiberg, *Measuring Combat Effectiveness*.

ratios and casualties, and force ratios and movement rates.* From movement rates, when related to the selected geography, it is possible to estimate territory surrendered or gained.

The use of the new firepower indexes to specify force ratios endowed the indexes with a dual quality. In some circles, they were regarded as a measure, or proxy measure, of combat power.** The acronym, *ICE*, with the *C* representing *combat* and *E effectiveness*, may have sustained this impression. Accordingly, the indexes came to be viewed as static measures of effectiveness, as contrasted with the outputs or results of computer simulations -- which take such forms as estimates of casualties, casualty exchange rates, or territory lost -- as dynamic measures of effectiveness.***

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*There is a substantial amount of literature on this subject, both theoretical and empirical. The subject of the relationship between force ratios and casualties (or attrition) is the focus of the Lanchester differential equation model, for which empirical verification is both scanty and ambiguous. Extensive efforts have been also made to estimate the relationship between movement rates and force ratios. For a survey of much of this literature and the results of recent empirical study of the World War II Northwest Europe campaign, see Leonard Wainstein, *Rates of Advance in Infantry Division Attacks in the Normandy-Northern France and Siegfried Line Campaigns*, Institute for Defense Analyses, P-990, December 1973; idem, *An Examination of the Parsons and Helse Papers on Rates of Advance*, Institute for Defense Analyses, P-991, December 1973.

**Enthoven and Smith, pp. 138-139, use the expression *combat power*, although they had made reference to the *firepower index* on page 136. They state that "the weights used were largely arbitrary, with little basis in theory or combat experience." Yet in the next sentence they note that the "firepower scores still indicated that a U.S. division had much more firepower than a Soviet division." Over the next three pages, they refer to combat power.

***This distinction between dynamic and static measures or indicators of effectiveness has been advanced in L. J. Dondero et al., *Methodology for Force Requirements Determination (MEFORD)* (U), Research Analysis Corporation, R-121, May 1971 (Secret), pp. 6-7. This study provides interesting background about the dialogue between the OSD Systems Analysis Office and Army. Its main theme is that the Systems Analysis Office focused on static indicators of effectiveness to support positions on *capabilities*, whereas the Army tended to employ models like ATLAS (and, hence, dynamic indicators) as inputs for its ASOP and JSOP deliberations to generate statements of *requirements*. It contends that this was a major reason why the two parties may have been talking past each other, and suggests that both parties should settle on a commonly accepted model as a way to reduce this problem.

This dichotomy between static and dynamic indicators of effectiveness is troublesome. To some, the adjective *static* can have a pejorative connotation, whereas *dynamic* is good. In the context of general purpose forces analysis and modeling, however, the operative content of the distinction is that most combat models explicitly incorporate or treat time.* Such variables as time-of-flight for a projectile, or time to acquire a target, the specification and bounding of conditional orders in some sequential fashion, or the employment of differential equations as illustrated by the Lanchester model are prominent examples of how time enters into combat models and computer simulations. The same models produce state histories,** or outputs, in numerical form. Because these are in numerical form, they have been labeled *measures*. But it is more accurate to view these measures or state histories as hypotheses in the scientific meaning of the word. At a minimum, they are creatures of both the model and the set of data fed into the model. The dichotomy between static and dynamic measures, therefore, might be viewed as one between something that is physically measured or counted versus the assertions or hypotheses of a model.***

However, this distinction is somewhat off the mark in the context of efforts to evaluate general purpose forces, and is illustrated by the Index of Combat Effectiveness. Different force structures, changes in these due to weapon acquisition or force structure decisions, and critical aspects of logistic support -- e.g., ammunition supply -- can be expressed in terms of this index. Standing alone, the resulting

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*It should be emphasized that a model need not necessarily explicitly treat time as a variable (as do many physical models and engineering equations).

**This term is taken from Evans, Wallace, and Sutherland, p. 6: "simulation consists of construction of a state history." Ibid.

***In this distinction, no conclusion should be drawn regarding the relative merits of the two types of measures. Although something may be measured physically, that measure may be irrelevant to the question at hand. Conversely, the assertions of a model may be either verified or unverified by tests or experience. When verified, the model may be regarded as a success, and its assertions can even come to be accepted as "fact." It should also be recognized that much prior "unsuccessful" modeling may have contributed to the development of the successful model.

numerical values have been cited as an indicator of relative effectiveness or potential. This particular measure, along with others (also static) came to figure in the Defense Department dialogue. One of the issues in this dialogue was whether dynamic measures (the results of models) or arrays of static measures (including the firepower indexes) were preferable.* For this reason interest focused on what the firepower index really meant, quite apart from the point that it served to specify input values for major modeling effort.

Reflection about the firepower index generated much criticism of the concept,** and stimulated attempts to formulate alternative index number concepts.*** One consequence of this question-raising has been to stimulate less aggregative approaches to model the subject, eventually perhaps to produce a second generation of conventional forces campaign models.****

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*See Dondero, MEFORD, pp. E4-E8.

**See, e.g., ibid., pp. 31-36.

***Prominent in this effort were the weapons effectiveness indexes (WEIs), which when weighted, were converted into scores, or weighted unit values (WUVs), assigned to combat units. Classes of weapons were specified -- e.g., tanks. Characteristics like firepower, reliability, and so on were defined. By Delphi technique, weights were assigned to define these characteristics for a given weapon -- e.g., an M60A1 tank. Given the point that different classes of weapons, e.g., an M16 rifle versus an M60A1 tank, are in a given unit, a further weighting question arises on this point. At this juncture, two approaches were employed: judgment and cost. For a further account and criticism of this and other indexes, see D. M. Lester and R. F. Robinson, *Review of Index Measures of Combat Effectiveness*, 1973 (Xeroxed).

****The principal feature of these newer models, from our viewpoint, is that they avoid aggregation by means of an index number, either by "playing" each Blue class of weapons against each Red class to fill the cells of a rather large attrition matrix, or by drawing upon the outputs of detailed simulations of combat -- e.g., that play weapon against weapon at the battalion level -- for inputs. In the latter case, there is an interrelated hierarchy of models. In both cases, admixtures of engineering, ballistics, and other detailed data are employed. Prominent examples of these two approaches are, respectively, *Vector-0* and the General Research Corporation's (formerly RAC) *Hierarchy of Models*. See S. Bonder, *Vector-0, The Battle Model Prototype:* Volume II, *A User's Guide*, Weapons Systems Evaluation Group, Report 222, December 1973, and *A Hierarchy of Combat Analysis Models*, General Research Corporation, Gaming and Simulation Department, NB 7056, January 1973.

The potential of these newer models will depend upon how they treat the effects of weapons, including their tactical application. Any combat or campaign model makes assertions about casualties or other effects of weapons and munitions. Such assertions must be based on some perception or understanding of many different facets of combat. Since these assertions take a numerical or quantitative form, they must also be based upon or deduced from quantitative statements about weapons and munitions effects, target acquisition and identification, and many other technical and tactical matters.

What is the nature of the empirical data bearing upon these subjects? What is its quality? What does much of the data really mean? Firepower scores and indexes sought to capture the seeming substance of much data. Yet these concepts are criticized for many reasons. Although less aggregated models may avoid some of the objections to the firepower index concept, can they avert all of them? Or might they eventually be criticized for reasons that have a foundation in the quality and nature of the data they use? These are rather fundamental questions that bear upon military study in its entirety. The rest of this study addresses this general problem.

IV. TERMINAL BALLISTICS CONCEPTS AND DATA

A. INTRODUCTION

The new firepower indexes advanced by the Army's Combat Developments Command in the middle sixties was the result of work that began a decade earlier. This effort in turn drew upon ballistics study carried out by Army laboratories. The key elements of this ballistics research, which were adapted to the new firepower index, are the concepts of (1) a *lethal area* for a fragmenting munition and (2) the *conditional kill probability*, P(K/H), of an antivehicle device, given a hit. These concepts are subtle, however, because they cut across the fields of ballistics, with its initial foundation in physics, on the one hand, and operational research and evaluation, on the other hand. To use data based on these concepts for an index number that was further to be employed either as a static measure of effectiveness or as an input measure for campaign models endowed them with additional operational significance. Because the new firepower indexes had part of their foundation in ballistics study, which consisted of some experimental work, an impression may have been created that they were more objective than measures or assessments such as those published in the *Maneuver Control* Field Manual, or judgmental assessments such as those developed for the TACSPIEL war game.

Awareness that the new firepower indexes may possess troublesome features suggested by the word *judgment* has increased. A result has been to stimulate development of campaign models that are more detailed in their structure. Much of this detail consists of assertions that draw upon ballistics data. Thus, the quality of these data can be even more relevant to modeling that seeks to avoid reliance on indexes derived from firepower scores. The purpose of this Section is to provide some insight into this phase of weapon analysis.

B. FRAGMENTING MUNITIONS AND THE LETHAL AREA CONCEPT

The lethal* area concept for a fragmenting munition is derived from

**Lethal* is used in this discussion to mean *damaging* or *destructive*, in which context it is understood that death is a probability.

work done in the complex field of terminal ballistics. Terminal ballistics, in turn, addresses two complex subfields and their interactions: (1) the behavior of munitions with regard to their penetration (terminal velocity) and fragmenting characteristics, including size, dispersion, velocity, and other physical characteristics of fragments and (2) the capacity of a human target to resist or absorb the energy of fragments or projectiles relative to being incapacitated. The concept of incapacitation can, in turn, be defined relative to ability to perform some mission or missions. The subject of terminal ballistics as applied to antipersonnel weapons thus critically ties into wound ballistics, which essentially is an assessment of the medical-pathological effects of munitions on human tissue and senses.

To make assertions regarding the lethal area, therefore, presupposes knowledge about interactions between two separately complex fields (the physics of fragmentation and their dispersion, and wound pathology), and how these relationships are further complicated by operational factors. Fragment and bullet behavior, in terms of energy imparted to human tissue, is further affected by other material they might have to penetrate (brush, foliage, winter clothing, and so forth). Operational factors can include possible countermeasures (such as the use of nets to catch submunitions or the redistribution of a combat infantryman's load), which troops might employ in the field. That incapacitation might be defined relative to different combat tasks (e.g., assault, defense, etc.) has been pursued by wound ballistics researchers and has led to efforts to specify criteria in terms of these different tasks.

Thus, the concept of a lethal area is complex. Indeed, the concept is itself an index number. This latter point may not be adequately realized by all weapon system analysts and operations researchers. Since we are interested in evaluating the new firepower index concept and ascertaining its empirical foundation, a general description of lethal area measure is of interest.*

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*For a detailed treatment, including a summary of the background and citations on technical work done with regard to fragment behavior, see Herbert K. Weiss, *Methods for Computing the Effectiveness of Fragmentation Weapons Against Targets on the Ground* (U), Ballistic Research

1. The Lethal Area Concept

Consider a shell exploding at a specific altitude, a given angle relative to the horizontal plane, and a given forward speed. The 0,0 axis in Fig. 1 is designated to be that detonation point. For that given altitude, angle, and forward speed, the shell, upon bursting, issues fragments that vary in size, distribution density over various segments of the ground surface, and terminal velocity upon striking the ground. These conditions are a function of the shell's physical characteristics. The most important physical characteristics are the ratio of explosive to metal, the kind of explosive, the kind of metal (e.g., cast iron for some mortar rounds, machined steel for artillery rounds), special design of the metal case to achieve fragment-size control (e.g., such as the grooved, 20-pound air-dropped "frag" bombs used in World War II), and the varying thickness of the metal at the side as compared with the nose and tail. The distribution pattern of the striking fragments resembles the shape of a butterfly due to the phenomenon of sidespray, which results

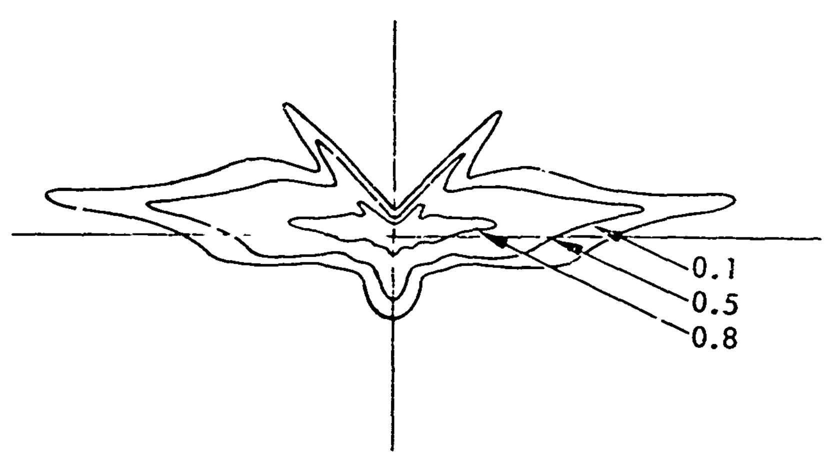

Fig. 1 -- lethal area concept and isoprobability contours indicating probability of decapacitation

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Laboratories, Report No. 800, January 1952 (Confidential), especially pp. 32-80. For a refinement of Weiss' method and a summary of the lethal area concept, see K A. Myers, *An Improved Method for Computing Lethal Areas Under the Assumption of a Sidespray*, Ballistic Research Laboratories, Memorandum Report No. 1021, July 1956.

from the fact that the shell's sides produce most of the fragments, and it is along the side that the most favorable ratio of explosive to metal exists to generate initially high-velocity fragments. (Spherical munitions do not, of course, produce a butterfly pattern.)

The probability that a target (expressed as the vulnerable area of a given target) will be hit by a lethal fragment(s) is a decreasing function of the target's distance from point 0,0. For this reason, the lethal area is not literally an area in the sense that, in a bounded real space specified by the lethal area, a man would necessarily be a casualty. Rather, the lethal area may be conceptualized as increments of real area, weighted by the probabilities that a target within the area will be a casualty. The concept is depicted by the isoprobability casualty contours shown in Fig. 1.*

The .8-probability isoquant, immediately surrounding point 0,0, can literally embrace real space -- say, 50 square meters. The .8 figure, therefore, specifies the minimum probability that any standing man within that area will be a casualty. Similarly, outside this isoquant, another area can be specified (where the fragments are less dense and will have a lower velocity) in which the minimum probability of a standing man's being a casualty is .5. This area may contain 200 square meters. Figure 1 also shows a .1-probability isoquant, outside the .5 contour, which is assumed to contain 400 square meters. (Isoquants for successively lower probabilities embracing successively larger areas, can be conceptualized.) The minimum lethal area, based on the three isoquants shown in Fig. 1, is the three real areas weighted by the respective probabilities -- that is:

$$(50 \times .8) + (200 \times .5) + (400 \times .1) = 180.^{**}$$

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*For an example that explains the formulation of this expository device, see William B. Ford, *A Method of Evaluating Effectiveness of Field Artillery* (U), Research Analysis Corporation, Technical Paper RAC-TP-48, November 1961 (Confidential), p. 14.

**If one envisages finer gradations of the isoquants shown in Fig. 1, increments of area can become very small. Calculus can then be used to define the lethal area (A_L) more rigorously as the double integral

$$A_L = \iint_R P_k (dA) da, \qquad (1)$$

The weighted probabilities and the derived lethal area are a critical function of the vulnerable exposed areas of the target(s) relative to the real area over which fragments are distributed. A given lethal area, like that illustrated in Fig. 1, might apply to a target of standing men, a target that, on the average, exposes 4 square feet per man. Other postures and degrees of exposure can be postulated (prone, sitting, kneeling, in foxholes, in a horseshoe trench, and so on).* The lethal areas for these less exposed postures will be smaller than that for a standing man. Account can also be taken of different average statures of men. For example, in some studies, it is assumed that the average Asian is smaller by a specified amount than the average American.**

Fragment density distribution, mass and velocity, then, are the real ingredients upon which the lethal area concept is based. It should be kept in mind that any given lethal area is a function of a projectile's burst height, angle of fall, and terminal velocity, as well as of the target's vulnerability, as examplified by the 4 square feet constituting the exposed or presented area of a standing man. Projectile burst height, angle, and forward speed can vary both from round to round and as a function of tactical deployment. Projectile fragmenting behavior can differ from round to round due to variation in manufacturing quality control; hence, the lethal area is a random

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where $P_k(dA)$ is the probability that a target in an increment of area dA is incapacitated, and the integral over the area R assumes the targets are uniformly distributed over the ground. Hence, the lethal area is a weighted area where the weights are derived from $P_k(dA)$. As the increments of area, such as those bounded by the probability contours depicted in Fig. 1, become smaller, they approach dA. However, there can be uncertainty regarding the concept of incapacitation (see the discussion below).

*For an example of an analysis employing a variety of postures and degrees of protection, see William B. Ford et al., *The Effectiveness of Indirect-Fire Weapons Against Machinegun Crews* (U), Operations Research Office, Technical Paper ORO-TP-26, January 1961 (Confidential).

**See Heiberg, *Measuring Combat Effectivenes*, p. 292. However, whether or not the size of vulnerable organs and parts of the body is proportionally less for smaller-statured men has been questioned.

variable. Actual fragment behavior is further affected by terrain (softness or hardness of soil with impact detonation; richochet of fragments from air bursts; rock fragments). Any given lethal area number, therefore, is an average of some, or even all, of these variables, or assumptions about these averages.

Thus far, we have discussed the lethal area concept only in terms of the spray of fragments emanating from a bursting munition. This spray can consist of a distribution of sizes, shapes, and velocities, with the velocity of a given fragment being a function of (1) the distance traveled from its burst point and (2) its mass and cross-section relationship, which determines drag. These munition spray characteristics can be measured in a straightforward manner by well-established and instrumented testing techniques. The product of such testing is actually a frequency distribution of fragment densities and their respective mass/velocity characteristics. This information, however, says nothing about lethality. Upon striking, the fragment must first penetrate and then damage the target's interior vital parts. This damage is what the word *lethality* describes and what the vast subject matter of wound ballistics is about. Although fragment behavior in terms of density of mass/velocity combinations can be measured objectively, it is not entirely so with what it is that fragments are designed to do. Yet to estimate a lethal area measure, or P(K/H), ordnance terminal effects as described by such words as *lethality* or *incapacitation* must be combined with fragment physical data in some quantitative way. However, estimates of terminal ordnance effects appear necessarily to contain elements of subjectiveness.

2. Wound Ballistics, Incapacitation Criteria, and the Concept of Lethality

Hundreds of years of warfare have confronted men with the subject matter of wound ballistics. For most of that experience, the thrust of whatever intellectual effort so stimulated appears to have been directed mainly toward the business of the military surgeon. However, understanding even in this department does not appear to have grown much until just prior to the turn of the present century, when a revolution in medical technique and technology resulted in some fundamental changes (to be available, happily, for World War I). During roughly the same transition period, the recent advent of smokeless powder was beginning to produce evidence that raised suggestive new hypotheses relevant to weapon and, especially, small-arms design.

Apart from drastically reducing pollution on the battlefield, smokeless powder effected a revolution in small-arms design because its efficiency, or power per unit of weight, and its combustion characteristics permitted attainment of much higher bullet-muzzle velocities. This possibility, in turn, provided many more options for bullet mass/velocity combinations. The availability of these options, however, primarily generated emotional controversy between opposing schools of thought on rifle and machinegun design. But whatever the pros and cons of these issues, all military students (to say nothing of troops in the field) were confronted with high-velocity bullets. Surgeons came to observe internal damage to tissue and organs that was difficult to rationalize or explain relative to the small bullet wound tracks and, especially, entry holes.*

The concept of lethality entails incapacitation. In the United States there had emerged during World War II the so-called 58 foot-pound rule, which assumed that any missile possessing a force of 58 foot-pounds of kinetic energy was sufficient to render a man a casualty,** provided the man was struck in some vital part of the body.

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*For an account of the evolution of research and thought on the concept of lethality and, in particular, wound mechanisms, see James Boyd Coates, Jr. (Ed.), *Wound Ballistics*, United States Army, Medical Department, 1962, especially pp. 91-235. For a summary of the post-World War II work sponsored by the U.S. Army, see Joseph Sperrazza, *Casualty Criteria for Wounding Soldiers* (U), Ballistic Research Laboratories, Technical Note 1486, June 1962 (Secret), and William Kokinakis and Joseph Sperrazza, *Criteria for Incapacitating Soldiers with Fragments and Flechettes* (U), Ballistic Research Laboratories, Report 1269, January 1965 (Secret).

**See Coates, p. 111.

The vital area of the human anatomy was, of course, less than the fully exposed area. For example, a wound in part of the fleshy anterior aspect was not normally deemed to generate a casualty relative to performing some task. Thus, the probability of getting a "kill," given a random hit on the exposed body, would necessarily have to be less than 1.0.

However, the 58 foot-pound rule was, at best, a crude benchmark and was no doubt derived from pre-World War I European research.* Nevertheless, it was probably better than the more prevalent "pine-board tests" employed in the United States, whereby munitions were judged by their ability to penetrate 1-inch pine boards spaced 1 inch apart. But neither of these tests was satisfactory, because the criteria of what constituted a casualty were inadequate, and this inadequacy derived in large part from insufficient understanding of wound mechanisms.

These and related uncertain intricacies of munitions design, lethality, and operational considerations are illustrated by the story of shrapnel. On the eve of World War I, shrapnel-loaded shells had become the standard antipersonnel artillery munition, and tons of them were fired during that war. However, as the war dragged on, an increasing proportion of high-explosive (HE) munitions came to be used, mainly to inflict damage on entrenchments by means of blast effects. The HE munitions were, on the whole, probably far more effective for antipersonnel purposes than was the shrapne. because the shell fragments -- due to the higher ratio of explosive to metal -- possessed much greater initial velocities than did shrapnel "bullets" weighting around 10 grams.**

Shrapnel bullets derived most of their velocity-caused kinetic energy from the forward velocity of the shell in which they were

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*Support for this assertion can be found in Wilhelm Balck, *[illegible]*, Vol. 2, *Cavalry, Field and Heavy Artillery in Field Warfare*, translated by Walter Krueger, U.S. Cavalry Association, Fort Leavenworth, Kansas, 4th ed., 1914, p. 235. Balck states that 8 kg-m is considered sufficient to "disable human beings" (8 kg-m equals 57.8 foot-pounds). Balck notes also that the comparable criterion in France at that time was 4.8 kg-m.

**Balck, loc. cit., indicates that the Germans employed a 10-gram bullet of 12.3-mm diameter.

contained at the time of detonation, and this would vary as a function of firing distance. A shell with zero velocity -- which would be the case with a ground-impact burst -- was apt to produce little damage. This point was dramatically conveyed by an incident when a shrapnel shell exploded amidst a group of close observers, resulting in the loss of only a couple of fingers for the man holding it and some bruises for the bystanders who were struck. There were apparently few shrapnel wounds recorded in World War I; those that were so called may have been mainly produced by shell fragments.*

Overall, prior to World War II, the fullest exploitation of the improved technology -- as illustrated by the advent of smokeless powder and the metallurgical and design changes that permitted the hollow-shell and longer range, quick-firing gun -- to achieve combat utility was inhibited by inadequate knowledge about lethality mechanisms, and wound ballistics in particular.

However, by 1928 it became known in some U.S. Army circles that velocity was a critical variable affecting lethality, as a result of the deliberations of the "Pig Board," so named because eighteen live pigs were the object of live-fire experimentation at the Aberdeen Proving Ground in which varying calibers and types of rifle ammunition were fired

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*Coates, p. 112. However, this assertion may need to be carefully qualified, and is intertwined with subtle aspects of field artillery doctrine. On the eve of World War I, much of prevailing doctrine was directed toward troops in skirmish lines or hastily prepared, open fortifications, against which air-bursts would be employed. A field gun with a muzzle velocity of 1500 to 1800 ft/sec could produce shrapnel sprays in which the bullets would have velocities of 800 to 900 feet per second at ranges between 4000 and 5000 meters, and which would meet the 58 foot-pound rule. Moreover, because of their flatter trajectory, field guns of the French model 1897 (75 mm) and the German model 1896 (76 mm) produced a deeper spray than did howitzers. This, plus their rapid rate of fire and better mobility, may have rendered them close to optimal for the kind of war contemplated at the time of their design. However, as the war became static, howitzers, with their higher angle trajectories and high-explosive ammunition, proved increasingly useful. Therefore, shrapnel may have been more effective than suggested by the above example of the accidentally detonated round; however, it may not have been as effective against personnel as a high-explosive, high-velocity munition would have been.

at the animals.[*] But little came of these insights, by way either of new weapon or munitions design, or the pursuit of further knowledge. Systematic research on wound ballistics did not get under way in the United States until World War II, when the Office of Scientific Research and Development (OSRD) sponsored the work of the Princeton University Biological Laboratories, which -- with the aid of improved instrumentation -- undertook controlled experimentation.[**] These findings, along with those of British wartime studies that focused mainly on aircraft-launched munitions, provided the foundation for a postwar U.S. Army research program on wound ballistics. The results of this research, combined with new knowledge and insights regarding fragment dispersion and velocity, provided the basis of the lethal-area concept and derivative measures.

The key to postwar wound ballistics work was provided by the recognition of the phenomenon of temporary wound cavitation. This phenomenon results from high-velocity (supersonic) bullets and fragments creating an "explosive effect," by which shock waves damage tissues and vital organs beyond the wound track proper, through the medium of fluids and soft tissues, displaced from the wound track, moving away from the

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[*] *Report of the Board of Officers to Recommend a Specific Caliber for the Future Development of the Semiautomatic Shoulder Rifle*, July 1928. The Board recommended that the U.S. Army adopt a smaller caliber rifle. The recommendation was eventually turned down and laid to rest by Army Chief of Staff Douglas MacArthur. The reason given was the cost entailed by a new caliber rendering obsolete the existing standby tooling necessary for wartime ammunition production.

[**] For an account of the OSRD-sponsored work, carried out between February 1943 and November 1945, see Coates, pp. 143-235. After November 1945, the responsibility for the American work was transferred to the Surgeon General, Army, and an experimentation program was undertaken by the Biophysics Division of the Army Chemical Research and Development Laboratories (CRDL). The findings of the latter efforts were, in turn, adapted to the technicalities of fragment (and later flechette and bullet) behavior by the Army's Ballistic Research Laboratories (BRL). For an account of the initial evolution of the postwar endeavor, with an emphasis on the formulation of "incapacitation critiera," see F. Allen and J. Sperrazza, *New Casualty Criteria for Wounding by Fragments* (U), Report 996, October 1956 (Regraded Confidential), esp. pp. 9-15.

path of the projectile at supersonic speed.[*] However, appreciation of a phenomenon is only a small but necessary first step. Real understanding requires measurement, and that generally requires instrumentation. The availability and adaptation to wound ballistics research of high-speed cameras (as high as 800 frames per second) and the ability to produce roentgenograms with an exposure of a millionth of a second provided the means to get on with the serious and fruitful work.

The Princeton Biological Laboratories pioneered in the wartime experimental method. There they fired various sizes of steel spheres (.251 to 16.05 grains) at differing controlled velocities (as high as 4000 ft/sec) into water, a 20 percent gelatin solution (to simulate body tissues more closely), and cats and other anatomical miscellany.[**] Explicit in the Princeton and immediately subsequent work was the postulate that certain parts of the body were invulnerable, an assumption that placed an upper limit upon the maximum proportion of vulnerable to presented area for certain parts of the body. This constraint, in turn, limited the P(K/H), regardless of variations in missile mass/velocity combinations.[***] The substantial finding of these efforts, however, was that the 58 foot-pound energy rule had poor or no predictive worth with regard to fatal or severe wounds. The concepts *severe* and *fatal* were the wound (or effectiveness) criteria. That this binary measure was inadequate became apparent as a result of this initial and subsequent work.

Further experimental work conducted by the Army's Biophysics Laboratory, plus the pondering of its results and those of the Princeton work, led to the consideration of fragment cross section. The Princeton

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[*] See Coates, pp. 143-147 for an account of an earlier observation of the phenomenon, particularly on the part of surgeons, and attempts to rationalize it. The present and correct explanation is called the *accelerated particle theory* (ibid., p. 145).

[**] Ibid., pp. 152-189.

[***] Allen and Sperrazza, p. 11.

experiments used spheres; the Biophysics Laboratory's first work used squares and spheres (and later it extended experiments to flechettes). These experimental findings were generalized and extended to chunky fragments by multiple regression techniques and judgment. Angora goats were used as experimental subjects (in lieu of cats and, earlier, pigs).* The experiment consisted of firing three different sizes of fragments, each fragment at three different velocities, to provide nine mass-velocity combinations and sets of observations. The goats were autopsied, and wound tracks were mapped out and "assessed on the basis of the level of incapacitation which a man would experience were he subjected to roughly the same wound."**

The Princeton work used the concept of fatal and severe wounds. The Army's efforts sought to formulate casualty criteria that were both less ambiguous and more sophisticated, relevant to performing military functions. To this end, fourteen time-sensitive tactical/functional categories were postulated. Subsequently, after the curve fitting and analysis, it was decided that the following four categories could represent the fourteen:***

Defense .... 1/2 minute
Assault .... 1/2 minute
Assault .... 5 minutes
Supply .... 1/2 day

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*It is possible that the experience of the "Pig Board," which reported that "shaving of the whole animal was found very necessary, as much trouble was experienced in locating wounds of entrance where the animal had been only partially shaved" (*Report*), had a bearing upon the selection of goats as experimentation subjects. The choice of goats rather than chimpanzees was dictated by cost.

**Allen and Sperrazza. The initial goat experiments were conducted with grenades, to which various-sized, preformed fragments were pasted. Subsequent experiments employed special guns that discharged individual missiles. For an account of these methods, see Kokinakis and Sperrazza.

***Ibid., p. 27.

Placement in a given category indicates that the wound is sufficiently severe to render a man incapable of performing a particular mission or job at the end of the specified time. Thus a more severe wound is required to incapacitate a man within one-half minute of the time he is hit than is required to incapacitate within 5 minutes. Rendering the limbs inoperative is the criterion that the medical assessors employed in evaluating wound tracks with regard to these functions. This does not necessarily imply that the wound must be received in the extremities; for example, wounds received in the spinal column can have the same effect.

Wounds were categorized into sixteen wound classes -- e.g., skull wound, lung wound, bone and cardiovascular wound, and so forth.* Any hypothetical wound, inflicted by a given mass/velocity combination striking the body at a specified segment was assessed in terms of severity. Severity was gauged in terms of five degrees of incapacitation -- from zero to 100 percent, in 25 percent increments. Thus, a leg would require a higher degree of incapacitation for assault than for defense. It was assumed for the purpose of these assessments that a naked man, standing upright, received a wound in each of the small segments into which the body had been divided, and from different angles. A degree of incapacitation was assessed for each assumed wound at a given mass/velocity combination. The weighting of these assessments provided a P(K/H) for a random hit.

To make the assessments, a surgeon examined the goat wound-track information for a wound produced by a given fragment mass/velocity combination, and estimated the degree of incapacitation the wound would cause if a human were struck in a specified segment of the body. That is, the observed damage as inflicted on goats by a fragment of given mass and velocity was translated or projected to a human, in terms of some degree of incapacitation relative to performing each of fourteen time-sensitive military functions and with respect to specified body segments being hit from different horizontal angles. The equal

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*For a listing and definition of these wound categories, see J. Sperrazza, pp. 19-20.

weighting of these probabilities is the overall P(K/H) for a given fragment size.

It appears that assessments of goat wound tracks by one surgeon constituted the basis of the estimates for humans, although this point is obscure. Two individuals were involved in these assessments: one of them treated only one of the fragments and its three velocities and the other assessed the remaining fragments. Adjustments were made to reconcile the estimates of the two assessors.*

The next important part of the effort was to generalize the findings. (This task was undertaken by the Ballistic Research Laboratories, whereas the wound assessments had been made by the Chemical Research and Development Laboratories.) This endeavor involved specification of a mathematical equation and estimation of its coefficients by means of fitting a curve to the empirical observations. The equation selected was

$$P(K/H) = 1 - \exp^{-a(mv^{\beta} - b)^{n}} \qquad (2)$$

where the exponent is the base of natural logarithms, m is fragment weight in grains, v is velocity in feet per second, and a, b, and n are parameters derived for each tactical situation and its associated time period (e.g., 1/2-minute assault). It should be emphasized that the parameters of the a, b, n, and β coefficients are unknowns for which the value of β is critical if the formula and the empirical findings that it portrays are to be applied to such matters as fragment and warhead design.

The curve fitting procedure employed was, first, to ascertain the important β coefficient. It was generally agreed -- given the observed phenomenon of tissue damage beyond the wound tracks proper -- that β should be greater than 1. If it was believed that kinetic energy is the principal cause of tissue damage, then the β coefficient could approach 2. It could also be argued that "work done," which is a function of v^3, is the relevant concept and that the β coefficient should

*Allen and Sperrazza, p. 17.

therefore approach 3. This issue had been debated.* However, plotting the nine experimental mass/velocity combinations for each tactical situation and fitting a visual, free-hand curve to those points served to establish a specific numerical value for β. Next, the b coefficient was specified in terms of some minimum threshhold of energy necessary to penetrate the skin. Finally, given these two parameters, the remaining two, a and n, were determined by applying the least squares method to each set of nine observations, as applicable to a given combat situation or task.**

It should be noted that the Eq. (2) approach entails three elements of judgment. First, is the selection of the particular mathematical form of Eq. (2), which is essentially the "model." Other formulations might be worthy of consideration, some of which would imply different concepts of lethality. For example, a Weibull probability density function, which is employed in reliability models to estimate mean time to failure, is one interesting alternative (various mean times estimates, and their higher moments, to incapacitation, death, or more objective manifestations of other clinical behavior could be adapted to such an approach).*** However, given the Eq. (2) specification, there is next the assessment of human incapacitation with respect to the time-sensitive military functions, or the "transformation" of goat wound-track observations to humans. Another final question centers around the selection,

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*See Coates, pp. 117-18, for a discussion of this point. It should be noted that a long-prevailing view was that momentum, as expressed by mv, was the relevant measure and that it was responsible for the preference on the part of big-game hunters for large-caliber weapons. Some of this sentiment has also been encountered in military circles.

**However, the b coefficient was varied somewhat between different tactical situations so as to help minimize the residuals with respect to the a and n parameters.

***I am indebted to Dr. Frank Grubbs who called my attention to this line of thought. For an interesting and imaginative extension of Weibull theory (which is well established in the reliability field) to a broader military application and combat modeling, see Frank E. Grubbs and John H. Shuford, "A New Formulation of Lanchester Combat Theory," *Operations Research*, Vol. 21, No. 4 (July-August, 1973), pp. 926-941.

by visual technique, of the critical β parameter for Eq. (2). A question also arises about the appropriateness of fitting such a complicated curve to only nine sets of observations -- that is, nine mass/velocity combinations.* The overall impact of these judgments is that there is some unknown element of error in any prediction that relates a P(K/H) to a particular mass/velocity combination. Moreover, it remains something of a statistical challenge to determine what the error estimates might be, or what they might mean even if they were determined.

One reply to these points is that the work and the estimates were adequate for the purpose for which they were undertaken. That purpose was to take explicit account of new insights about wound mechanisms as they might bear upon munitions design, and to address the question of whether fragments should be sized at around, say, 100 grains, or some order of magnitude smaller. It can also be argued that subsequent follow-on empirical work that examined the results of both occasional accidential detonations and recent combat experience have provided a rough verification of the findings.** However, in the latter cases,

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*There appear to have been twelve mass/velocity combinations treated in the laboratory work, but one fragment (and its three velocities) was thrown out. Hence, nine mass/velocity observations constitute the data points employed to estimate the Eq. (2) parameters.

However, another aspect of the issue regarding the number of observations centers not over the number of fragment mass/velocity combinations, but over the number of surgeons (or other qualified persons) making the assessments by which the goat wound-track information was translated to estimates of human incapacitation. For example, if several individuals had assessed each mass/velocity combination, 27 observations would have been available, which may have permitted estimation of a useful error term. But, if such an approach had been taken, an equation different from the one actually employed might have been suggested. In all this are some subtle but important issues of model specification and statistical inference.

**See, for example, Keith A. Myers, *A Comparison of Actual Casualties Arising from an 8-Inch Howitzer Shell Accident with Theoretical Casualty Estimates* (U), Ballistic Research Laboratories, Memorandum Report No. 1503, August 1963 (Confidential), and J. R. Lind, K. Harris, and G. S. Spring, *FAST-VAL: Summary Report on the Comparison of Model with Combat Results (Infantry Firefight Outcomes and Effectiveness of Small Arms, Bombs, Artillery and Mortar Rounds)* (U), The Rand Corporation, R-810-PR, November 1971 (Secret).

the criterion measured is numbers of hospitalized or evacuated casualties. This experience, within limits, may partially support the direction that some munitions design has taken. But it would not seem either to verify or to refute the time-sensitive, functionally specified casualty criteria. Indeed, the fact that the original fourteen categories were combined into four, after the visual plottings were made, lends support to the idea that perhaps the distinctions among the four may be hard to maintain. One may then go a step further and simplify Eq. (2) by making it log-linear. Partial additional justification for this approach may be derived from other uncertainties that bear upon ordnance terminal effects. Yet, over the years and in connection with important weapon development and acquisition issues, the estimates derived from Eq. (2) and its parameters have figured significantly in assertions regarding effectiveness.

3. Terminal Lethality, Field Conditions, and Ball Ammunition

Munitions lethality might be degraded, or in some cases enhanced, by field conditions as affected by terrain, vegetation, or operations. Although most of the consequences of field conditions can be handled conceptually by the formal models currently deve'oped to treat terminal effects, substantial ranges of uncertainty rema. . These problems are, perhaps, even more severe with respect to the lethality of ball, or small-arms, ammunition, and can impact upon the effectiveness of infantry systems.

A *lethal-area measure* is a function of the portion of the soldier's body that is exposed (i.e., presented area), and is recognized by such categories as *standing*, *prone*, and *crouching in foxholes*. Consider, then, the situation in which troops are assaulting, when it could be postulated that some of them are standing and others are prone. The exposed portion of prone troops may be a critical function of minor variations in the terrain, from which they could derive the benefit of terrain masking, depending on the shell's burst height and delivery angle.* Some munitions, however, provide a sound signature that warns

*For an example of an effort to treat terrain variation, see B. W. Harris and K. A. Myers, *Cover Functions for Prone and Standing Men Targets on Various Types of Terrain* (U), Ballistic Research Laboratories, Memorandum Report No. 1203, March 1959 (Confidential).

of their arrival, allowing the troops sufficient time to seek cover. Not only will the standing men resort to a prone position, but also all the troops may seek out terrain masks that provide maximum protection. Munitions signatures differ markedly -- a point well known with regard to conventional artillery versus mortars and high-velocity flat-trajectory guns. It appears that the lethal areas assigned to these weapons do not take account of the differences. Or conversely, to take account of these differences may obligate the analyst to assume that weapons with a sound signature should be evaluated in terms of a larger number of soldiers in a prone and masked position than is the case with mortars or tank antipersonnel munitions.

Terrain, soil, and foliage conditions operate to retard fragment velocities. Soft soil or snow reduces sharply the proportion of submunitions that detonate upon impact. Marsh grass, tree foliage, and brush retard fragment velocities. However, these same factors can enhance bullet lethality by inducing the bullet to tumble.* Rocky terrain, such as mountains, can enhance terminal lethalities of impact-fuzed rounds, the blast effect of which produces rock fragments (in the World War II Cassino action, opthamologist sections had to be added to field medical units to accommodate the higher-than-normal incidence of eye injuries caused by rock fragments). Finally, elements of the soldier's combat load, such as packs, rifle magazines, canteens, and so on, provide a form of armor protection.**

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*For an example of brush tests, see Robert E. Carn and Albert W. Toepel, *The Effect of Brush on Projectile Dispersion, Hit Probability and Striking Velocity of Various Small Arms Projectiles* (U), Ballistic Research Laboratories, Technical Note No. 1638, November 1966 (Confidential). We have already noted that pigs, cats, and goats have been shot at. For brush tests, honeysuckle was the experimentation material.

**For an account of these and other factors that can degrade munitions' antipersonnel effects, see *Project New Light Doctrinal Guidelines Defense Against Cofram* (U), U.S. Army Combat Developments Command, Final Report, August 1966 (Secret). The same point has been emphasized in European literature; see Balck, Vol. 2, pp. 125-26.

All these phenomena, of course, can be handled conceptually by applying the appropriate retardation factors or formulas to the predictions that one makes about fragment velocity behavior.* But these predictions should be subjected to extensive experimental work and more rigorously modeled relative to probable exposures as influenced by signatures and possibly other field expedients permitted or constrained by tactical situations.**

Actual estimates of bullet lethality have not entered into the new firepower scores. Nevertheless, it is useful to address this subject, both to fill out the main technical aspects of terminal effects and their related uncertainties and, more important, to provide background that bears upon the vital subject of the relative importance attributed to major combat arms -- especially infantry and artillery -- which will be treated later.

It should be pointed out that most of the post-World War II wound ballistics research focused on fragments, both in terms of the specific aspects of the experimentation efforts and the major design and systems choices, the awareness of which stimulated and drove those deliberations.

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*See, for example, John J. McCarthy and Mary Ella Kelly, *Lethal Area Estimates for U.S. Artillery Projectiles* (U), Army Materiel Systems Analysis Agency, Technical Memorandum No. 23, March 1969 (Confidential), especially pp. 8-19, which outlines the methodology for deriving such factors.

**During recent years (roughly since 1965) a large amount of effort has been devoted to modeling the subject of terminal effects, with a primary focus on air-to-surface munitions, as part of the preparation of the *Joint Munitions Effectiveness Manual* (JMEM). See, especially, the volume on *Methodology* (Confidential). A number of elegant models have been developed, and accordingly, it is possible to conclude that progress has been made. Much of this work, in our view, however, seems to consist mainly of combining in a single model (or computer algorithm) aspects of the overall subject previously treated in separate models. Some even provide for taking account of aiming errors, a provision that transforms a set of essentially technical phenomena into a tactical-technical set. Whether the overall subject matter is really better understood is moot, since the empirical work has not been commensurate with the modeling. The point seems to be acknowledged in the last two pages (149-150) of the *Methodology* volume.

The systems choice centered on the relative merits of fragment sizes in the neighborhood of one hundred or more grains versus those that were much smaller.* This research provided information that contributed to the design characteristics of newer fragmenting munitions. However, its application to ball ammunition, and especially to small-arms design, was indirect.**

Although for certain purposes ball ammunition may be regarded as a fragment, its lethality is inseparable from design features of the weapon that launches it. The design of small arms, in turn, was long governed by other performance characteristics judged to be relevant to operational effectiveness or combat utility. Thus, by around 1900, most countries had settled on around .30-caliber ball ammunition for military use, based on the belief that long-range*** accuracy and lethality were desirable effectiveness attributes. The U.S. 1903 Springfield (which was essentially the

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*Although the research on this subject derived its initial thrust from the World War II effort, its support was no doubt sustained by our Korean War infantry casualty experience with Chinese mortars. The "technologically inferior" Chinese used iron in the manufacture of mortar ammunition, as contrasted with the machined steel preferred by our Ordnance Corps. It is now well understood that mortar rounds permit a high ratio of explosive to metal, a quality which enhances initial fragment velocity, and that iron breaks into small fragments with a more effective spray.

**However, pre-World War II concern with bullet lethality was probably a major force in stimulating thought on the relationship between wound ballistics and ordnance design. We have already noted the insights generated by the U.S. Army's "Pig Board" of the late 1920s. Observant surgeons were also struck by the phenomenon and seeming paradox of small entry and exit holes accompanied by large bullet wound tracks, which are caused by tumbling within the body, as well as by secondary cavitation.

***The specification of long range as it applies to infantry small arms is itself a controversial subject, and one for which it is not possible to provide a precise number. However, it is not necessary to be precise, since relevant issues bearing upon the selection of infantry weapons, tactics, and organization center around the pros and cons of differences in magnitude. Specifically, the issue is: Should the standard infantry weapon (with which the majority of infantrymen are equipped) be optimized with respect to engagement ranges of less than 200-400 meters (as is the case with such weapons as the M16 and AK47), or should it be keyed to the concept of "aimed fire" to and beyond 1000 or so meters (as were the high-velocity, .30-caliber weapons that had become so prevalent by 1900)?

German Mauser design), for example, fired a projectile of about 200 grains, with a round nose.* By around 1910, the Germans had introduced a pointed bullet (the so-called Spitzer) with a "boat tail," which the United States and other countries quickly adopted; thereafter, the United States standard .30-caliber ball ammunition weighed about 150 grains.

The lethality of ball ammunition is, of course, a function of its mass and velocity, and its velocity is a decreasing function of range, dependent upon the drag coefficient applicable to the specific projectiles's mass and cross-section. A bullet -- or any projectile -- will yaw when launched; that is, it will turn at a cyclically varying angle about its own longitudinal axis as it travels.** Yaw results from barrel whip, which is a function of the weapon's design. As a result of yaw, a fired bullet's center of gravity and the center of the forces retarding it differ, creating a "lever" effect, which, in turn, causes a bullet to tumble upon striking and penetrating a denser medium. The energy imparted by striking and penetrating can increase substantially in the wound tracks. A bullet's cavitation effect can also be influenced (and likely in ways that render the bullet more damaging at high velocity) by the levering when it strikes foliage or bone, or when it penetrates clothing. The tendency of a bullet to tumble due to the leverage effect, however, can be mitigated or enhanced by the degree of barrel twist, which governs the rotation or spin imparted to the bullet and its stability. Hence, a small projectile that possesses high velocity but low stability due to a low spin rate can be extremely damaging. The same projectile, however, will likely be less accurate and possess less penetration capability at a longer range against nonhuman targets than would a more stable bullet.

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*The round-nose bullet was also favored by big-game hunters because of its allegedly superior hitting power.

**The same phenomenon should not be confused with the "keyhole effect" (although the terminal effects are similar) which can occur at very long ranges (and when observed in early times was confused with tumbling). The keyhole effect was produced by the bullet's retention, throughout its trajectory, of the elevation angle at which it is launched. For a discussion of these and related points, see Coates, pp. 127-132.

For these reasons, estimates of bullet lethality cannot be unambiguously extrapolated from the estimates treating fragments exhibiting similar mass/velocity combinations. Because of differences in barrel whip and barrel twist between different weapons capable of firing the same ammunition, lethality for a given ball ammunition can differ between weapons. This lethality is also sensitive to range, although not necessarily in a simple way. However, bullets varying in size from 50 grains to 150 grains, launched at muzzle velocities of around 3200 ft per second for the American 5.56 mm and 2700 ft per second for the NATO 7.62 mm, are extremely damaging at the relatively short engagement ranges that characterizes most infantry firefights. Field conditions, including foliage, often enhance this quality by inducing tumbling. With automatic weapons, barrel heating caused by high firing rates reduces bullet stability and increases yaw and the size of wound tracks. It was for this latter reason, incidentally, that M16-rifle-wound tracks observed in South Vietnam were substantially larger than those predicted from equations based on laboratory work.*

C. ANTIARMOR CONDITIONAL KILL PROBABILITIES

The role of armored vehicles, especially main battle tanks, in present-day land forces looms large, if only because of their cost implications. The effectiveness of both armored vehicles and weapons designed to defeat them has become increasingly shrouded with uncertainties -- in analysis, if not in tactics -- as a result of technical changes. Consequently, armor and antiarmor systems properly attract much analytical attention. For this purpose, the counterpart of the lethal-area concept as it applies to a fragmenting munition is the probability of an armor-defeating device producing a kill, given a hit. It might seem that the terminal lethality of antiarmor and other antimateriel devices would be somewhat better understood than human incapacitation effects, primarily because it is feasible to conduct experiments in which munitions are employed against materiel. But

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*See Joseph R. Blair, "Analyzing Data on Munitions Effectiveness and Wounds," *Army Management Views*, U.S. Army Management School, Ft. Belvoir, Virginia, Vol. 15, Book 1, especially pp. 133-135.

this is not necessarily so. Many rounds have been expended against tanks and armor plate for the purpose of addressing the complex technicalities of both vehicle and munitions design.* However, critical uncertainties and ambiguities pervade endeavors to apply this information to estimating the kill probabilities or the force ratios that are the outputs of models that simulate combat or campaigns. Attempts have also been made to incorporate antiarmor capabilities in firepower indexes used to derive force ratios, and these estimates have some foundation in technical ballistics work.

Experimental processes consist of firing rounds against varying thicknesses of armor at different angles of obliquity. A standard measure is the "V_{50}" concept, or the terminal velocity at which 50 percent of the rounds will penetrate armor of a given thickness. For shaped and plastic charges, information on both armor-penetration depth and armor-spalling characteristics is sought.**

Prediction of penetration probabilities as applied to a vehicle (as contrasted with armor) is tricky. "Many target and projectile

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*There is an enormous literature on this subject. In addition to those cited below, the following items serve to provide a useful overview of its major branches: Bernard N. Goulet, *Report of Support Provided by Ballistic Research Laboratories for TATAWS II*, Part 1, *Computer Simulations* (U), Ballistic Research Laboratories, Memorandum Report No. 1817, February 1967 (Secret), provides useful general technical descriptions of antimateriel (armor) weapons and munitions, plus a good summary of the "numbers" about which this paper voices skepticism; E. A. Zeller, *Methods of Analysis of Terminal Effects of Projectiles Against Tanks* (U), Memorandum Report No. 1342, April 1961 (Secret/Noforn); and for a recent description and critical evaluation of the BRL methodology, see R. R. Kneece et al., *First Round Hit and Kill Probabilities for Tank Duels: Methodologies and Results* (U), Institute for Defense Analyses, Study S-363, August 1970 (Secret), especially pp. 25-55, which treats conditional kill probability.

**For a discussion of the V_{50} concept, see Robert C. Conroy, *Evaluation Criteria for VRFW-S Candidates vs. a Lightly Armored Vehicle* (U), Ballistic Research Laboratories, Technical Note No. 1689, May 1968, pp. 27-30 (Secret). For a technical account of measuring shaped-charge performance, see Robert DiPersio et al., *Shaped Charge Warhead Performance* (U), Ballistic Research Laboratories, Manuscript, September 1965 (Confidential), and Julius Simon et al., *Ceramic Armor Applique: An Evaluation for Defense Against Shaped Charges* (U), Ballistic Research Laboratories, Memorandum Report No. 1853, June 1967 (Confidential).

parameters ... are practically impossible to measure in detail during testing. Furthermore, it would be virtually impossible to predict their occurrence in target vehicles."* If the armor thickness of the vehicle varies substantially relative to vulnerable components inside the vehicle, penetration probabilities can change abruptly, depending on range of engagement and azimuth of fire. Nevertheless, estimates of penetration probabilities are made, by means of computer simulations for a given device, from various angles of fire and at different ranges, against different segments of the vehicle.** These penetration probabilities then need to be weighted to derive an overall penetration probability given a random hit. One method is to weight them in proportion to the surface area of the different vehicle segments themselves (as is done with respect to antipersonnel munitions and human incapacitation). Another method is to weight the penetration probabilities that apply to each of the segments in proportion to some expected relative frequency of hits that different segments might receive. It is believed that tanks receive relatively more hits in the front than they do in the rear; hence, the penetration probabilities for the frontal section are weighted more heavily than are those estimated for the sides or rear. This line of reasoning led to the "angular frequency of attack" concept,*** or the "cardioid distribution," and

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*Conroy, p. 27.

**See, for example, W. T. Miller and A. J. Romito, *An Armor Analysis of the Soviet BTR-50P APC, PT-76 Light Tank, BRDM Reconnaissance Vehicle, and the U.S. M114 Command and Reconnaissance Vehicle* (U), Ballistic Research Laboratories, Memorandum Report No. 1710, October 1965 (Confidential); and Robert R. Andrews et al., *Target Description and Armor Distribution Analysis of the USSR BTR-50P, APC* (U), Ballistic Research Laboratories, Memorandum Report No. 1720, October 1965 (Confidential). The recently developed BRL "Method B" for treating thickness of armor distribution conceptualizes the vehicle into four-inch grids for seven attack azimuth angles; see Miller and Romito, pp. 15-19.

***See, for example, A. E. Roden, *Distribution of Soviet Armor* (U), Ballistic Research Laboratories, Memorandum Report No. 612, June 1952, pp. 11-13 (Confidential), for a description of the concept and its equation, and an empirical estimate based on World War II experience.

empirical estimates of it have been derived from examination of World War II data.* For this reason, an overall single P(K/H) so derived ceases to be a purely technical or physical measure. Rather, it is an index number that employs a set of weights entailing estimates about tactics.

Given a specific penetration, derivation of a kill probability involves estimating what happens to the interior of the vehicle and its different components. Fragments, including kinetic energy devices, spew inside the tank; spalling from plastic rounds is conceptualized as fragments; shaped charges produce very-high-temperature metals, including the copper "slug" that is part of the shaped charge, to function as penetrators. These fragments possess their own velocities and proceed to damage operating components inside the tank, and crew members. A vehicle is conceptualized in terms of four-inch square grids. For each of the grids receiving attacks from seven azimuth angles ranging from 0 to 180°, penetrating fragments are then "projected" to the interior components. The terminal lethality of these fragments is a function of a set of factors, including space between the armor and the components, the tumbling characteristics of the penetrators, the number and size distribution and the dispersion of fragments, and the vulnerability of internal components (e.g., generators, people, optical glass) that are apt to be struck. Although much firing at old tanks has been conducted, it has been noted that "very little information exists to relate

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*This subject quickly blends into that of treating the anatomy of armor/antiarmor engagements. Several good empirical studies exist treating past wars. They are: Alvin D. Coox and L. VanLoan Naisawald, *Survey of Allied Tank Casualties in World War II* (U), Operations Research Office, ORO-T-117, 31 March 1951 (Confidential); Vincent V. McRae and Alvin D. Coox, *Tank-Vs-Tank Combat in Korea* (U), Operations Research Office, ORO-T-278, 8 September 1954 (Confidential); and D. C. Hardison et al., *Terrain and Ranges of Tank Engagements* (U), Ballistic Research Laboratories, Memorandum Report No. 702, June 1953 (Confidential). These studies are highly complementary. ORO-T-117 is encyclopedic in its analysis of some 12,000 tank casualties in various theaters and periods, and among allies. ORO-T-278 undertakes a similar analysis for Korea, where the action was concentrated in the first six or so months of that war. The BRL Memorandum is a much more detailed analysis of the subject suggested by its title.

the penetration capabilities of kinetic energy penetrators to non-armor materials and/or combinations of target components and space."*

The subject of vehicle conditional kill probability, given a hit and a penetration, may be approached in two ways: One approach is to estimate the probability of "killing" the vehicle. This concept may be unambiguous if it refers to a permanent loss to the inventory, which occurs if stowed ammunition explodes or its internal fuel burns. The so-called K-kill measure treats this probability. The second, and more sophisticated approach, in addition to treating K-kills, attempts to develop estimates of so-called mobility and firepower -- or M- and F- -- kills. Although these latter concepts strongly appeal to the intuitive believe that various kinds of damage short of causing a K-kill can degrade a vehicle's combat effectiveness, they are troublesome because they must be derived from the judgments of assessors.

With regard to the F- and M-kill concepts, judgment of the assessors enters at two levels. First, an estimate must be made of whether a fragment(s) hits and renders, say, a rangefinder or a radio inoperative. Next, the question of whether rendering a rangefinder inoperative reduces the tank's firepower must be addressed. The answer to this question depends on one's view of whether a rangefinder makes any difference with regard to tank-gun accuracy.** This subject entails assumptions about

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*Conroy, p. 29. The author continues, "Since the methodology for predicting the performance of kinetic energy projectiles against a target as simple as solid-homogeneous armor plate is not well in hand, it is premature to expect to be able to accurately estimate the performance against non-homogeneous materials with or without space separating them." It should be emphasized that the date of this publication is May 1968.

**This and similar issues need not be purely a matter of judgment or uncertainties bearing upon tactical/operational unknowns. For example, if the engagement in question occurs at short range, and if the tank has high-velocity kinetic-energy rounds, the loss of the rangefinder might not be of moment in a tank duel. (It may not matter in long engagement ranges either.) For examples of some of the complexities bearing on this subject, see Floyd I. Hill et al, *Study of the Range Finder for the Light Tank T41E1* (U), Ballistic Research Laboratories, Memorandum Report No. 554, June 1951 (Confidential), and R. C. Hu and B. N. Goulet, *An Analysis of the Times Required for Tank Crews to Fire First and Subsequent Main Armament Rounds* (U), Ballistic Research Laboratories, Memorandum Report No. 1307, November 1960 (Confidential).

subtle issues bearing upon operational effectiveness, and many of these assumptions are either uncertain or controversial. Similarly, destruction of the tank's radio can affect mobility of the tactical unit. Thus, there is uncertainty bearing upon both the narrower physics of penetration and internal physical damage assessment, and what impact these judged effects will have upon operational performance, as suggested by the concepts of mobility and firepower kills. As illustrated by the rangefinder and radio examples, the meaning and operational effectiveness implications of seemingly "narrow" technical damage is unclear if not highly uncertain.*

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*We have not by any means addressed all of the complexities of the interaction between the phenomena of penetration and lethality. One highly important related field that poses conceptual problems similar to those discussed with armor is the effects of fragmenting munitions (artillery and bombs) on thinner-skinned vehicles. See, for example, Robert R. Hare, Jr. and Martin N. Chase, *Effectiveness of Air-Burst Artillery Shells Against Personnel and Trucks*, Operations Research Office, ORO-T-303, June 1955 (Unclassified).

Similarly, small arms have a limited antiarmor capability, and in this case the penetration induces "tumbling," which affects human incapacitation. For an example of the analyses of the former phenomenon, see Theodore C. Carlson et al., *Penetrational Capability of Various Spin and Fin Stabilized Projectiles into Armor Targets* (U), Ballistic Research Laboratories, Memorandum Report No. 1789, September 1966 (Confidential).

It should also be noted that blast effects of certain munitions can be quite harmful to lightly armored vehicles. See R. F. Wilkie and N. H. Ethridge, *Blast Damage of M113 Armored Personnel Carriers Exposed to a 500-Ton TNT Explosion on Operation Snowball* (U), Ballistic Research Laboratories, Memorandum Report No. 1888, September 1967 (Confidential). It is also possible that a hit by a heavy infantry and antitank weapon, such as the TOW, on a "nonvulnerable" portion of an armored personnel carrier could render the vehicle nonoperative from the blast effect alone.

A closely related and important subject, which is also related to (or "mixed" with) the subject of wound ballistics, is the employment of main tank armament against personnel, both in the open and under various protective means, such as hasty field fortifications. Informative works are T. Donald Dixon et al., *A Comparison of HEAT and HEP Tank Ammunition Against Point-Type Soft Targets* (U), Research Analysis Corporation, RAC-T-434, October 1964 (Confidential); Andrew J. Eckles III, *Tank Gunnery Techniques to Exploit HEP Fragmentation Effects* (U), Research Analysis Corporation, RAC-SP-188, February 1963 (Secret); Glenn P. Beichler and Laura K. Ross, *A Comparison of the 105-mm M393 HEP, M456 HEAT and Beehive Projectiles in Roles Requiring Fire Against Soft Targets* (U), Ballistic Research Laboratories, Memorandum Report No. 1728, January 1966 (Confidential); G. P. Beichler and L. K. Pitts, It should be repeated that the discussion in this section concentrates on kill probabilities, given a hit. Getting a hit is a separate subject fraught with numerous operational complexities, and is treated in a later section. However, as noted, kill probabilities -- like lethality -- are themselves concepts that possess operational content, as illustrated by the incapacitation criteria applied to troops and the M-, F-, and K-kill concepts applied to vehicles. It is these latter -- particularly the mobility and firepower kills -- that figure in the P(K/H)s employed in the new firepower scores or in detailed models treating tank engagement.

D. SUMMARY ON MUNITIONS TERMINAL-EFFECTS DATA

Ballistics research as it relates to operational effectiveness of weapons is not an exact science, and probably never will be. Numbers that specify lethal areas and conditional tank-kill probabilities are subjected to several distinct sources of uncertainty. The human incapacitation criteria are the results of a subjective evaluation process on the part of medical men. Principal elements of judgment centered on how the observed goat wound tracks would produce pathological effects on human beings. As judgments, they may thus be subject to a degree of error that is simultaneously both different from and perhaps greater than the kinds of estimating error with which statisticians normally work. However, an estimate of possible "errors in judgment" as exhibited by possible differences among surgeon-evaluators is not provided.

A vehicle P(K/H) is a weighted average for hits received in each of the vehicle's segments. An estimate for a specific hit is subject to unknown errors about vehicle penetration. The firepower- and mobility-kill concepts, in turn, are based on judgments about (1) whether and the extent to which a particular interior component

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The Downrange Effectiveness of the 105-mm XM4[illegible]4E[illegible] Beehive Pro[illegible] Against Personnel Targets (U), Ballistic Research Laboratories, Technical Note No. 1656, May 1967 (Confidential); and Glenn P. Beichler and Laura K. Ross, *Comparison of the 105-mm M456 HEAT Round and the [illegible]-mm M393 HEP Round Against Soft Targets Requiring HE Fire* (U), Ballistic Research Laboratories, Memorandum Report No. 1620, December 1964 (Confidential).

will be damaged and (2) the degree to which the component contributes to either "firepower" or "mobility." If the people making these judgments are also participants in an institutional setting that advocates sophisticated fire-control and communications equipment, it is highly likely that their firepower- and mobility-kill estimates may be excessive or optimistic. Combat models using these estimates as data inputs could produce peculiar conclusions.

Both the human and vehicle P(K/H)s would seem to describe a degree of incapacitation, rather than a probability of incapacitating, given a hit. This definition appears clearly to be the case with vehicle firepower and mobility P(K/H)s. But it would also seem to extend to the human and the vehicle K-kills. That is, say, if four individuals receive random hits by fragments with a .25 probability of incapacitating, the method of formulating the incapacitation criterion would suggest that each individual is 25 percent incapacitated. In detailed models of firefights, such a happening might be interpreted to mean that one individual (or vehicle) is 100 percent incapacitated. Yet, if a model purports to probe the dynamics of a firefight, it may make an important difference which of the two outcomes is postulated. For models that assert that finite numbers of targets are killed, or 100 percent incapacitated, it is not clear how the estimates are derived. One line of argument that can be advanced to counter these questions is that "a hit is a hit," and it is sufficient to take a man out of action either physically or by sufficiently shaking him so as to render him ineffective. The same argument could be extended to vehicle combat effectiveness, provided armor penetration is achieved.

Whether the present state of empirical knowledge derived from terminal ballistics work provides a basis for attaching useful numbers to sophisticated concepts, such as the lethal area index or the weighted firepower- and mobility-kill probabilities, is unclear. It is quite possible that the present state of empirical knowledge is not adequate for this purpose and that the numbers currently used to "measure" these concepts, at best, mask many intertwined subjective judgments. Whether more refined terminal ballistics work (which can be justified in its own right for purposes of ordnance, component, and weapon design) can serve to make these terminal effects concepts useful for combat or campaign modeling is a separate and highly debatable issue.

That is, it does not necessarily follow that, even if the ordnance terminal effects estimates were greatly "improved" as a result of more work, they would be helpful numerical inputs for detailed combat models, in view of other uncertainties pertaining to operational effectiveness. But before exploring this issue, let us take up the second ingredient that was embedded in the new firepower indexes: the EEA (estimated expenditure of ammunition).

V. AMMUNITION QUANTITY AS AN ELEMENT OF FORCE-EFFECTIVENESS INDEXES

A. INTRODUCTION

The concept of a lethal area of a fragmenting munition -- whether based on the methodology recounted in the previous section, or some other methodology -- describes some of the effects of a specific munition. Modern artillery (and mortars), however, fire different kinds of munitions, and for many of these it is possible to vary the burst height by fuze selection or setting. High-velocity guns employ a variety of armor-defeating devices -- including some, such as shaped charges and plastic rounds, which issue fragments damaging to personnel as well as high-explosive and phosphorus ammunition. Each of the munitions, in turn, possesses its distinctive ballistics characteristics, which partially govern both terminal velocity and angular aspect relative to the ground, and which influence the fragment spray and hence the lethal area. For these reasons, no single lethal-area figure can be assigned to a given artillery piece or mortar, or even to the high-explosive munition available for tank guns. Nor can a single conditional kill-probability number -- even for a given range -- be estimated for a tank gun, given a variety of armor-defeating munitions available for any system.

The idea prevails that the capability of a military unit is partly a function of ability to sustain operations. Sustainability is at least constrained by available ammunition: If two forces possess equal capability in all other respects, the one with the most ammunition and related logistic support should prevail. Consequently, a large amount of resources are tied up in ammunition stocks and the means to manage and distribute it. This capability, however, incurs a cost and affords a tradeoff opportunity that is summarized by the expression "teeth versus tail" as an aspect of designing the force.

These and other considerations have provided a rationale to try to incorporate ammunition expenditure as an element of the new firepower indexes. Table 8 illustrates the idea, using hypothetical numbers.

Table 8

HYPOTHETICAL FIREPOWER INDEX FOR 105-MM HOWITZER BATTALION

Type of Munition	Lethal Area (Sq m)	Rounds/ Weapon/Day (EEA)	Product or Index
HE, Point-Impact Fuze	120	20	2,400
HE, VT Fuze	200	10	2,000
Antipersonnel	300	5	1,500
Total/Gun			5,900
x 18 Guns/Battalion			106,200

The first column shows the lethal-area index for each of several types of ammunition available for a weapon. The second column shows the number of rounds available (or projected) per day for each ammunition type. These figures are called *Estimated Expenditure of Ammunition* (EEA). The sum of these products provides firepower score per gun. Multiplying the latter number by the number of guns per battalion gives the firepower index for the unit. Similar numbers can be generated for infantry company and battalion mortar sections, for field artillery units equipped with other types of weapons, naval gunfire, and per-aircraft sortie. Larger aggregations of these, of course, constitute the measure of a force as employed in models such as ATLAS. This section develops some of the problems associated with the EEA variable when it is incorporated in an index number used to represent force ratios.

B. WAYS TO TREAT AMMUNITION QUANTITY

A variety of approaches exists for determining an ammunition allowance (or factor) from which to derive a firepower measure. The Army Field Manual FM 101-10-1, for example, presents data on:

1. Combat vehicle ammunition loads
2. Estimated expenditures of ammunition in
   a. rounds per weapon per day
   b. tons per unit per day

3. Artillery expenditures in
    a. rounds per weapon per hour
    b. tons per battalion per day
4. "Basic loads" by TO&E units*

Other ways of measuring ammunition expenditure can be, and are, conceptualized. Payload per aircraft sortie, which is also a function of mission radius, can be applied to air operations. Or, it is even possible to contemplate existing or planned stocks of munitions, wherever they might be. Any and all of these measures might be multiplied by the appropriate lethal areas or vehicle P(K/H)s to generate an estimated firepower potential.

"Basic load," is not, of course, an expenditure (or flow) measure. Rather, it is a "stock" figure determined by the design of equipment, organizational Tables of Equipment, or doctrine. Thus, a rifleman's basic load may be 300 rounds of 5.56-mm ammunition; that of a tank will be determined by its design. Usually, battalions possess additional stocks, as permitted by organic transport. In addition, battalions can draw upon divisional stocks.

Maximum rate of fire for a very short period -- say, two or three minutes -- is another important way of measuring ammunition expenditure, since it describes the "surge" capability of fire support systems. Concern with this attribute is central to much of force structure design, equipment selection, and doctrine. Surge capability, however, is also a function of a weapon's range, rate of fire, speed, and payload, since these characteristics affect the ability to concentrate force and fire. It is with regard to these relationships that issues related to mortars versus guns versus missiles versus airplanes come to a head. Also, it is possible to equip guns with automatic or semiautomatic loaders, whereby the consequent increased rate-of-fire per gun might enable a

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*_Staff Officers' Field Manual: Organization, Technical, and Logistical Data_, Department of the Army, FM 101-10-1, January 1966, pp. 5-48 and 5-106.

four-gun battery to produce a peak fire equal to that of a six-gun battery. But budget, manpower, and command-slot allocations among military services, as well as among combat specialties within a service, are potentially at stake when such choices are considered; hence, they are approached gingerly. It is perhaps for this reason that the ammunition "day of supply" measure has been the basis for firepower indexes that have been used in some force-planning models. This measure is based on a mixture of experience and estimating procedures. Some probing of its nature is relevant.

C. AMMUNITION "DAY OF SUPPLY" ESTIMATES BASED ON EXPERIENCE

The ammunition day of supply is expressed in terms of rounds per weapon per day required to sustain operations in a theater. It encompasses each type of munition (e.g., high explosive, white phosphorous) employed for each type of weapon and a mix of appropriate fuzes (e.g., VT, point detonating) for each munition.* The numbers are published in *Army Supply bulletin SB 38-26*. They are also changed periodically to reflect ammunition-procurement objectives, and are consequently influenced by such forces as the political-budgetary negotiations that take place at the higher levels of government decisionmaking. That these data do have some relationship to ammunition-expenditure experience during past wars, as recorded in terms of ammunition that enters combat theaters, does not alter the fact that much uncertainty prevails regarding their relevance to future combat, or to different combat situations. For example, a certain amount of the ammunition that entered combat theaters was lost, captured, or destroyed by enemy action. Some was expended in training -- this is particularly so with regard to small-arms ammunition, because troops in a reserve status or awaiting assignment in replacement depots are often occupied on firing ranges, if only to give them something to do to relieve boredom. But these "leakages"

*For an exhaustive treatment of the concept, including its origin, evolution, uses, and relationship to the basic load concept, see Dorothy Kneeland Clark, *[illegible], World War [illegible]*, Operations Research Office, ORO-TP-18, December 1960.

pose a minor problem relative to the major analytical difficulties that pervade the subject.

During the early planning stages of World War II, U.S. force planners were attracted to the German model of a field army that placed emphasis upon mobility, which was facilitated by dispensing with large artillery trains. They were also motivated to deploy divisions overseas quickly, in the face of severe shipping constraints. Hence, there was an incentive to keep both the division and its field army "slice" as light as possible.* Simultaneously, large resources were to be allocated to the Army Air Force, which also generated the expectation that air power could be substituted for much of the medium and heavy (nondivisional) artillery. All the while, the War Department had to adapt its planning and procurement objectives to those of the Navy, and both the War and Navy Departments were waging a major bureaucratic war against the common enemy that represented civilian requirements. As overseas forces built up (especially in Europe), theater commanders requested ammunition supply that exceeded production allocations. Army Headquarters realized, however, that there was an element of "gaming" in these requests and that subordinate commanders always had a tendency to squirrel stocks away for future emergency or opportunity.

An important turning point in ground force planning occurred with the Battle of Cassino, after the attempt to facilitate the capture of the town by means of saturation bombing on March 15, 1944.** The main conclusion drawn by ground force planners was that airplanes could not

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*The driving force behind implementing this philosophy was General Leslie McNair, chief of the newly created Army Ground Forces. For those who might think that vigor and hard-nosed question-raising in defense management was something invented by civilians during the 1960s, it is informative to read the history on General McNair's efforts. See Kent Roberts Greenfield et al., *United States Army in World War II: The Army Ground Forces: The Organization of Ground Combat Troops*, Department of the Army, 1947, pp. 265-432.

**This action should not be confused with the highly controversial bombing and destruction of the Abbey of Monte Cassino, overlooking the town, which took place on February 15, 1944.

deliver the desired results and that the earlier decision to minimize the number of medium and heavy artillery battalions in the Troop Basis might have been overdone.* Promptly, force plans were changed and additional 155-mm, 8-inch, and 240-mm artillery battalions were programmed. Meanwhile the "artillery deficiency" could be partially compensated for by higher firing allowances, to the extent that increased ammunition production and availability of shipping space permitted. By early 1944 the shipping space constraint was less severe due to increased production and to having coped with the submarine threat. But with the mitigation of these constraints, a new set began to take hold after large ground forces were operating in Northwest Europe. Overland transportation, as illustrated by increased shortages of trucks and trucking companies, and the hard choice of allocating this resource between POL and ammunition, began to dominate Theater logistics decisionmaking (and even major strategy decisions), as well as procurement and programming in Washington.

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*This interpretation is controversial, and its resolution and "lessons learned" are more relevant for current problems. Air advocates can reply that the infantry follow-up was laggard, in vigor and level of effort. The point is probably correct as far as it goes, since the New Zealand Division had been in the line for over a month, and was considerably shopworn. It was also true that the ground attack was not well prepared, partly due to insufficient time to plan it. The reason there may have been insufficient time was that Air Force planners indicated that the attack had to take place on that particular day because weather forecasts offered the prospect of clearing in central Italy and further north, a circumstance that facilitated returning to the more favored Air Force missions of theater interdiction and strategic bombing. Also, the overall quality of bombing and its accuracy were poor. Bombs fell among the advanced waiting elements of the assaulting troops, 1000 yards from the town; among friendly artillery units; and in the corps commander's bivouac area, to destroy his house trailer. One B-24 group mistook the "initial point" (IP), which was the town of Venafro some 20 miles away, for the target, and got good results on field hospitals containing French Morrocan troops. Had all this destruction been visited exclusively on the German enemy, and had the ground attack been better planned and executed with fresh troops, the results could well have met planners' expectations. The failure, in our view, was one of command and control, and the technical proficiency of some 15th Air Force units, which were newly arrived in the Theater, in performing a close support mission.

Artillery expenditure rates in the Korean War greatly exceeded those in World War II. Excess stocks were quickly expended, and the subsequent shortages were the object of Congressional investigation. The motivation for the greater expenditure rates in Korea was the laudable aim of theater commanders to save the lives of friendly troops. The day of supply increased predictably. One major uncertainty remained; it was epitomized by one of those theater commanders, Gen. Maxwell D. Taylor, who said at the close of the war "that he could not judge whether 1/10 or 10 times as much ammunition should have been expended in Korea."*

A case can be made that the artillery ammunition-expenditure rates experienced in past wars provide an ambiguous indicator for estimating a force's capability and, especially, the ratios between possibly opposing forces. These particular historical data for one side reflect a myriad of allocation and strategic decisions that affected the conduct of a war. Strategic decisions, in turn, often are governed by the ability to provide field logistic support. Given the capacity of a field army's logistic transportation apparatus, a rationale can exist to expend ammunition to avoid piling it up at Theater supply points. Such behavior is not necessarily irrational, because some capacity to move ammunition must nevertheless be maintained, and it is not likely to be maintained well if it is not also exercised. Thus, given the size of a Theater Army's logistic apparatus, both the opportunity and a "requirement" to shoot will be created. Yet the size and, hence, capacity of the logistic system has to be determined, and such a determination must be related partly to desired anticipated firing rates. There is an inescapable element of circularity in this. The problem has long bedeviled force planners. However, to couch it in terms of firepower, when it is more accurately an issue centering around the kind of field logistics capability one should have, may detract attention from the difficult problem of just how the support apparatus should be designed.

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*Dorothy Kneeland Clark, p. 40.

D. THE METHODOLOGY OF AMMUNITION STUDIES

Historical experience provides an input, if not a foundation, for ammunition expenditure planning factors and, hence, for EEAs employed in firepower measures. It should be emphasized, however, that any actual numbers encountered are not necessarily based exclusively on empirical data. Ammunition expenditure planning factors are periodically revised as a result of study. Examples of a recent revision are shown in Table 9.

Table 9 displays published planning factors for selected weapon and unit expenditure rates as a function of kinds of combat. The 1966 estimates were based on World War II and Korean War experience. Those of 1971 indicate a sharp upward revision. For division units, an increase in tonnage partly reflects the fact that present-day divisions are heavier and larger than the World War II divisions. The data for corps howitzer battalions and, especially, the weapons types nevertheless indicate more intense rates of fire per weapon.

How might changes like these be derived? One approach is illustrated by a series of Army ammunition studies* that employed formal modeling techniques. The effort used various detailed models by which targets are acquired, fires assigned, and casualties assessed,** and a separate tank-antitank engagement model. Personnel casualty assessment is based on the 5-minute assault criterion of incapacitation. The account of the artillery submodel of the ammunition study states that ammunition requirements are generated from "requirements" that are developed separately for various artillery functions. Thus, antipersonnel casualty production objectives (e.g., the 30 percent casualty criterion, which seemed to be considered a unit's break point) are provided by ammunition expenditures. To this amount is added a requirement for

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*See *Nonnuclear Ammunition Combat Rates, Programming [illegible] (Ammo-P-75)* (U), Vol. 1, *Main Report* and *Annexes A, B, H, I,* and [illegible], May 1968, (Secret/Noforn).

**See ibid., Vol. 2, *Annex C -- Methodology*, pp. C-1 to C-II-B-6, for the discussion account of the method.

Table 9

AMMUNITION EXPENDITURE FACTORS, U.S. ARMY, 1966 AND 1971

	Types of Combat				
	Defense of Position				
	First Day 1966/1971	Succeeding Days 1966/1971	Meeting Engagement 1966/1971	Retiring or Delaying Action 1966/1971	Protracted Period 1966/1971
Rounds/Weapon/Day					
Mortar, 81-mm	80/145	50/88	49/73	30/52	20/37
Mortar, 4.2-inch	80/163	59/99	40/82	30/58	20/41
Howitzer, 155-mm	140/231	85/140	70/116	50/82	35/58
Howitzer, 8-inch	100/143	60/87	50/72	0/0	25/36
Tank, 105-mm gun	25/78	15/47	12/39	8/28	6/20
Tonnage/Unit/Day					
Inf. Div., Mech.	835/2180	516/321	411/1090	278/752	214/552
Armored Division	969/2574	596/7560	476/1287	321/888	247/651
Corps 155-mm How. Bn.	142/240	86/145	71/120	51/83	35/61
Corps 8-in. How. Bn.	137/205	82/124	68/103	0/0	34/52

SOURCE: *Staff Officers' Field Manual: Organizational, Technical, and Logistical Data*; 1966 data are from Table 5-32, pp. 5-50 and 5-51 of the 1966 ed.; 1971 data are from Tables 5-21 and 5-22, pp. 5-36 and 5-37 of the 1971 ed.

"harassment and interdiction" (H&I) fire, which is another artillery mission. However, in this estimate, no esoteric modeling is employed. Rather, H&I expenditure rates experienced in South Vietnam were applied.[*] H&I fire may be defined in various ways. But one working definition is that it is the shooting that gunners engage in when they have nothing else to do and when ammunition stocks are available.

A question can be raised regarding the application of, and interrelationships among, firepower scores as proxies for force ratios and the use of campaign models as adapted to artillery studies for generating estimates of future ammunition requirements. First, force ratios are expressed in terms of firepower indexes. Next, the artillery "game" is played, in which ammunition expenditures fall out as the dependent variable that produces the desired "objective function" in terms of casualties produced or relative force ratio changes. Thus a "requirement" emerges for new EEAs for the weapons. But these new EEAs might be applied to the lethal areas and tank-antitank P(K/H)s to produce new indexes of unit combat effectiveness. The analytical process appears circular. It can even suggest that one can counter an opponent solely by ammunition expenditures -- especially of those items that have high lethal areas or theoretical accuracies. But this tendency can be offset by assuming that an opponent employs similar increases in ammunition expenditure. Some study work appears to have adopted this approach, which avoids developing the full implications of the idea that ammunition expenditure can be linearly substituted for launchers and tubes.[**]

A related troublesome feature of incorporating an ammunition expenditure rate in a measure intended to estimate force ratios is that it

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[*] Ibid., Vol. 4, p. C-IV-16.

[**] See *Theater Battle Model*, which shows evidence of adapting this expedient. Tables A-1 and A-2, pp. A-9 to A-11, present EEAs for major U.S./NATO and Soviet/Chicom weapons.

requires useful information about an opponent's logistics capabilities and his doctrine. Suppose, for example, that an opponent has a doctrine of using artillery in an assault role, rather than one which emphasizes centrally controlled, indirect fire? The force structures, including that of logistics support of these divergent outlooks, can differ in many respects. The respective planned ammunition objectives would also differ in numerous ways. The use of a firepower index that is significantly influenced by estimated expenditures of ammunition would seem to incur the risk of not examining the pros and cons of two fundamentally different approaches.

VI. ASSESSING THE RELATIVE WORTH OF THE MAJOR COMBAT SPECIALTIES

A. INTRODUCTION

The armies of different countries, prior to World War I, did not possess markedly different structures with regard to the three major combat specialties: infantry, cavalry, and artillery. First, the need to feed horses limited the relative sizes of both the cavalry and artillery arms, and either constrained strategic mobility or limited military operations to seasons and territory that provided lush forage. The amount of artillery in a force was further restricted by the tactical requirement of infantry to protect the artillery, as well as by the fact that artillery horse teams, caissons, and supply trains required a disproportionate share of the length of a division when on the road. This latter factor hampered the ability to deploy quickly into battle order after completing movement. Hence, there were no significant differences between major armies with respect to artillery densities (as measured by number of guns per 1000 infantry), and the ratio of cavalry to infantry in major campaigns hovered between 30 to 10 percent, with a convergence toward the lower figure after the Napoleonic wars. For these reasons, force comparisons could be made on the basis of "battalions" -- i.e., infantry -- or even "divisions." An army might also possess some number of howitzers and heavy siege guns suited for busting fortresses such as Metz or Namur, and thereby take care of what it was hoped were limited "static" phases of operations. These howitzers and heavy guns were assigned to a corps or army on an as-needed basis.*

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*This roughly describes the major constraints on land forces planning and structure from the period of the French Revolution to World War I. The period started out with very low artillery and cavalry ratios, exhibited by the French and also characteristic of Wellington's Peninsular Army. That Napoleon practiced the massing of divisional artillery tends to mask the fact that French field armies were often outnumbered in terms of guns.

These observations are based mainly on Gaston Bodart, [illegible], C. W. Stern, Vienna, 1908, and Balck, Vols. 1 and 2. Bodart provides, through battle-strength information, insight about force-structure trends. Balck distills and compares much information from drill regulations of various countries and data that is relevant to immediate pre-World War I force structure.

The military application of the internal combustion engine altered these essentially horse-determined constraints on the ability to vary the force structure on the basis of major combat specialties, although similar constraints prevail today. Tanks, functioning initially in World War I as an infantry support weapon, revived the cavalry tradition and gave rise to an extremely sophisticated combined-arms style of combat operations. Division artillery and trains could be of shorter length, and ammunition resupply capability was enhanced. It was possible to increase both the ratio of guns to other force elements and their weighted average caliber. Airplanes could perform some of the cavalry and artillery functions. The substitution possibilities among combat specialties seemed much greater. There also appeared to be greater scope to substitute *capital*, as embodied in artillery, aircraft, and tanks (and other combat vehicles), for *labor* in the production of military force. Through these forms of capital investment, to be greatly expanded by the application of electronics equipment, something called *technology* came to be purposefully applied to and embedded in the force structure.

These changes confounded the problem of counting and, especially, of assessing opposing forces. The more capital-intensive combat elements necessitated expanded maintenance and supply services to be provided by uniformed personnel. The proportion of the armed force actually engaging in combat fell sharply, and a mere count of people ceased to have clear meaning. As part of the same set of effects, numbers of divisions (or other administrative units, such as battalions and squadrons) became unclear metrics. An explicit recognition of the inadequacy of body or division counts may have provided the impetus to the advancement of the new firepower index concepts as a force *measure*. Thus, it might be argued that, even though there are uncertainties about terminal ordnance concepts and effects and the relevant ammunition expenditure rates from which the new firepower indexes were constructed, the indexes are a better measure than either bodies or divisions. If one takes this position, it might also be reasoned that the uncertainties about lethal area, tank P(K/H), and ammunition expenditure estimates will affect firepower indexes for both sides and that, therefore, one need not worry about the detailed building blocks of the index.

As it stands, this argument is correct. It derives force from the point that the new firepower indexes, which incorporate estimated expenditure of ammunition, are extremely sensitive to that variable. (Other indexes, like those developed for maneuver-control purposes or the TACSPIEL model, do not depend on ammunition expenditure, because rates of fire are constrained in the context of the model or war game in which the indexes are used.) However, the new firepower-index concept, which is keyed to the lethal area, tank P(K/H), and EEA for each type of ammunition, posed a weighting problem. As illustrated by the lethal-area and tank-P(K/H) concepts, which tend to have an "effectiveness" flavor, quite distinct military functions are denoted by the word *firepower*. Thus the problem arises: How are these diverse types of firepower weighted for purposes of constructing an overall index? Specifically, how are ball ammunition or infantry small arms, fragmenting munitions, and tank-defeating devices to be *aggregated*? This aggregation can also involve making estimates about the relative importance of infantry, armor, and artillery.

B. BALL AMMUNITION VERSUS FRAGMENTING MUNITIONS

An attempt was made, in formulating the new firepower indexes, to assign a lethal-area value to a round of ball ammunition; this value is then multiplied by the number of rounds assumed to be fired by rifles, automatic rifles, or machineguns.* There is nothing inherently wrong in the concept of a lethal area for bullets. A bullet or a burst of bullets can be viewed as a fragment or fragments, and the resulting spray can be related to a target's presented area.** This approach is consistent with the treatment of fragmenting munitions, given the assumption of uniform distribution of targets over the terrain. However, given their long

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*See *Measuring Combat Effectiveness*, Vol. 1, pp. 9-11, for a description of the methodology.

**In the same manner, a lethal area for tank-defeating devices could be estimated.

ranges (1000 meters or more), bullets would exhibit very high lethal areas. Such numbers, incidentally, would lend support to a widely held view that bullets are highly effective.

Another approach is to take account of the belief that bullet fire is aimed. Here the analysis tends to focus on hit probability, with aiming errors and tactical doctrine becoming critical variables. But this approach entails developing empirically valid assertions about the anatomy of infantry firefights, especially as they might relate to the relative effectiveness of different weapons and tactical doctrine. To pursue that line of inquiry would also suggest that it be applied to the operational performance of artillery and armor systems. So another approach was adopted.

The reference point is World War II. On the basis of interpreting the evidence of casualty-causing agents upon U.S. troops in the Mediterranean and European theaters, it was concluded that "approximately 20 percent (of casualties) were caused by point-fire weapons and 80 percent by area-fire weapons."* From estimates of lethal areas of U.S. World War II munitions, and their respective expenditure rates, an aggregate lethal-area estimate was made for the U.S. World War II division force. On the basis of the 80 to 20 ratio of fragmenting-artillery and mortars to ball-ammunition casualties developed from the interpretation of World War II casualties, a 25 percent portion of the fragmenting weapons' lethality potential is assigned to weapons firing ball ammunition. Estimates of the amount of ball ammunition expended by weapons in World War II infantry companies are divided into this latter figure. The result of the arithmetic is the lethal area for a bullet. The number of small arms and their EEAs in existing organizations is then multiplied by this bullet-lethal-area measure, which takes account of the point that battalion sizes differ according to time, country, or infantry specialties.

One criticism that can be raised about this approach is that the 80 to 20 ratio of artillery and mortars to ball ammunition is not

*[illegible], Vol. 1, p. 9.

supportable by the World War II historical evidence. Although an Operations Research Office study is cited to support the assertion that 83.2 percent of the U.S. Army casualties experienced in Northwest Europe (ETO) and 73.2 of those in the Mediterranian (MTO) were due to "Mortar and Artillery" (table caption),[*] the cited study indicates that the ratio was 64 and 69.1 percent, respectively.[**] It does not seem correct to attribute all or most nonball ammunition (e.g., hand grenade and mine) casualties to artillery and mortars. Nor does the 80 to 20 ratio take account of the likelihood that a bullet wound would inflict a higher degree of incapacitation than would a fragment wound -- a point suggested by the fact that a higher portion of bullet wounds are fatal than are fragment wounds.[***]

A question might also be raised as to why the relative casualty production of weapons on an enemy is inferred from information on the casualties his weapons may inflicted upon us. Ideally, it would be desirable to know the nature of his casualties by causative agent. This kind of information is difficult to get, and it is probably why friendly wound statistics are used But none of the enemies of the

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[*] Ibid., p. 9.

[**] L. VanLoan Naisawald, *The Causative Agents of Battle Casualties in World War II*, Operations Research Office, ORO-T-241, July 1953, p. 3.

[***] See Gilbert W. Beebe and Michael E. Debakey, *Battle Casualties: Incidence, Mortality, and Logistic Considerations*, Charles C. Thomas, Springfield, Illinois, 195[illegible], pp. 132-136.

It should be pointed out that casualty analysis, in terms of ascertaining causative agencies, is difficult for a number of reasons, although much painstaking, careful, and good work has been done. See, also, the more recent study by Jeffrey Burt et al., *Distribution of Combat Casualties by Causative Agents* (U), Research Analysis Corporation, RAC-T-445, March 1965 (Confidential), which employs multiple regression techniques connecting engagement conditions with casualty causation, especially Table 8, p. 27. Here, the "artillery-small arms" ratio looks markedly different, with the 80 to 20 ratio approximated only in the case of "attacking an almost impregnable enemy" -- a case where the enemy is no doubt able to do extensive prior registration. In many tactical modes, the ratio is close to 1 to 1. Mines and "miscellaneous" (the latter including one's own "instruments") are substantial casualty producers.

United States in World War II and the Korean War possessed the artillery densities or expended the munitions tonnages we did -- both because of conscious force-structure programming and because our air-interdiction programs did inhibit tonnage throughput.* For this reason, one might expect that U.S. fragmenting munitions may have been responsible for an even higher proportion of enemy casualties than our experience indicated. However, interrogation of a sample of 1000 prisoners-of-war wounded in action in the Korean War suggests this may not be the case. The findings were as follows:**

Casualty-Producing Agent		Percent
Ground Weapons		
"Gunshot"	43.0	
Shell Fragment	23.5	
Grenade	1.2	
Total		67.7
Air Weapons		
Machinegun	9.4	
Bomb	10.9	
Rocket	3.0	
Napalm	4.4	
Total		27.7
Nonbattle		4.6

These latter criticisms, however, need not carry much force with respect to their impact on the values attached to firepower indexes for actual units. The values do warrant criticism, however, to the extent that they result in any particular significance being attached to the empirically incorrect ratio of 20:80, or a possibly correct one of 50:50, or to the extent that they suggest anything about the relative importance of different weapons or combat specialties. The use of lethal

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*See *Commitment of Flak and Fighters to Protect the German Route of Supply in Italy, 1944-1945*, Department of the Army, Office of the Chief of Military History, MS D-191.

**Coates, p. 723. The prisoners were interrogated in January 1951; therefore, they were wounded prior to the very heavy artillery fires that came to characterize the later phase of U.S. action.

area figures may not exert a transparent influence on estimates of relative force size, whether derived from ballistics concepts or imputed, because a firepower index that employs an estimated expenditure of ammunition can be dominated by the assumed or specified ammunition expenditure rates.

C. ANTITANK CAPABILITY

The lethal-area aggregate derived for a unit by the use of the method described above may provide some rough estimate of a potential to inflict personnel casualties. All combat units also have some potential to kill armored vehicles. The antipersonnel and antivehicle capabilities, however, are not directly addable. How is the problem caused by this fact handled in the formulation of the new firepower indexes?

The main element of the approach was, first, to estimate tank kills for tanks and infantry battalions. This is done by multiplying a munition's P(K/H), for either a firepower or mobility kill, by a hit-probability number estimated for each weapon and each munition category -- e.g., an M60 tank and a 105-mm high-velocity, armor-piercing round. The "hit probabilities" are related to hitting a 7.5- by 7.5-ft. target at varying known distances. (Some of these estimates may actually have been verified on a proving ground; others are deduced from physical equations.) Thus a kill-probability estimate for each type of munition, per round, is obtained. Account was also taken of a weapon's maximum effective range: If the range was less than 500 meters, the kill probability was multiplied by 1; for 500 to 1000 meters, the multiplier was 2; for a range greater than 1000 meters, 3. Multiplication of these numbers by the EEAs for each munition type and number of weapons per unit provided an antitank kill potential for each unit. Thus, for a hypothetical division one could arrive at the following pair of aggregate antipersonnel and antitank "firepower-potential" estimates:

Antipersonnel (lethal area)	900,000
Antitank (kills)	200

Obviously, a lethal-area-derived firepower index number and a tank-kill-per-unit estimate are not directly addable. So what was done to develop an index number?

Recourse was taken to the set of inequalities used in the TACSPIEL war game,* which evaluated the relative worth of small-unit antitank and antipersonnel capabilities.** For 1965 TO&E units, tank-kill and antipersonnel potentials derived from the ballistics and ammunition-expenditure data were substituted into the TACSPIEL equations to yield the following inequalities:

Antitank Potential			Antipersonnel Potential	
Infantry Company	28.7 f	·	Tank Platoon	47,313
Infantry Company	28.7 f	·	Tank Company	189,250
2 Infantry Companies	57.4 f	·	Infantry Company	264,700

For the then-prevailing U.S. organizations, any value for f of between 3631 and 11,694 satisfied these inequalities. A value of 3750 was selected. Multiplying a unit's "antitank potential" by this number was advanced as a means of adding a unit's antitank and antipersonnel capabilities.

D. SUMMARY OF THE WEIGHTING PROBLEM

The conceptual difficulty in the new firepower indexes may be summarized as follows: A firepower index is an index number. An index number, in turn, is an aggregation of unlike things by means of some valuation process. The formulation of an index number requires

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*See *Measuring Combat Effectiveness*, Vol. 1, pp. 17-19, for an account of the methods. See also Lester and Robinson, pp. 5-7, for an unclassified discussion of the techniques and the relevant numerical estimates.

**These values are described in Section III of this Report in the discussion centering around Table 6.

a theory, or a set of principles, by which value weights are attached to the unlike things. If principles are lacking, however, the index can take on highly arbitrary values.

If index numbers are the main numerical inputs for, say, the construction of a model or theory of war, or for a campaign entailing the use of general purpose forces, we have a situation where arbitrary or postulated numbers are inputs for a theoretical model. There may not be anything inherently bad about such a situation, if it is recognized that the end product of the model itself is assertions in the form of quantitative statements that can in principle be refuted by some independent test. But without a testing process, or similar empirical effort, which demonstrates that one (or a selected subset) of models employing one set of arbitrary data inputs is the best of all such conceivable combinations, it is not clear just where the intellectual effort leads. If one accepts the idea that a model (or theory) should have predictive -- or explanatory -- worth, it is even possible that a good model might be rejected because it has poor predictive worth, when the reason for the poor performance will have been the poor (or irrelevant) numerical inputs. Thus, the procedure seems to be an extremely inefficient way to try to discover a good theory by trial and error. At best, it is a computational exercise with a limited or murky empirical foundation.

The new firepower indexes, based on munition lethal areas and theoretical tank kills, are extremely sensitive to the estimated expenditure of ammunition assigned to each weapon. They also exhibit an admixture of precision in the use of some data, adjusted by rough factors, particularly in deriving tank-kill estimates. Thus they would seem to be poor indicators of relative force capability. At best, they might provide rough estimates of relative capability, if both sides possessed comparable force structures and employed similar artillery practices, since it is the lethal areas of fragmenting munitions that weigh heavily in the index.

It must be concluded that the new firepower indexes are extremely rough estimators. This feature in itself is not sufficient ground on which to condemn them insofar as they are used for modeling purposes

VII. DETAILED MODELS AND OPERATIONAL EFFECTIVENESS

A. THE MILITARY PRODUCTION FUNCTION

The principal shortcoming of the firepower-index concept is its linear quality. This assertion means that the output derived from any of the inputs -- e.g., a given type of munition -- is constant. Constant marginal returns are awkward for a modeling effort that treats large aggregations of diverse combat specialties, in a context in which there are latent questions of the force mix -- or, more accurately, the allocation of fiscal and manpower resources among those specialties.

It is awkward because constant returns (or marginal products) for each of two or more inputs are another way of saying that each input is a perfect substitute in production for any other input. And, if this is true, the problem of optimizing the force structure is simple: Buy *only* the cheapest input. Hence, the force could be all machinegun squads, or 155-mm howitzers, or B-52s, and so on. The resource allocation problems suggested by the expression *optimum mix* would not exist, because no *mix* need be required at all.

Acknowledgment of the point that the marginal product of an input is not constant, however, raises the question of just what is the marginal product of a single input as a function of other inputs, and what are the marginal products of other inputs that may be substituted for it? If the answer to this question were available, then optimal allocation would be achieved by equating the ratios of marginal products to marginal costs of the respective inputs. The fundamental question that has to be answered is: What is the military *production function*? It might also be noted that if knowledge of the parameters of the production function were available, then the problem of constructing an index of combat effectiveness would be simple: the weighting factors for the diverse inputs could be derived from the marginal products themselves. But then why any need of an index number at all? Whatever else might be said about the firepower index, it sweeps most of the tough problems of military-resource management under the rug.

The subject can be illuminated by recourse to aspects of the formal theory of production encountered in economic literature. Essentially, the general mathematical form of the production function is:

$$P = f(x_1, x_2, \ldots, x_n), \tag{3}$$

when P represents the product and the x's are the various inputs. For our purposes, assume these inputs to be military specialties such as infantry, artillery, tactical aircraft, and so on.* (Let us put aside the question of precisely what constitutes the product.)

The objection to the firepower index's linear quality (assuming the index's value as an indicator of effectiveness or productivity) is an objection to the idea that a less general specification of Eq. (3) is:

$$P = \alpha_1 x_1 + \alpha_2 x_2, \ldots, + \alpha_n x_n. \tag{3.1}$$

As Eq. (3.1) stands, the independent variables are independent of each other, and the respective marginal products of the x's are simply the "α" coefficients. Specification that the independent variables are independent of each other means that the substitution elasticities between them are infinite. It is this case which says that a military force could be all one specialty.

An opposite case is also consistent with the linear condition, and is encountered in the application of linear-programming techniques to production management. In this case, it is assumed that to get any output,

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*For treating many problems that are the object of economic analysis, the inputs are specified in terms of the services of "factors of production," especially labor (L) and capital (K), which, logically, can be broken down into more specific inputs such as machines, tractors, and so on. Acquired ingredients like power and raw materials can also be specified as inputs. Similarly, one could specify the labor and the capital (weapons) for the infantry, armor, and other combat specialties, as well as procured inputs such as POL and munitions, in estimating military production functions. For a good general survey of production functio literature in economics, see A. A. Walters, "Production and Cost Functions: An Econometric Survey," *Econometrica*, Vol. 31, January-April 1963, pp. 1-66.

each of the inputs must be employed in fixed proportions as asserted by the ratios of $\alpha_1, \alpha_2, \ldots \alpha_n$ to each other. Here the substitution elasticities between inputs are zero. A military example is the assertion that the composition of a carrier task force must be two attack carriers, three frigates, six destroyers, and a specified logistics train.

It is generally recognized that most production processes are not linear in the sense postulated by either linear specification of Eq. (3.1). Rather, nonzero, finite substitution possibilities exist in the majority of cases. A frequently encountered example in economic literature of a nonlinear production function is:

$$P = Ax_1^{\alpha_1} x_2^{\alpha_2} \ldots x_n^{\alpha_n}, \tag{3.2}$$

where

$$\alpha_1 + \alpha_2 \ldots + \alpha_n \gtreqless 1$$

$$\frac{\delta P}{\delta x_1}, \ldots, \frac{\delta P}{\delta x_n} > 0$$

$$\frac{\delta^2 P}{\delta x_1^2}, \ldots, \frac{\delta^2 P}{\delta x_n^2} < 0.$$

The specification that the first partial derivatives (marginal products) exceed zero conveys the point that the practical problem is one of constrained maximization (as are all resource-allocation problems). The negative second partial derivatives capture what is meant by the so-called law of diminishing returns.*

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*The assumption in Eq. (3.2) that the exponents $\gtreqless 1$ captures the question of whether the activity exhibits "economies or diseconomies of scale." There is much controversy on this subject in economic literature centering around the *cause* of apparent economies or diseconomies, and much resulting ad hoc theorizing. One school of thought argues that any actual observed economies are due to the existence of "lumpy" inputs, improved technology, or inadequate identification of inputs or factors of production, or combinations of these. So-called diseconomies arise from inefficient management, which potentially can be avoided by decentralization, or from inadequate property-right specification that is responsible

Nonlinear production functions like Eq. (3.2) express in mathematical terms much of what military thinkers have been concerned with over the centuries. When Carl von Clauzwitz observed that an army should have a structure of one eight-gun artillery battery per 1000 to 3000 infantry and from 20 to 30 percent as much cavalry as there was infantry (with variations depending on relative costs and geography), he was both assigning specific bounds to the "α" coefficients in Eq. (3.2) and taking into account the relative costs of the combat specialties. When William Mitchell advocated air power, he was implicitly arguing that the "α" coefficients for battleships and coast artillery were considerably smaller than commonly believed. When present-day policymakers and analysts urge that we must find ways to reduce relative military-manpower costs by substituting capital equipment and weapons for labor, they are asserting some specific beliefs about military production functions. Specifically, they believe that rather high substitution elasticities exist between capital and labor, or capital-intensive force elements (e.g., tactical aircraft and artillery) and labor-intensive ones (e.g., infantry) or both.* The difficult problem associated with the production-function formulation, then, is to determine empirically what the relevant coefficients are. This problem is further complicated by the impact of changing technology.

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for perverse incentives affecting the use of certain resources or inputs. To specify that the sum of the coefficients can be unequal to one permits overlooking these kinds of problems, an assumption that is convenient for many theoretical purposes. However, to take a military example, it may not do to assume away such "lumps" as an air-defense warning net, or a command and control apparatus, and so on.

*In this case, the Equation 3.2 specification does not apply because its form asserts that the substitution elasticities are 1. This means that the relative shares in terms of dollar budgets allocated to any given input (the specialty) remain constant, given changes in the relative cost of inputs. The argument that there be greater substitution of capital for labor, to the extent that it entails spending relatively more on capital, seems to imply that the relevant substitution elasticities must be greater than unity, or that R&D effort can change the relevant parameters.

The effect of technical change alters the coefficients of the production function. The numerical values assigned in Eq. (3.2) to any one, some, or all of A, α_1, α_2, and so on, would differ from what existed prior to a technical change. How to estimate these changes can be as difficult as determining the coefficients of an existing production function. The techniques employed range from making deductions from the relevant physical or engineering equations to applying empirical methods, and usually some combination of these. In the civilian sector, trial-and-error methods are often used -- perhaps in a pilot plant. Both theoretical and experimental techniques are likely to be more fruitful when there is good knowledge about the existing production process. The field of agriculture is a good example of one where much empirical data about existing production functions exist and where, incidentally, rather modest R&D expenditures have provided numerous spectacular inventions and resulting shifts in production functions. Research and development applied to military matters, of course, is an attempt either to create new production functions or to evoke favorable shifts in existing ones.

Military exercises, maneuvers, troop tests, field trials, and studies, including combat and campaign modeling, can all be viewed as efforts to produce knowledge about the military production function. Campaign modeling, or analysis of the use of large force aggregations in a theater context, may further be viewed as an effort to generate assertions or insights about an aggregated military production function. It is also an attempt to address the modern counterpart of the "men, horses, and guns" question discussed in the previous section; but the subject is greatly complicated by the presence of opposing air forces and air defense systems. It is complicated further because continual injection of new weapons into the force causes the production function to shift in some unknown way.

To view the intertwined problems of determining the optimum force mix in the context of changing weapon technology in terms of production theory might display more sharply some critical aspects of general-purpose-forces study and modeling. The firepower or similar index as an indicator of force capability would seem to entail the linear assumption. The logical implications of this assumption may be avoided or mitigated, however, by numerous ad hoc qualifications that explicitly or implicitly change the weights assigned to different inputs. The weapons effectiveness indexes (WEIs) advanced by the Army's Strategic Analysis Group (STAG) in 1971 illustrate such an approach. That they rely on judgments to assign weights to weapon technical performance attributes (to define the WEIs), and on either judgments or relative costs of weapons to derive indexes for tactical units consisting of diverse weapons (WUIs), is regarded by many to be a shortcoming. For one thing, the resulting indexes are still linear; for another, the basis for determining the weights is not transparent. Hence, the problem remains of how to get some indicators of military marginal products that are relevant to the fighting end of the business.*

B. THE USE OF DETAILED MODELS TO ASSESS EFFECTIVENESS OF LARGE-FORCE AGGREGATIONS

Dissatisfaction with firepower and similar indexes has stimulated effort to model campaigns by using less aggregated approaches. Indeed, there is in the offing a new generation of campaign models in various stages of development,** all of which appear to have two common features.

The first is that they attempt to estimate casualties, damage, and attrition, and in some cases, suppression, of major groups of weapons against each other in the context of a large confrontation. This idea is illustrated by Table 10, which we label a "combined arms attrition

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*It should be pointed out that much information can be and is developed which is relevant to activities that provide "intermediate outputs," of which aspects of logistics support is the prime example. For example, the product of Eq. (3.2) can be specified to be some rate of flying hours or number of sorties. Determination of a production function can be a fairly straightforward endeavor. For a good example, see George F. Brown, Jr. and Arnold N. Schwartz, *A Study of Aviation Resources and Readiness Relationships*, Vol. 2, *A Ready-Hour Production Function for Naval Aviation*, Center for Naval Analyses, Institute of Naval Analyses Study 32, June 1970. But when we focus on combat effectiveness, the subject acquires its difficult coloration.

**See, e.g., S. Bonder, *Vector-0; A Hierarchy of Combat Analysis Models*; Dondero, *MEFORD*; and Lulejian and Associates, *Prototype of a Theater-Level Tactical Combat Model*, Vol. 2, *Model Logic and Equations*, Weapons System Evaluation Group, WSEG Report 227, February 1974.

Table 10

AN ILLUSTRATIVE COMBINED ARMS ATTRITION MATRIX

Red \ Blue	Infantry	Antitank	Tank	Artillery & Mortars	Helicopters	Tactical Aircraft	Air Defense	Logistic Support
Infantry	B, R	B, R	B, R	B	B, R	B		
Antitank	B, R		B, R	B	B	B	B	
Tank	B, R	B, R	B, R	B	B, R	B		
Artillery & Mortars	R	R	R	B, R	B	B		
Helicopters	B, R	R	B, R	R		B	B, R	
Tactical Aircraft	R	R	R	R	R	B, R	B, R	R
Air Defense		R	R		B, R	B, R		
Logistic Support						B		

matrix." The Table portrays, for example, that Blue's artillery and mortars can inflict damage on Red's infantry, antitank weapons, tanks, and artillery. Conversely, Red's artillery can produce similar effects on comparable Blue elements. (These interactions are indicated by the letters "B" and "R" in the respective corners of the relevant cells.)

Cells containing both an "R" and a "B" portray the established or especially intense types of engagements that characterize, for example, infantry firefights, flak suppression by aircraft, artillery counter-battery fires, etc. Where there is only one letter in a cell, relevant interactions between the opposing elements are, for the most part, one-sided. For example, it is unlikely under most circumstances that infantry would destroy artillery; consequently, questions regarding the effectiveness of infantry weapons and doctrine should be focused on how infantry can best deal with and destroy opposing infantry, tanks, etc.

A blank cell implies virtually no direct interaction or potential for mutual attrition.

Effort to model such a complex of activities in detail may, in one sense, involve a misuse of the word *model*. Perhaps a better description of what appears to be going on is that effort is made to *piece together* or somehow *to integrate* the outputs of *separate* models that treat in detail various subsets of engagements. Thus, in a given study, frequent reference is made to an "artillery model," a "combat-air-support model," etc.* Any single endeavor may also aggregate selected aspects of the subject. For example, TALLY/TOTEM aggregated the first four elements of Table 10 in TOTEM, which is essentially the firepower-index/ATLAS model, but employed a more detailed air-battle model (TALLY) to treat the last three elements. Similarly, an existing detailed air-defense and aircraft-penetration model (of which there are many) might be modified so as to make it compatible with a given integrated model. Similarly, a number of helicopter-combat models have been developed in recent years, and choices are available among these.

Table 10 should not be construed to suggest the precise approach of any specific model, especially with respect to assessing interactions among groups of weapons. For example, the category "Air Defense" in Table 10 aggregates guns and missiles. However, if account is taken of forward-area air-defense systems that contain a high density of guns in the 14-mm to 57-mm regime, these can be useful in other combat roles. Moreover, numerous other groupings are feasible, and various conceivable combinations provide a basis to sustain a large amount of modeling.

The precise way weapons or force elements are grouped and aggregated will also govern aspects of the techniques of analysis. *Technique* in this context refers to whether critical core parts of the analysis of combat relies mainly on stochastic or deterministic models. These different approaches are illustrated by the *hierarchy* approach, as pursued by the General Research Corporation, and the *Vector-0* set of models. Both of these study strategies, however, employ the same data base, which is the second common feature they and other current models share. That data base is the main one from which the improved firepower

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*See, e.g., S. Bonder, *Vector-0*, passim.

index is derived. A comparison of two current models can illustrate this point.

C. THE *HIERARCHY OF MODELS* AND *VECTOR-O* APPROACHES TO ANALYZING LARGER FORCE AGGREGATIONS

The *Hierarchy of Models* and *Vector-O* approaches differ in how they generalize about the effectiveness or marginal products of key combat elements — particularly maneuver battalions composed of diverse mixes of weapons -- to derive assertions about the contributions of any type of weapon in the larger context of a campaign.

The *Hierarchy of Models* approach relies on the ORO/RAC Carmonette (or a similar stochastic) model as its initial building block.* Up to 54 weapons, on both sides, in a platoon or company context (e.g., a platoon in defense against a company in attack) can be played with Carmonette, in a very fine-grained way. Its use to simulate the fire-fight entails, at a behavioral level, two major aspects. The first is target acquisition; the second is shooting and, it is hoped, getting a hit and damaging or destroying the target. The target-acquisition problem is handled in Carmonette by means of its terrain model, which generates line-of-sight opportunities, and by opposing weapon signatures as influenced by firing behavior. Crews and riflemen acquire targets.

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*Carmonette has had a long (and ongoing) gestation period. For its early version, see Hebron E. Adams et al., *Carmonette: A Computer Played Combat Simulation*, Operations Research Office, ORO-T-389, 1961. For a more recent version, see Norman W. Parsons, *Carmonette IV and Carmonette V*, Research Analysis Corporation, draft of RAC D12-CR, October 1972. And for an interesting recent application, see R. E. Zimmerman et al., *Equal Cost Firepower Study II (ECF:II)* (U), Vol. 1, *Main Report* and *Appendixes A* through *C* (U), Research Analysis Corporation, RAC-R-146, September 1972 (Secret).

It should be emphasized that the *Hierarchy of Models* approach discussed in the text does not necessarily have to be based on Carmonette. Other combined arms stochastic models can also serve. A prominent alternative is DYNTACS, which was developed to treat armor problems. For a description, see Albert R. Bishop and Gordon M. Clark, *The Tank Weapon Systems: Final Report*, U.S. Army Combat Developments Command, Armor Agency, Report AR69-4, September 1969.

They fire, in accordance with specified doctrine. The effects of fire are then deduced from input data such as P(K/H), time to fire upon acquiring target, probability of getting a hit for a specified range, time of flight of the projectile or missile, and time to fire a second round if the first round missed. Similar data are used for small arms or heavier automatic weapons, but applied to bursts when appropriate. Since the model is stochastic, a half dozen or more replications for each set of opposing weapons, conditional orders, weather and terrain conditions, and so on, must be undertaken. The model's outputs take the form of frequency distributions of kills, or other estimates regarded or judged to be proxies of effectiveness.

The results of the simulated Carmonette engagements are processed and employed as inputs to another routine called Commonex, which is keyed to the Lanchester paradigm.* Here, regression analysis techniques, for which Carmonette outputs are the inputs, are used to ascertain the coefficients for the differential equations that describe the rates at which opposing weapons or force elements attrit each other.

The results of Commonex are then used as inputs for a division battle model. The results of the division battle model are further extended, by means of regression analysis, to a larger theater framework. At higher levels of aggregation, such as the division or theater, the models are constrained by logistic considerations as influenced, for example, by theater supplies or air interdiction. By sufficient replications of the Carmonette/Commonex models, it is possible to estimate indexes of unit effectiveness. And, of course, there is no reason why the same outputs could not be used to estimate by multiple regression techniques the first derivatives and perhaps the scale parameters of production-function equations such as Eq. (3.2) above.

Vector-0 can be contrasted with the Carmonette-based Hierarchy insofar as it is deterministic and eschews the detail of Carmonette. Ground engagement takes place at battalion levels. Vector-0 recognizes

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*See G. M. Clark, *The Combat Analysis Model*, University Microfilms, Ann Armor, Michigan, 1969, pp. 139-210, for a development of this transition.

five weapon systems: armor, antitank weapons, riflemen not associated with special weapons, infantry -- automatic weapons, and infantry -- area fire weapons.* These five groups are aggregated into two distinct groups of three, depending on whether the engagement is armor- or infantry-intensive.** That is, in any given battalion sector, there is either an armor battle -- which, in turn, could involve either tanks and infantry on both sides or only infantry-manned antitank elements on the defending side -- or an infantry battle.*** In the infantry battle, battalion antitank weapons are apparently not engaged.

Within this framework, the engagement entails sequential target-acquisition and firing processes. Target acquisition involves determining line-of-sight (on the part of the model), acquisition, and selection (on the part of firers). Either of two target-acquisition and selection modes can be assumed: serial and parallel.**** It should be noted that this (or any other) target-acquisition model involves a number of implicit assumptions on the modeler's part of just what it is that stressed or fatigued combatants see, or think they see, in the context of a firefight.

With the selection of targets, a fire "model" is invoked. Specifically, two important equations (labeled "Markov fire") are employed, respectively, for armor and infantry engagements. For armor engagements, it is:*****

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*S. Bonder, *Vector-0*, p. 72.

**Ibid., pp. 81-82.

***To give an idea of the scale of the *Vector-0* ground combat routine, it is designed to handle ten sectors, consisting of up to ten segments each; a battalion-sized engagement can occur within each segment. (See ibid., pp. 4-5.)

****Ibid., pp. 85-107. The basic difference between these is that with serial acquisition, firers of a given weapon are assigned a priority target type, and upon destroying a target in that group the firer searches for another target of the same type; with parallel acquisition, the firer proceeds to fire at the highest priority target "among those presently under surveillance" (ibid., p. 102).

*****Ibid., pp. 221-225. There is also an equation for estimating personnel casualties produced by near misses against crew-served weapons.

$$E(T) = t_1 - t_h + \frac{t_h + t_f}{P_K} + \frac{t_m + t_f}{p}\left(\frac{1 - U}{P_K} + U - P_1\right) \qquad (4)$$

where

$E(T)$ = mean time to kill,

P_K = probability of getting a kill given a hit [called P(K/H) in this Report],

P_1 = first round hit probability,

p = conditional probability of a hit given the preceding round missed target,

U = conditional probability of a hit given preceding round hit target,

t_1 = mean time to fire first round after decision is made to engage a particular target,

t_h = mean time to fire a round given preceding round was a hit,

t_m = mean time to fire a round given preceding round was a miss, and

t_f = projectile flight time.

For automatic weapons and infantry combat, the equation is:*

$$E(T) = t_1 - t_b + t_b\left(\frac{1 - S_1 + S_2}{S_2}\right) \qquad (5)$$

where

$E(T)$ = mean time to kill,

S_1 = probability of kill on the first burst,

S_2 = probability of kill on each subsequent burst,

t_1 = time to fire the first burst after a decision to engage is made, and

t_b = time between subsequent bursts.

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*Ibid., p. 227. There is also an equation for "area weapons," which would presumably apply to launched grenades or beehive munitions.

To the extent that the word *methodology* treats the subject of just how models "A," "B," "C," and so on are structured -- in terms of their respective levels of detail or aggregation, the behavior propositions implicit in either their equations or sequential computer routines, the ease with which they permit the user to reallocate such resources as artillery fires or aircraft sorties, the amounts of computer time they absorb, and so on -- comparisons of the Hierarchy of Models and Vector-0, as well as other approaches, can be the object of much discourse. With regard to the Hierarchy approach, some critics might object to Carmonette, perhaps, because it does not permit adequate mobility for, say, tanks. A response to this objection might be to substitute an alternative stochastic model, or to refine Carmonette to rectify the alleged deficiency. With regard to the Vector-0 approach, there might be objections about some of the assumptions employed apparently to facilitate use of its equations. One such assumption is that infantry antitank weapons are stationary when in the tactical defensive mode. This and similar problems can no doubt be handled during the post-prototype stage.

But, however much these detailed models may be modified, either by finer-grained tuning or different aggregations, a problem still prevails: How valid is the detailed engagement model -- whether it be stochastic like Carmonette or deterministic like Vector-0 -- with respect to the estimates of kills it generates? This question can be raised because of two underlying questions, one of which involves behavioral relationships and the other, the relevance of the data inputs. First, how valid are the behavioral relationships postulated by equations such as (4) and (5), or those implicit in routines of a stochastic model? Second, given the point that these detailed models have been tailored to employ data emanating from technical sources and that some of these data have unknown relevance or empirical validity, what is the validity of the results of models that utilize such data -- even if behavioral relationships of the models should be "correct?"

D. SUMMARY

Firefight or engagement models may be regarded as an effort to provide some information about military production functions. Any detailed model can provide only partial indicators about a more aggregated production function. How to integrate many such partial indicators is now being explicitly addressed, and this is a healthy development relative to the use of aggregated index numbers.

However, firefight or engagement models posit at least three distinct sets of behavioral relationships. They are target acquisition (including identification and selection), firing and hitting the target, and damage assessment given a hit. Entailed in the damage assessment is the important matter of how combatants perceive that a hit target is "destroyed," at which they proceed to acquire another target. Each of these activities is treated somewhat mechanically, as suggested by the conditional probabilities of stochastic models. The data inputs for the acquisition phase -- given whatever line-of-sight constraints are built into a simulation by a terrain model -- are obscure. The consequences of firing are governed by "hit probabilities," which in turn are usually deduced from physical equations, with account also taken of loading and weapon-laying time. Kill probabilities given a hit are of unknown relevance and empirical validity. Refinements of "interactions" may be introduced to evaluate "doctrine," as illustrated by the alternative modes employed in Vector-0. In some instances, aiming errors, which are generally unknown, are thrown in and varied in accordance with the analyst's doctrine of "sensitivity analysis."

Whether an engagement model is stochastic or deterministic, it is tailored to readily available data -- specifically, hit probabilities as deduced from interior and external ballistics sources, and conditional kill probabilities. Psychological models regarding visual processes, plus estimates of times to aim or to adjust ranging instruments, constitute ingredients for target acquisition. How relevant these latter models of visual processes are to what combatants perceive may be as open to question as, say, the relevance of the conditional kill probability estimates. Given the uncertainties that becloud these data, the availability of which has also governed the way the models have been structured, a further question arises: How valid is any particular model?

When the question of model validity is raised about a deterministic approach such as the one employed by Vector-0, a comparison of its outputs with the results of a stochastic model can be offered.* Such a comparison then raises the question of whether the stochastic model is valid. But the question of model validity will remain obscure when the data inputs employed by the stochastic model may be either inadequate or not relevant. That is, a good or valid stochastic model might be rejected because its results are not credible. The lack of credibility may be due to the data fed into it. Or it may be due to a faulty structure.

Is there any way of disentangling these two unknowns, or understanding anything about their magnitude?

Until better understanding about the anatomy of engagements is available, it is unclear what validity prevailing stochastic engagement models have. To suggest that a deterministic model is valid because its results compare favorably with those of a stochastic model may thus be stretching a point. The nature of this overall condition arises from what we label the "operational effectiveness problem." An illustration of it and how it may be better coped with is the subject of the next section.

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*See Seth Bonder and John Honig, "An Analytical Model of Ground Combat: Design and Application" (Unclassified) in *Proceedings, 27th Military Operations Research Society* (U), June 1971 (Secret), pp. 73-104, esp. pp. 84-94.

VIII. THE OPERATIONAL EFFECTIVENESS PROBLEM AND OPERATIONAL TESTING

A. INTRODUCTION

The operational effectiveness problem may be illuminated by the following paradox: Why is it that each war casualty, on the basis of whatever rough estimates one might employ to allocate casualties between bullet and fragmenting munitions, seems to require thousands of rounds of small-arms ammunition and tons of artillery ammunition? For example, it has been estimated that in the Anzio beachhead action, from which German 14th Army casualty data are available, 500 to 900 pounds of small-arms ammunition (11,000 to 16,000 rounds) and 7000 to 8000 pounds of fragmenting munitions were required to produce a German casualty.* Performance in Okinawa was better: Only 118 pounds of small-arms and 2000 pounds of fragmenting land-armaments munitions were needed per casualty.**

The paradox these kinds of figures suggest arises when they are compared with theoretically derived hit and kill probabilities and lethal area estimates. The large discrepancy between lethal-area and tank- or vehicle-kill estimates, on the one hand, and casualties actually produced, on the other hand, reflects what may be called *operational degradation*. It is known how ordnance terminal effects may be degraded by terrain masking, foliage, and changes in troop posture given the munition's signature. High leakages can also occur due to errors in target location, range estimation, and deflection. For direct-fire weapons, aiming error, imperfect target-acquisition ability, and other factors affect the probability of getting hits.

Indeed a case can be made that hit probability is a poor measure, if not a "nonmeasure," of effectiveness. At best, it might say something

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*See L. VanLoan Naisawald, *The Cost in Ammunition of Inflicting a Casualty*, Operations Research Office, ORO-T-246, July 28, 1953.

**Neither estimate takes into account aircraft-launched munitions or naval gunfire.

about ability to economize on ammunition expenditure. Hit probabilities, based on ballistic equations, are one of the principal inputs employed to deduce weapon performance in detailed models. But, even as data input for an elaborate equation or stochastic routine, it may be irrelevant or relevant in an unknown way. Another way to get at the problem of measuring effectiveness is by operational testing. Development of this approach and some of its implications can be illustrated with respect to infantry and tank systems.

B. INFANTRY SMALL ARMS

An appropriate measure of weapon effectiveness is one that takes into account the ability of a weapon system -- such as a rifle squad or a tank element, viewed as a tactical unit -- to acquire and engage enemy target systems and to obtain hits or near misses on those targets as a function of time. Subsumed in this kind of measure could be (1) the ability to acquire a target and to slew, point, and fire one's weapons rapidly, (2) the minimization of obfuscation and distraction on the part of friendly firers so as to permit keeping an acquired target under surveillance, and (3) weapon and ammunition reliability, as well as other factors. With small arms, the signature of one's own weapons should be minimal so as to reduce the likelihood of friendly firers being acquired as targets. Recoil and muzzle blast of small arms can distract and thereby reduce the effectiveness of the troops using them. Seemingly minor design features can have possibly important effects. For example, a notched as compared to a ring machinegun sight can mask the gunner's view short of his aiming point. Or, one can have a tracer ammunition which the firer cannot detect in daylight, although it can be seen by someone standing a few feet from the weapon and by the enemy.* These and other factors affect system performance.

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*Such appears to be the quality of the present U.S. standard trace, which is pink instead of the yellow that was standard with the older .30 caliber systems. The use of tracer ammunition entails some of the finer points of machinegun tactics and countermeasures, and bears upon the subtle but important issue of the relative importance of casualty production and suppression as objectives of fire. For example, it was an old German trick for one gun of a two-gun team to fire high with tracer ammunition to lure opposing infantry to move, but for the other gun, firing only ball, to fire low and thereby produce casualties.

It might be attempted to model the detail of these relationships. But a problem exists because we do not possess adequate knowledge to assess the relative importance of the large number of variables or their interactions. With small arms, however, it is possible to bypass these difficulties by testing systems in a setting that tries to approximate the operational environment.

One such experiment was conducted during the winter of 1965-1966 by the Army Combat Developments Command, Experimentation Command.* Instrumented target arrays consisting of weapons simulators and of pop-up and -down silhouettes of standing, kneeling, and prone soldiers were laid out in tactical arrays, on three ranges. Targets were programmed by an on-line computer to simulate nine different tactical scenarios, six for rifle squads, three for machinegun squads. Targets were instrumented to record hits in real time and to go down when hit. For three of the rifle squad and two of the machinegun scenarios, acoustic or camouflaged panel sensors recorded in real time misses within six feet of an individual target. The purpose of measuring near misses was to get a proxy measure for "suppression" and to obtain more comprehensive data on fire distribution. Different squad mixes (composed of a sample of six squads for each mix) equipped with major families of weapons -- e.g., M16, U.S. 7.62, and AK47 -- were played in each scenario.

The ability to program target behavior and to record hits and near misses in real time permitted measuring not only target hits, but also the timing of hits. Thus, it was possible to conceive a measure that was called "cumulative exposure time" (CET), which along with near misses, constituted measures of fire effectiveness. The essential quality of cumulative exposure time was as follows.

In each tactical situation, the pop-up targets and weapon simulators were programmed for a given scenario. In the day defense situation, for example, 50 pop-up targets were employed and exposed in such a fashion as to simulate an attack, supported by fire from machineguns. The length of the scenario was about six minutes.

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*See *Small Arms Weapons Systems (SAWS)*, Part 1, *Main Text*, and Part 2, *Appendices*, U.S. Army Combat Developments Command, Experimentation Command, May 1966.

The 50 targets, in the aggregate, were programmed to be exposed for a total of about 15 minutes. A given single target might be programmed to be exposed an aggregate of two minutes during the scenario, at 20-second intervals, for 15 or 20 seconds per exposed interval. But if that target, when exposed, was acquired and hit within 10 seconds, it would go down and not come up again. Thus, the objective function was to minimize the cumulative exposure time of a target array.

If a given squad acquired few exposed targets and failed to hit any that were acquired, its cumulative-exposure-time score would be the maximum 15 minutes for which the individual targets were programmed to be exposed. To the extent that targets were quickly acquired and hit, the recorded cumulative exposure time would be lower. In this fashion, account was taken not only of the number of hits, but also of their timing. Thus, it was possible for squad A to hit more targets than squad B, but for squad B to have a better score because it got its hits quicker. It is implicit in the specification of cumulative exposure time as a primary effectiveness measure that squad B is superior on the ground that by reducing more quickly the enemy's exposure time it is subjected to less fire and hence fewer casualties. This measure might also be regarded as a proxy for survivability, or it can be held that as an effectiveness measure it encompasses survivability.

Near misses, within a two-yard sphere of the target, were obtained in three of the rifle-squad situations and two of the machinegun situations. For purposes of scoring weapon systems or mixes of weapons, total near misses were used for each situation. However, time plots of near misses were recorded, the visual inspection of which revealed that no anomalies resulted from using total near misses as an effectiveness measure. For example, if system A could get more near misses than system B, but system B could do better early in the scenario, it would be a matter of judgment or further analysis to determine which system was preferred in a particular tactical situation.

The final effectiveness measure was "sustainability." The primary determinant and measure of weapon sustainability is the length of time during which a unit with a basic load of ammunition could have sustained an achieved level of fire effects. Each squad member was constrained by a weight limit that applied to both the weapon and the ammunition. For riflemen, this was 17 pounds; for automatic riflemen and machinegun crews, it was 33.1 pounds. Because different weapons and their ammunition had different weights, this constraint meant that the basic load of ammunition could vary -- from 100 rounds for one system, to 300 rounds for another, as in the case of riflemen. The specific measure of sustainability selected was the percentage of a squad's ammunition remaining, where squad starting-system weight, tactical situation, and firing time are held constant for all squad mixes.

If one squad weapon mix used 50 percent of its ammunition load to attain a given level of effects, it would have less sustainability than a system that attained the same level of target effects with an expenditure of only 30 percent of its ammunition. To ensure getting independent measures of the three effectiveness criteria, the scenarios were made sufficiently short so that the system that would normally be the first to run out of ammunition did not, in fact, run out.

Table 11 shows the performance of four of the squad mixes tested, as measured by these criteria. Two of these -- the M16 and AK47 mixes -- provide the closest approximation to U.S. verses Soviet dismounted infantry capability. The mix consisting of seven M14s and two M14Es approximated the standard pre-M16 U.S. infantry squad equippage, for which the M14E2 was designed to supplant the old BAR when it became apparent that the M14 was inadequate to fire automatically because it was too light relative to the muzzle impulse of the NATO 7.62-mm round.

Table 11 suggests that the M16 is slightly better than the AK47 in Cumulative Exposure Time (CET), substantially better in producing near misses and hence suppressive effects, and between two and three times better in sustaining these effects in the course of a firefight should the soldiers be limited in ammunition-carrying ability. These qualities, if placed in the context of a two-sided firefight, would imply an even greater advantage for squads equipped with M16s, since the timing of producing effects figures in relative casualty production

Table 11

EFFECTIVENESS MEASURES FOR SELECTED INFANTRY SQUAD WEAPON MIXES FOR SIX TACTICAL SITUATIONS

Tactical Situation	Infantry Squad Weapon Mixes			
	7 M14s & 2 M14E1s	9 M14s	9 M16s	9 AK47s
	Cumulative Exposure Time (minutes)			
Assault	24.1	25.5	25.8	26.1
Base of Fire Supporting Assault	80.0	77.5	78.2	85.1
Approach to Contact	2.06	2.04	1.97	2.05
Base of Fire Supporting Approach to Contact	42.5	40.2	42.6	43.2
Defense Against Day Attack	6.3	5.4	5.2	6.1
Defense Against Night Attack	6.8	6.8	6.7	7.4
	Number of Near Misses			
Assault	315.5	312.8	393.8	324.4
Base of Fire Supporting Assault	312.0	259.0	323.0	173 0
Base of Fire Supporting Approach to Contact	106.2	130.3	121.5	119.0
	Sustainability (% of ammo remaining)			
Assault	45.2	47.5	72.2	39.2
Base of Fire Supporting Assault	10.3	22.0	50.5	36.0
Approach to Contact	71.7	78.7	80.8	75.8
Base of Fire Supporting Approach to Contact	54.4	60.3	84.8	55.9
Defense Against Day Attack	50.1	72.5	77.1	59.1
Defense Against Night Attack	43.7	46.0	68.6	31.9

SOURCE: *Small Arms Weapon Systems*, Part 6, pp. 5, 16, 18, 23, 41, 51, 55.

and survivability of the friendly elements. But these possibilities require a more careful analysis whereby the separate relative squad performances are modeled in a platoon context and in terms relevant to sequential scenarios. For example, a successful assault is often followed by an enemy counterattack. For this combination, examine the relative performance of the squads as shown in Table 11, and note especially the ammunition remaining to a squad *after* it has completed its assault. This amount constrains the ability to fight off a counterattack, and indicates a situation where the data on defense would apply.

If one were to examine hit probabilities generated from this experiment, one would find that the M16 would not look as good as the AK47, or even the M14. Yet hit probability has been the principal input employed in most of the prevailing modeling undertaken on the subject. If one set out to model an infantry firefight using, say, a separate target-acquisition model and the Markov fire model (Eq. 5, p. 90), it would be possible to arrive at a variety of conclusions depending on how a model-builder chooses to view the subject, and the data source used.

When "hit probability per burst" is used, does it include an aiming error? If so, what is it; is it the same for all weapons? This point can be debated, and perhaps "resolved" by sensitivity analysis. Would account be taken of the point that the larger muzzle blast of an M14 might have a different distracting effect upon a companion in a group context than the muzzle blast of a lighter weapon? And how might the recoil of different weapons, their different sighting systems, and their malfunction rates, as well as the ground strikes of different sized bullets and their burst size, affect target aquisition or surveillance? Even to try to take account of these and other subtle interactions, which may be of different magnitude in varied tactical situations, would leave open the problem of judging their magnitudes and in some instances the arithmetic sign that might be assigned to these variables or related to the different weapons.*

*For example, it was speculated that the M16, because of its elevated sights, would not be as good in "pointed fire" as was a more

But, whether one uses a stochastic model or some set of deterministic equations, the approach may take either inadequate or no account of such subtle interactions, or it may easily lead itself to speculation about its consequences.

The small arms experiment cast some light upon, or at least raised a question about, some long-standing issues that have prevailed in infantry circles. One of the questions centered around the value of automatic rifles, such as the old BAR and the recent M14E2. The automatic rifle (BAR) is given a score of 3 in the 1958 *Maneuver Control* field manual, and 4 in the 1973 version, in contrast to a score of 1 for a rifle (M14 or M16)* in both versions, where all scores refer to 300-meter range. In the assessments of the relative capability of U.S. and Soviet infantry units, to derive indexes for the TACSPIEL war game, a rifle was given a score of 1, and both automatic rifles and machineguns were given a score of 3. Thus, the two M14E1 automatic rifles and six M14 semiautomatic rifles in the U.S. infantry squad would obtain a score of 12, versus a score of 10 for a Soviet squad composed of one light, belt-fed machinegun and seven AK47 rifles capable of fully automatic fire. For eight weapons in each case, the U.S. side was therefore given a 20 percent margin of superiority in the assessment developed for the TACSPIEL war game.**

There are a number of subtleties of infantry tactics that center around the use of special automatic weapons in a "base of fire" role; the field experiment was not intended to address all of these. However, it did compare rifle squads equipped with and without traditional automatic rifles. With regard to the assumption that one automatic

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orthodoxly shaped weapon that permits sighting down the gun barrel (as is practiced with trapshooting). In the "approach to contact" situation (see Table 11), enemy ambushes at close distance were simulated, and the firing doctrine was that of "pointed" rather than "aimed" fire. The hypothesis did not stand up.

*Although the ordinary M16 is capable of firing automatically, there is also a heavy-barrel version, which when equipped with a bipod, is intended to function as an automatic rifle.

**The U.S. infantry squad also contained two grenadiers equipped with M79 grenade launchers, the capability of which was assessed separately as part of larger units' indirect-fire capacity.

rifle is worth three rifles, compare the performance shown in Table 11 of the mix of seven M14s and two M14E1s with that of the nine M14s. For cumulative exposure time, in five of the six tactical situations, nine M14 semiautomatic rifles performed better than the rifle-automatic rifle mix; in near misses, the performance was a toss up; in sustainability, the nine rifles were superior. These results do not support the assertion that one automatic rifle is worth three rifles.

The relative worth of machineguns and rifles is a more complex matter, because riflemen in rifle squads and machineguns in machinegun squads perform distinct functions in the team context of an infantry platoon. Machinegun squads perform a base-of-fire mission when infantry squads maneuver. When mounted on a tripod in a defensive situation, a machinegun can maintain a field of fire over a predetermined zone that may not be visible to the gunner due to darkness, fog, or smoke. Yet rifle squads can perform certain machinegun missions, and vice versa. The feasibility of equipping every infantryman with a fully automatic rifle, thanks to lower muzzle-impulse weapons such as the M16 (or AK47), however, raises a question of whether separate machinegun and rifle squads really need be a feature of a platoon organization. Although a revolution in infantry tactics may not necessarily follow from such a basic change, there can nevertheless be opportunity for a richer range of tactical options and greater organizational flexibility.

The small-arms field experiment compared machinegun squads equipped with different weapons firing in both the tripod and bipod modes. This phase of the effort provided opportunity to compare rifle squads and machinegun squads in performing a base-of-fire mission. Table 12 compares the performance of an M60 machinegun squad, composed of seven men, firing in the tripod mode, with those of rifle squads equipped, respectively, with the ordinary and the heavy-barrel (e.g., "automatic-rifle") versions of the M16.

The latter concept was introduced into the experiment to test the hypothesis that the heavier M16 provided a useful degree of extra stability for longer firing bursts, and because the reduced wear

Table 12

EXPERIMENTAL FINDINGS FOR SELECTED RIFLE- AND MACHINEGUN-SQUAD MIXES IN PERFORMING A MACHINEGUN-SQUAD ROLE

Tactical Situation	Weapon Mixes: 2 M60 Machineguns (tripod)	9 M16s	9 M16 Automatic Rifles
	Cumulative Exposure Time (minutes)		
Base of Fire Supporting Assault	87.8	78.2	79.9
Base of Fire Supporting Approach to Contact	40.0	42.6	38.1
	Number of Near Misses		
Base of Fire Supporting Assault	273.8	323.0	426.0
Base of Fire Supporting Approach to Contact	198.5	121.5	268.0
	Sustainability		
Base of Fire Supporting Assault	41.8	50.5	38.6
Base of Fire Supporting Approach to Contact	69.3	84.8	34.7

SOURCE: *Small Arms Weapon Systems*, Part 1, p. 6-97.

afforded by a heavy barrel had utility for a squad whose mission was that of a machinegun squad.

These findings support the idea that rifle squads equipped with fully automatic rifles can perform some of the important functions of machinegun squads. In terms of fire effects, the performance of the rifle squads was better than that of machinegun squads.

These results do not necessarily support the idea that platoon machinegun squads be eliminated. They do, however, suggest greater substitution possibilities between these specialized infantry units than is currently believed. They also support the belief that lighter-weight infantry weapons possess a potential for innovation in tactics and organization. A more thorough evaluation of the possibilities would, of course, entail taking into account different grenade-launching systems, as well as different mixes of bullet and grenade fire. As increased insights (and data) are generated about squad and platoon weapons mixes, attention should be extended to company-support weapons, and so on. The interrelated analytical and experimental endeavor could lead to a new infantry "production function." At a minimum, it should enhance making judgments about the relative capabilities of units that are differently equipped and organized.

C. SOME UNKNOWNS BEARING ON TANK GUNNERY

Tank gunnery entails at least three kinds of firing: the use of the main armament against (a) tanks and (b) "softer" targets, and the use of two kinds of secondary armament against (c) personnel and other soft targets, such as helicopters. Both the tank commander and the gunner acquire targets and shoot. The driver's responsiveness to commands and hence skills might also influence some aspects of the activity. To list these three kinds of firing should not be construed to mean that there are always three separate target acquisition problems. Rather, there is often a problem of judging something about an acquired target, and then deciding what firing "doctrine" to employ.

Even this description fails to capture adequately other subtleties of the subject. Sometimes shooting at *likely* enemy antitank positions is practiced; tracer ammunition bounces off concealed enemy tanks to provide target cues. During World War II, U.S. tankers often fired phosphorus rounds to becloud the vision of enemy gunners who enjoyed a range advantage; this tactic provided some time to scramble to get within closer range and thereby to take advantage of the superior tank-turret slewing rate that friendly tanks enjoyed. In effect, target acquisition, target selection, firing, and countermeasures appear to be closely intertwined in the tank gunnery business. The list of variables -- which could be classified under such subheadings as "technical," "physical," "nontechnical," and "tactical" -- that would have a bearing on effectiveness might be embarrassingly long. Is there a priori any reason to believe that the variables listed for Eq. (4) are the relevant ones? If not, is there any independent evidence that the ones selected are, in fact, the relevant ones? Indeed, what evidence can be uncovered that suggests a possibly different conclusion?

In 1953, an extensive "shoot out" -- Project STALK* -- was carried out at Camp Irwin, California. This experiment seems to underlie much of the currently used data. But the results of the STALK experiment were controversial. It was essentially a "tank-versus-tank" experiment, and for certain purposes served to verify and modify theoretical hit probabilities derived from engineering data. The experiment also cast up numerous additional questions. For one thing, it suggested that neither training, as measured by then existing standards of crew proficiency, nor different equipment combinations, e.g., fire control and ranging, revealed any effectiveness differences as measured by hits, which were also a function of crew reaction times. These test results were the object of subsequent controversy centering over the test design. The controversy was not, however, resolved by more pointed testing. In the late 1950s, a less well-designed test suggested that tank sections and platoons distribute their fire poorly against enemy tanks. More than one tank fires at a single opposing tank, and that fire continues to be directed at a tank which is hit. What does this

*For a brief description of the STALK experiment and a detailed statistical analysis of its results, see David C. Hardison et al., *A Partial Analysis of Project STALK Data with Results of Single Tank vs. Single Tank Duels*, Ballistic Research Laboratories, Technical Note 980, February 1955.

behavior imply for models that posit such refinements as "serial" versus "parallel" acquisition modes?

Another test -- Project PINPOINT* -- was designed to measure the ability of tank crews (in an overwatching position) to acquire targets by means of target weapons signatures and to identify enemy tanks as contrasted with recoilless-rifle infantry antitank weapons. The results suggested that this kind of identification was not performed well. This deficiency suggests that crews should obtain training on the subject; such training could lead to better distribution of fire, as well as to more rational selection of ammunition to fire. But just how to train crews may itself be a matter requiring experimentation.

Given the many unknowns about tank gunnery, but including some of its established subtle features, a case might be made that to try to model the subject a priori is overly ambitious. Perhaps a better way both to get richer data about the activity and to gain insight on how to model it is to undertake a field experimentation program. Sections of from, say, three to five tanks could fire at various numbers of simulated enemy targets, which are realistically programmed to behave like and to emit signatures resembling those of their combat counterparts under varying conditions of terrain, movement, and visibility, using scenarios involving different tactical situations. Regular GI tank crews, trained in both existing doctrine and experimental, alternative doctrines, should man the tanks. The number of targets hit within a given time would be one measure of effectiveness. Similar experiments could also be conducted against simulated personnel and crew-served weapon target systems, to derive antipersonnel target effectiveness of vehicle systems.

D. SUMMARY OF THE OPERATIONAL EFFECTIVENESS PROBLEM

Although many production processes have common features and pose similar problems, as suggested by such words as *queuing*, *scheduling*, and *allocating*, virtually every production activity has its peculiar anatomy.

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*John P. Young et al., *Project Pinpoint: Disclosure of Antitank Weapons to Overwatching Tanks*, Operations Research Office, ORO-T-362, 1958.

The anatomy of most civilian-sector production operations -- collecting tolls at the turnpike, feeding baby chicks, and so on -- is either sufficiently transparent, or it is repeated with such frequency as to become transparent to the interested observer. Operational research or statistical techniques can then be applied. Effectiveness measures or surrogates for them can also be specified rather easily -- although there is always some risk of suboptimization. But, by applying any new program gingerly and experimentally, even that risk can be minimized. Nor does the larger activity's aggregated production function necessarily have to be perceived. Brooding baby chicks and collecting their eggs six months later are distinct operations whose respective structure can be readily grasped.

Current attempts at detailed combat modeling in certain respects resemble an effort to model, say, poultry raising, without a clear idea of the operation's anatomy or structure, and where the modeling effort is constrained by the availability of only specific kinds of data. The combination of these conditions would seem to preclude the possibility of making assertions about the poultry-raising production function.

Standard computer-simulated firing engagements generally posit at least three models -- target acquisition and selection, firing, and damage assessment. They implicitly entail a feedback from damage assessment as perceived by fighters to a subsequent round of target acquisition and selection. Each of the models often generates inputs for another model. However, it is difficult to believe that the three or more sets of activity are not interrelated in obscure ways and that these interrelationships do not differ importantly in different kinds of engagements. An illustration of this kind of interrelation is the "serial correlation" obscurity affecting automatic-weapon fire against flying aircraft. The behavior of the second burst is not independent of the first, and so on. But does a succession of bursts converge, diverge, or behave randomly with respect to hitting the target? Knowledge of this phenomenon might be important with respect to training gunners and to specifying weapon characteristics. The phenomenon of "target fixation" on the part of strafing pilots illustrates a further complexity about target acquisition and firing. It is also evident with infantry machinegunners; hence, the assistant gunner plays a critical role in target acquisition. Many similar interactions can be listed with respect to different kinds of engagements, and the ideas and opinions expressed at a conference of thoughtful people who have been under fire would probably fill a catalogue. Some of these interdependencies may be of no moment; but others -- who knows? Operational testing offers possibilities to make the anatomy of some aspects of combat operations more understandable. It is also a way of testing detailed models like Carmonette, or deterministic equations like those in the Vector-0 model.

It might be asserted that a great distance exists between whether a viable conventional option exists in NATO, on the one hand, and whether one's machinegun design and tactics are optimal, or what is the best-suited tank fire control system, on the other hand. Yet, there is a connection. Unfortunately, however, the connection is implicit when it is assumed that more costly and "technologically superior" weapons provide a way to offset a possible opponent's larger numbers of weapons. The assumption, in some cases, may be correct. In others, it may not. What is distressing, however, is that there is presently very little basis upon which to validate the assumption as it applies to many systems, combat elements, and operational procedures. Models based on firepower scores or engineering data, especially after several cycles of weapons developments, will usually tend to support the idea that the more costly weapons provide a qualitative edge.

Yet, if weapons are designed with poor information on how their incremental technical performance provides better combat capability, the hypothesis that a superior technology provides qualitative improvement is contestable. Most recent and existing modeling, however, supports a contrary view. Operational testing is one way to evaluate the hypothesis critically.

Thus, if enough testing were done -- and it would have to be undertaken as an ongoing process -- it should be possible to come up with estimates of *small-unit* relative capabilities similar to the hypothetical numbers shown in Table 13. Such estimates should be based on measures such as those recounted in the previous description of the small-arms field experiment.

Table 13

HYPOTHETICAL U.S. CAPABILITY AS A RATIO OF THE OPPONENT'S CAPABILITY FOR COMPARABLE UNITS, BASED ON OPERATIONAL TESTING

	Relative Effectiveness
Dismounted Infantry	
Defense, Platoon	105
Meeting Engagement, Platoon	100
Assault, Platoon	110
Tank versus Tank	
Assault, Section	120
Meeting, Section	130
Defense, Section	100
Aircraft versus Tank Element	130
Infantry versus Tank	
Battalion, Company	100

It might be contended that it is doubtful that the testing would lead to evaluations such as those in Table 13. The basis for this doubt is twofold. One is that the measures selected may not be relevant. However, the question of relevance is often in the beholder's mind. But this issue cannot be addressed in the abstract. Rather, it is one of whether, in the case of a particular system, as illustrated by the small-arms experiment, a measure such as hit probability derived from either a ballistic equation or from firings at a fully visible target on a known-distance range is better or worse than the measures of cumulative exposure time and near misses when the shooting was done by regular troops against targets designed to appear and behave like tactical target systems. Similarly, the subject of pilot target-detection capability -- at various stand-off ranges and types of target complexes and under different degrees of lighting, terrain coverage, and degrees of pilot training -- is a subject of no small importance and one that is susceptible to empirical methods.

It is also possible, as an aspect of conducting this kind of testing, to improvise existing systems (or target systems) to simulate critical performance characteristics of contemplated new systems. Thus, the question, for example, of how much does an increment of acceleration for a tank really confound opposing gunners might be addressed.

In many instances it might be discovered that increments of or differences in effectiveness, such as those portrayed in Table 13, cannot be discerned at all. But this is useful information whenever there are differences in the cost or performance characteristics of opposing systems. A strong case is thus established to opt for the cheaper system and to use the saved resources for other purposes, such as larger numbers or, perhaps, more advanced training of crewmen.

An objection to operational testing, which is nevertheless controlled in accordance with some experimental matrix, is that the experiment itself is a model. It is therefore unrealistic, as is a computer-simulated mathematical model, particularly because the subjects doing the shooting, target acquisition, or flying are not getting shot at. Moreover, there are constraints on the activity because of safety. The points are valid, and coping with them poses a challenge for experimentalists.

That the troops are not getting shot at can cut two ways. The primary effect of getting shot at is that the individual is under stress. It should be realized that participation in a field trial, particularly when the individual has not seen the simulated target system, itself evokes stress. To what extent this degree of stress approximates that of actual combat is unknown and probably varies greatly among individuals and as a function of training. Some individuals perform better when stressed; others, worse. And getting shot at may cause certain individuals to behave in surprising ways. Yet the fact that a well-designed experiment exposes individuals to a degree of stress not encountered in a maneuver or on a training or proving ground is one of its virtues. That it cannot possibly replicate the effects of being fired at means merely that there is no substitute for the real thing. But it is not clear what the relevance of this observation is. One answer might be that if measured performance is less sparkling in a field trial than might be suggested by an unverified mathematical model, then comparable performance in real war will generally be even more degraded. What this means with regard to actual productivity in war is worthy to ponder.

It should be emphasized that controlled operational testing need not be confined to live firing activities, as the examples treated in this section might seem to suggest. The activities of moving, acquiring and processing intelligence, and acquiring and locating targets are also critical to operational effectiveness. Substantial resources are put into sensors, communications, and so on. Many of these can be tested in a field context, but with controls that permit measurement of effectiveness attributes. Ground-surveillance radars and night-vision devices are good examples of equipment that can be so tested. The charge that crude firepower scores are "one dimensional" is correct. Yet detailed modeling of the other dimensions of military operations, when the modeling is based almost solely on a priori methods, does not seem likely to overcome the shortcoming of crude firepower scores.

IX. ISSUES OF FORCE STRUCTURE, THE AGGREGATION PROBLEM, AND NET ASSESSMENT

A. INTRODUCTION

An objection to the idea that simple models be keyed to and validated by operational testing or other empirical work is that these models can treat only narrow sets of engagements, such as infantry versus infantry, tank versus antitank, and so on, and that their information falls short when questions arise about larger aggregations of different combat specialties and resource allocation among them. One of the objects of this section is to examine this argument.

The subject of major force-structure allocation acquires a special dimension, given the possibility that opposing forces can possess markedly different structures -- with respect to both major combat specialties and their capital and labor intensities. For example, Blue can outclass Red in both numbers and quality of tactical aircraft, whereas Red can outnumber Blue in tanks. Such discrepancies confound the task of assessing relative military capability. They pose a difficult aggregation problem insofar as there is no single metric, like the pre-World War I division or battalion counts, which provides both a comprehensible and roughly adequate estimate of relative military capability. The firepower index can be regarded as an attempted surrogate for such a single measure.

The newer campaign models avoid using such a gross measure. However, their reliance on unvalidated detailed combat models, or deterministic equations, is cause to have reservations about conclusions they might produce. These efforts do have the merit of attempting to address head-on the subject of tradeoffs among weapon systems.* Nevertheless, a two-fold problem remains: How should forces composed of diverse combat elements be counted or measured, and what might such counts mean with respect to both assessing capabilities and

*See Memorandum to Distribution List by Lt. Gen. Glenn A. Kent, in S. Bonder, *Vector-O*, p. 1.

allocating resources among different combat specialties? More to the point: How can the techniques of quantitative methodology -- including modeling and empirical methods -- provide help?

B. A PRODUCTION-FUNCTION PERSPECTIVE ON THE SUBJECT

A sharper perspective of force structure allocation and net assessment may be provided by posing aspects of these subjects in terms of production-function terminology. Essentially, there exists some sort of aggregated conventional-forces production function, such as:

$$P_{agg} = f(P_i, P_a, P_t, P_{ta}, \ldots, P_n). \qquad (6)$$

Here P_{agg} denotes aggregate product and the P's on the right side refer to the intermediate products of such combat specialties as infantry, artillery, tanks, tactical aircraft, and so on (as suggested by the subscripts i, a, t, and ta).

For any given combat specialty, its production function might be further specified in terms of specifically defined inputs, like the following for tactical aircraft:

$$P_{ta} = g(L_c, K_c, L_s, K_s, M, S_1 \ldots S_n) \qquad (7)$$

The Eq. (7) formulation is designed to convey what we call military labor (L) and capital (K), and with respect to these, to make a further distinction between combat versus support elements, indicated by the c and s subscripts, respectively. K_c encompasses weapons; K_s includes other items like spare parts, tools, construction and transportation equipment, and so on. In addition, Eq. (7) indicates civilian-produced inputs, like munitions (M), and diverse supplies and services like fuel, food, hired civilians, and so on ($S_1 \ldots S_n$). With respect to these latter civilian-produced inputs, one could, by examining the structure of the civilian activities providing them, estimate their respective labor and capital ratios.

By substituting Eq. (7) formulation into Eq. (6) and aggregating the respective L's and K's, one can derive an aggregation like

$$P_{agg} = f(L_{c_j}, K_{c_j}, L_{s_j}, K_{s_j}, M_j, S_j). \quad (8)$$

Here the j subscripts denote the different manpower specialties, weapons, purchased inputs, and so on.

It would be ideal to have for each of the combat specialties an exact mathematical specification of Eq. (6) and of the less general aggregations such as Eq. (7). It should be emphasized that Eq. (6) is nonlinear and multiplicative -- a point that everyone seems to agree upon, in view of the widespread usage of such expressions as *combined arms* and *joint operations*. However, such a specification is difficult to come by. Yet it should also be borne in mind that certain parts of the subject are tractable. For example, if we take Eq. (7), representing tactical aircraft, *productivity* can be defined as the number of sorties per period. Then we proceed to analyze both by study and exercises the magnitudes of P attainable from various mixes of L_s, M_s, and other procured inputs. Alternative mathematical specifications of this function can be tested, key parameters estimated, and some useful ideas of the important first partial derivatives are attained. But the difficult question remains: What is the contribution of the sorties in the more aggregated Eq. (6) context?

Attempts to ascertain qualities of the aggregated Eq. (6) and (8) production functions are complicated by technical change and military R&D. As sophisticated weapons and systems are developed and acquired -- perhaps over several or more acquisition cycles -- two changes occur. These can be illustrated by their application to the Army, which has been traditionally the least "technical" of the three services. First, the capital intensity, or the ratio of equipment cost per fighting man, increases. This development takes place in a rich variety of ways: Infantry battalions acquire surveillance radar sections, heavy mortars and antitank weapons, and armored personnel carriers; artillery units receive self-propelled guns and computerized data-processing systems; tanks become equipped with sophisticated fire-control gear; aviation densities increase, and helicopter gunships are first improvised and subsequently designed. Second, the sophisticated equipment necessitates more maintenance and support. Either the "division slice" of manpower increases, or the number of fighters and combat elements in a field force decreases as a proportion of total uniformed manpower.

One result of this development is that the older metrics employed in force planning, and even the distinction between traditional combat branches and technical services, become blurred, and this, in turn, creates the difficulty of deciding just what should be counted. The process by which metrics become blurred takes place incrementally, because it is keyed to weapons development and procurement budgets. Within limits, new doctrine and organization are also modified to accommodate some of the technical developments. It perhaps cannot be anything but an incremental process, given the fact that technical development impacts upon a large number of systems. Moreover, what with institutional specialization along combat branch and technical service lines, each development and acquisition acquires advocates. Nor can this be any other way, given the fact that nothing can be done unless somebody vigorously strives to get it done.

Another consequence of this process is that the overall force structure acquires an unknown quality with respect to effectiveness -- a quality that is not clearly commensurate with cost experience. This disparity is likely to be acute when little or no operational testing has taken place. Yet it is awkward for the military services, or combat branches within a service, to acknowledge a possible major discrepancy. Over a series of weapon-procurement cycles, they were obligated to assert that each new system was superior to the one it replaced, or to some counterpart of a possible military opponent. Fine-grained combat models have served this advocacy. However, when questions are raised about the adequacy of some aggregate level of forces, answers forthcoming from the services are less optimistic. In this instance, the coarse-grained campaign models have often been employed to support arguments.

One conclusion that might be reached from contemplating Eq. (6) and (8) is that it is impossible to determine useful parameter estimates for such constructions. Much discussion can also arise with respect to defining the *aggregate product* indicated in Eq. (6) and (8). Is the product *winning* the war, *deterrence* of war or the *holding or gaining of territory*? These objectives, although commendable, are rather abstract. Moreover, attaining them is always also a function of an opponent's behavior and, in case of actual war, a matter of how much resources he chooses, or is able, to expend in the form of casualties and materiel. A less abstract definition of product is ability to exhaust an opponent's force at a favorable casualty exchange rate.

If the focus is on achieving the most favorable exchange rate, the relevant questions then become whether new weapons in the force structure, or emphasis on certain elements of the force structure rather than others, contribute to or detract from that end. Although these are hard questions, it may be feasible to address them without attempting to determine or pretending to assert what the actual parameters for such equations as (6), (7), and (8) are likely to be in the event of a real war. Rather, the force planning and study process could explicitly focus on an array of marginal changes with the purpose of asking which of them might be the most fruitful in terms of improving an exchange rate. To adopt such an approach essentially involves question-raising about prevailing judgments that are implicitly revealed by the existing force structure and the costs of different military inputs. What follows develops further some aspects of these points.

C. COUNTING AND COSTING

The business of assessing the relative capability of opposing conventional forces possesses both a counting and a cost dimension. From an existing friendly force structure and knowledge about the costs of diverse force elements, it is possible to get insights about prevailing judgments of relative marginal products. Key parts of these latter judgments, in turn, might be tested.

Tables 14 and 15 illustrate aspects of the counting problem. The example used in Table 14 is taken from the United States Army pattern of around 1969, as displayed in U.S. Army Field Manual FM-101-10-1. The organization is that of a four-division corps, consisting of one infantry, two mechanized infantry, and one armored division, plus a separate mechanized infantry brigade and one and

Table 14

MAJOR UNITS AND PERSONNEL IN A FOUR-DIVISION CORPS
OF A THREE-CORPS FIELD ARMY

Major Combat Units	No. of Units	Personnel per Unit	Total Personnel
Infantry Divisions	1	17,568	17,568
Mechanized Infantry Divisions	2	18,021	36,042
Armored Divisions	1	17,994	17,994
Total Division Troops	*4*		*71,604*
Armored Cavalry Regiment	1 1/3	3,483[a]	4,643
Separate Infantry Brigade	1	5,040[b]	5,040
Subtotal			*81,[illegible]87*
Field Army Division Slice		51,955[c]	207,820
Tactical Air Force Wings	4	7,000	28,000
Total			[illegible]

SOURCE: *Staff Officers' Field Manual: Organizational, Technical, and Logistical Data*, Department of the Army, FM 101-10-1, January 1969, pp. 4-3 through 4-8, and 4-13.

[a]One armored cavalry regiment is assigned per corps and one per field army; one-third of the latter is allocated to the corps.

[b]Separate mechanized infantry brigade, consisting of brigade base (2,189 personnel), two tank battalions (599 personnel each) and two infantry battalions (849 personnel each), is assigned to the corps.

[c]Comparable "Worldwide Slice" is 71,955; does not include Theater "Air Wing Slice" of 7,000, of which 1,000 are COMMZ Army Troops.

one-third armored cavalry regiment. This corps, however, is part of a larger field army, which includes communication-zone elements. Hence the *theater* division slice concept is relevant to provide a better overall perspective of the resources involved. The division slice is about 52,000 Army troops. The corps is heavily armored, with 19 mechanized infantry battalions and 16 tank battalions out of a total of 45 maneuver battalions and with a preponderence of self-propelled artillery. Table 14 also shows an allocation of one Tactical Air Force wing per Army division, each wing involving an additional 7000 personnel.

The numbers of units and personnel in Table 14 are poor metrics because the units are aggregates of both combat and support elements. Armies vary between countries and over time with respect to combat and service elements organic to divisions on the one hand, or assigned to higher elements such as corps or armies on the other hand. Combat battalions can be either fat or lean in organic-service support capability and equipment. They can also possess heavy, crew-served weapons that provide artillery-type fire support or antitank capability, which could otherwise be located in specialized units. Heavy mortars can be in traditional artillery battalions, or in infantry and tank battalions. (During World War II, U.S. infantry regiments owned a cannon company equipped with 105-mm self-propelled guns.) For these reasons, the demarcation between traditional combat branches has become blurred.

Table 15 suggests an alternative tabulation. A key concept embodies the definition and identification of combat infantry. For our purposes, combat infantry includes all personnel in infantry platoons (i.e., riflemen, machinegunners, and grenadiers) plus personnel in weapons companies serving weapons, such as 81-mm mortars and 90-mm recoilless rifles, in infantry and mechanized infantry battalions. "Man portability" -- if only for a limited but tactically relevent distance -- of crew-served weapons and ammunition constitutes the criterion by which we count combat infantry. Heavier weapons,

Table 15

COMBAT ELEMENTS OF A FOUR-DIVISION/AIR FORCE WING FORCE

Total Personnel		235,820
Combat Infantry Personnel		17,612[a]
Artillery and Heavy Mortars		
Tubes and Launchers	614[b]	
4.2-inch Mortars	219[c]	
Total Artillery and Heavy Mortars		833
Tanks		1,153[d]
Antitank Weapons (heavy)		335[e]
Antiaircraft Weapons		
Gun/Chapparal	362	
Hawk/Hercules	74	
Total Antiaircraft Weapons		436[f]
Army Aircraft		680[g]
Air Force Tactical Aircraft		288[h]

SOURCE: *Staff Officers' Field Manual*, FM 101-10-1, January 1969, and *Armor Reference Data*, Army Armor School, Fort Knox, Kentucky, April 1965.

[a]*Combat Infantry* is defined as all troops in infantry companies, except those manning heavy crew-served weapons, specifically the 106-mm RR, which is tabulated separately. Also includes members of battalion scout platoons. Members of the scout section, armored cavalry troop hq., platoon rifle squads, and the air cavalry troops aerorifle squads -- a total of 247 -- were included in the division armored cavalry squadron. Comparable personnel in the armored cavalry regiment totaled 359. (Estimates were derived from *Armor Reference Data*.)

[b]Artillery total consists of 320 in division artillery; the independent infantry brigade and the armored cavalry regiments each are authorized 18 155-mm SP howitzers (for a total 42); corps consists of 19 battalions possessing 248 tubes or launchers. No count was made of Pershing missile battalion, assigned to field army.

[c]Allocation is 4 per maneuver battalion (including tank battalions), 27 per armored cavalry regiment, and 4 to the infantry brigade base.

[d]Fifty-four tanks per tank battalion, plus 27 per division armored cavalry squadron and 132 per armored cavalry regiment.

[e]Eight 106-mm RR and 3 Entac launchers per infantry battalion; 12 heavy antitank weapons per armored cavalry squadron.

(Continued)

like 4.2-inch mortars, 106-mm recoilless rifles, and Entac or TOW missiles, are tabulated separately, partly because these weapons are substitutes for artillery and tank guns for certain purposes and because they have identifiable specialized functions. In addition to infantry in infantry companies, the definition of combat infantry also includes people in battalion reconnaissance platoons organized as infantry squads, infantrymen assigned to armored cavalry squadrons, plus a small number of infantry detachments, such as pathfinders, assigned to corps. Thus, for this four-division corps, the combat infantry is estimated to be 17,512, out of a total corps slice of 207,820 Army troops, or 3.5 percent of the total.

Table 15 also displays the number of major "weapons" that constitute the four-division force. The seven categories -- from "combat infantry" to "air force tactical aircraft" -- may be regarded as the modern counterpart of the "men, horses, and guns" that were often the focus of force planners in a bygone era.

One question that might be raised is: What significance may be attached to a number like the 235,820 total personnel shown in these tables (or comparable numbers that may be revealed in connection with possible opposing forces)? One answer is that its significance is unknown. Of course, it includes the crews that serve the major weapons and man the tanks and aircraft. It also includes combat engineers (in U.S. lexicon), and the "pioneers" in other armies where tradition or doctrine might warrant their classification as infantry

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[f] Field army allocation shows 4 Hawk battalions and 1 self-propelled automatic weapons battalion per corps, plus additional units (Hawk/Hercules; Vulcan/Chapparal). Of the Gun/Chapparal units, 256 are organic to divisions, 144 are the force's "slice" of an assumed 9 battalion assignment to a 12 division field army.

[g] Army aircraft for divisional TO&E's of G series was 101 aircraft per division, for a total of 404. Armored cavalry regiment aircraft, 64; infantry brigade, 32. Aviation assigned to corps consisted of 8 companies, estimated to possess 180 aircraft. Overall composition of total aircraft roughly as follows: OU-1, 34; LOH, 232; UH-1 (gunships and transports), 242; CH-47, 2; utility, 1.

[h] Seventy-two aircraft per each of 4 wings.

because of an emphasis on specialized assault missions, including city fighting.* The total manpower figure also includes the uniformed personnel who process information and paper work, provide services, handle supplies, and maintain equipment. These latter personnel can be and often are substantially augmented by indigenous civilians. Thus, the total manpower that provides some sort of "direct" support for military operations has a slippery dimension, and the relative proportion of this quantity that happens to be in uniform is a complicated function of a wide variety of practices, customs, and conditions.

From the information of Table 15 plus certain kinds of cost data, it is possible, however, to derive cost ratios that suggest prevailing beliefs about relative marginal products.** These same cost ratios also indicate presently available major force-structure tradeoffs. For example, 18 self-propelled artillery pieces require 1086 personnel (507 in the artillery battalion, plus 579 support personnel), or 60 people per gun; the support of an infantry battalion requires an external complement of about 50 percent more personnel.***

Thus one artillery piece entails a manpower tradeoff of at least 40 combat infantrymen. If account is also taken of the point that artillery is a more capital-intensive force element than combat infantry, an incremental annual capital cost is imputable to the artillery. The

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*In late 1942, virtually all the pioneer battalions of the German Army on the Eastern Front were expended in the Stalingrad fight. The U.S. Army, on occasion, has also employed engineer battalions as infantry.

**A valid question can be raised regarding just what kind of costs should be employed for this kind of exercise. The United States has long costed military manpower under conditions of manpower conscription and thereby understated its true social or opportunity cost. With the recently instituted all-volunteer system, it still seems implicit that conscription would be instituted should any serious shooting break out. Thus a case can be made that the true social cost of manpower, especially for combat branches that will likely take heavy casualties, is understated, even in the recent context that has witnessed a sharp increase in dollar military manpower costs.

***Department of Defense Appropriations for Fiscal Year 1974, Part 2, *Department of the Army*, United States Senate, Subcommittee of the Committee on Appropriations, Government Printing Office, Washington, D.C., 1973, pp. 134-135.

annual manpower costs, plus the differential capital and O&M costs, would be both the relevant tradeoff costs and the "prevailing consensus" of the relative marginal products of the two force elements. Thus, a reduction of 100 guns in the force shown in Table 15 would mean 4000 additional personnel that could be infantry, to bring total combat infantry strength up to 21,612 instead of 17,612. If the weighted average TO&E investment per man in artillery were $2500, as contrasted with $500 for combat infantry, then an investment cost saving of $8 million would be achieved. If we accept the notion that, under most circumstances, infantry is the primary combat element of land forces, it is also pertinent to ask, given an existing ratio of 34.9 guns per 1000 combat infantry, is one gun worth 40 infantrymen plus a net investment outlay of $80,000?

Similarly, an Air Force tactical fighter-bomber requires about 100 men to support it, as compared to the 60 per 155-mm self-propelled gun. In this case, given a cost of from $3 to $4 million per aircraft, the air unit is the more capital-intensive force element. To take account of this and other differentials, the cost trade between gun tubes and aircraft may be 2.5 or 3.0 to 1. Given the points that the aircraft can perform a variety of missions and that aircraft fires can be concentrated to a much greater degree than can artillery fires, are 100 guns worth between 30 and 40 aircraft? And what do these ratios mean if the aircraft managers can figure out ways to generate five or six sorties per aircraft per day for limited surge periods?

Questions like these are, of course, debatable. Explicit debate might contribute toward a more careful specification of just what is meant by "marginal product" as it applies to military affairs. It is also relevant to ask whether, and in what way, the new campaign models can make a contribution to this kind of debate. It is my assertion that they cannot, given the questions that center around the points that (1) the submodels (or behavioral equations that comprise them) are unverified and (2) the data inputs they employ are beclouded by the unknowns described in this study.

Stated more bluntly, any assertions that current modeling efforts come up with regarding the marginal products of force-structure elements will be highly contestable. They will be especially (and predictably) contested by service proponents for self-serving budgetary reasons whenever a budgetary realignment is suggested by a model. They are contestable in terms of traditional standards that have prevailed among practitioners of quantitative methodology. Unless the models can generate hypotheses testable by field trials, or verified by other empirical support, it would be a rash if not imprudent civilian decisionmaker who would make force realignments on the basis of a campaign model. So what is the likely payoff from further modeling? The same question would also seem to be relevant for the current interest in net assessment of general-purpose forces.

D. ASSESSING OPPOSING CAPABILITIES

Let us focus on the problem of the policymaker who seeks some estimate of relative capabilities. Assume that Blue's force is structured like the four divisions shown in Table 15. Red combat elements are estimated in the same way. Let us further assume that Blue's policymakers indicate a desire for a force ratio that is 80 percent of Red's. If we take Blue's base as 100, we might find the ratios to be as shown in Table 16.

Given ratios like those in Table 16, it would seem that a quest for any simple estimate of an overall relative force ratio, such as parity, 80 percent or even 50 percent, is not a feasible intellectual undertaking. Implicit in the likely force arrays are possibly markedly different doctrines, both of which can be viewed to "make sense," provided sets of expectations entertained by each side can be fulfilled. These expectations, in turn, center around fine-grained tactical prospects, which, in varying degrees, are destined to be refuted or verified in war. At least some of these possibilities are nevertheless susceptible to questions that may be partly resolved by peacetime physical testing and related analysis.

Given the hypothetical ratios in Table 16, it is apparent that Blue has the desired 80 percent ratio in infantry, is greatly outnumbered in tanks, and outclasses Red in artillery (and "firepower"), as well as tactical aircraft. With regard to tactical aircraft, let us

Table 16

HYPOTHETICAL FORCE RATIOS AS MEASURED BY MAJOR COMBAT ELEMENTS

Combat Elements	Red/Blue Ratio, Blue=100	Blue as % of Red
Combat Infantry	120	83
Antitank	110	91
Tank	200	50
Artillery	80	125
Army Aircraft	80	125
Air Force Tactical Aircraft	90	111
Number of Sorties	60	166
Air Defense	150	67

assume that Red's force leans heavily toward short-legged interceptors, and Blue's toward fighter-bombers with long ranges or long loiter times and good payloads. The ratio of air-defense weapons, however, suggests that Red would enjoy a denser air-defense system. Thus it would seem that Blue expects to derive a payoff in the ground battle from some combination of tactical interdiction and combat air support, whereas Red expects to nullify this expectation with his air defense, including interceptors.

When we turn to the major ground-combat elements, the broad doctrine implicit in Blue's force structure suggests a belief that his artillery firepower edge can both counter Red's artillery and, especially, kill his infantry and suppress his antitank capability. Blue's surviving infantry, equipped with man-portable antitank devices, plus his tanks and antitank weapons can then proceed to handle Red's larger number of tanks. Also, Blue's aircraft might emerge as top-notch tank killers. However, whether they can depends on a number of present unknowns. Among them might be: Are the pilots trained to identify friendly versus unfriendly combat vehicles in the context of a melee? Or is there some agreed-upon, and field-tested, set of doctrinal rules with respect to flak suppression on the part of Blue ground elements against Red's forward-area air-defense units? Might Blue employ an in-depth defense in which his ground units are both concealed and stationary, in which case Blue's aircraft could employ the decision-rule that anything moving is unfriendly?

The entire subject of the infantry-antitank-artillery interrelationship has been beclouded by the advent of the armored personnel carrier (APC), which promises to evolve into a combat vehicle with a turret-mounted gun in the 20-mm to 40-mm regime. The Soviets have an infantry carrier that sports a gun of around 76 mm, a machinegun, and a Sagger antitank missile.* Precisely what combat role these carriers can play as fighting vehicles is problematic. But whatever that role, it is critical with regard to the implications of the APC for the effectiveness of artillery fragmenting munitions. Against infantry in personnel carriers, the lethal area of a fragment spray is zero. At some point, infantry must dismount and fight the way they always have. But a high density of quick-firing weapons in the 20-mm or more regime could make the point of dismounting a function of vehicle-versus-vehicle engagement outcomes. If the tactics and techniques in this context are such that infantry is exposed for a very short period, before which fragmenting munitions also endanger friendly troops, it is not clear what an artillery edge provides. Direct-fire weapons, including those mounted on aircraft, therefore loom important. Tonnages of artillery munitions and their implications for the logistic apparatus can acquire a high-opportunity cost; conversely, attempts to curtail supplies by such means as tactical air interdiction might not have the payoff they had on other occasions. Key parts of this broad set of interrelated questions might warrant tests.

Perhaps even more fundamental for net assessment of opposing forces is the relative quality of key combat personnel, by which we mean

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Jane's Weapon Systems, R. T. Pretty and D.H.R. Archer (editors), Haymarket Publishing Group, London, 1969-1970, p. 222. It also possesses a three-man crew and transports an eight-man infantry squad, which is able to play an active combat role when mounted. This design follows the pattern of the West German Marder vehicle.

tank commanders and gunners, antitank gunners and assistant gunners, infantry squad leaders and perhaps two or so additional individuals per infantry squad, forward artillery observers, and pilots. In a force like the 236,000 shown in Tables 14 and 15, the critical individuals might total around 15,000.* In many lines of human endeavor, it is observed that individuals reveal a log-normal distribution of talent and skill. A well-documented military example of this characteristic is the performance of fighter pilots in air-to-air combat, in which a small proportion of individuals achieve a disproportionate share of total kills.** A similar pattern seems evident with respect to the performance of World War II submarine skippers.*** In the small-arms experiment recounted above, the performances of squads within the subsets of those equipped with a given type of weapon exhibited greater variance than was revealed by the different weapons. Casual observation suggested that, in a minority of squads, distributed randomly with respect to weapons being tested, a single individual in the tactical context was exceptionally good at acquiring targets. His shooting and the ground strike of his bullets would apparently cue other squad members and thereby enhance the squad's overall target acquisition ability.

These and other examples suggest that the quality of people, and a relatively small number of people at that, could dominate relative

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*Derivation of this estimate is as follows: For 17,612 combat infantry, assume 1761 ten-man squads and assume three key men per squad (squad leader, grenadier, plus one other; for machinegun and light antitank weapons squads, assume squad leader and two each gunners and assistant gunners). Subtotal: about 6000. For each heavy weapon, tank, and aircraft, assume two men (e.g., commander and gunner, gunner and assistant gunner), for a total of 3000 weapons and about 6000 men. Subtotal: about 11,200. Allow about another 3000 or 4000 for such specialties as forward artillery and air observers, air-defense radar observers, and a few others.

**See Herbert K. Weiss, "Systems Analysis Problems of Limited War," *Annals of Reliability and Maintainability*, Vol. 5, AIAA, New York, July 1966.

***See Theodore Roscoe, *United States Submarine Operations in World War II*, United States Naval Institute, Annapolis, Maryland, 1949, pp. 527-63.

force effectiveness. If so, then attention should be focused on methods employed by both sides in selecting, training, and motivating these key individuals. How much time do troops spend in the field, conducting realistic tests and exercises? How much opportunity do they have to shoot, fly, scout, and perform other combat-like tasks? How is excellence in, say, tank gunnery rewarded? Or is a systematic attempt even made to measure it under conditions that strive to approximate actual tactical settings? What is done to identify attributes of individuals who possess the potential of being top gunners, infantry squad leaders, and so on?

To the extent these activities do take place, they are on-going aspects of training, maneuvers, readiness evaluation, and operational testing. In all instances, they relate to the fine-grained tactical doctrine that bears upon each combat specialty. It would seem that only if there are some empirically validated insights about the capabilities and limitations of friendly systems with respect to these fine-grained tactical questions is it possible to get some idea about the capabilities of possible opposing systems. At present, most of the new generation of campaign models do not seem to show much prospect that they will raise many testable propositions.

X. CONCLUSIONS

No satisfactory simple metric exists for aggregating the diverse fighting elements that comprise modern conventional forces. The question may be raised, therefore, whether and in what way it is meaningful to try to model confrontations of such forces. Almost any attempt to develop an aggregate metric of the diverse elements must involve assigning a set of value weights to the diverse specialties. The firepower index, as an example of such an endeavor, drew upon an admixture of physical measurements and implicit assessments regarding the tactical worth of different combat specialties. Older indexes, such as those presented in the *Maneuver Control* Field Manual, were derived from the judgments of military men. The latter indexes are essentially the outputs of models which, however, are not transparent.

A case can be made that many of these assessments corresponded to valuations embedded in ongoing weapons procurement decisions that provided, through time, more costly weapons and force-structure elements. But, apart from superficially rationalizing the idea that more costly and technically superior systems might provide combat capability commensurate with cost, has any useful knowledge followed from the intellectual effort of deriving firepower indexes? Further, has any useful knowledge followed from aggregative campaign models that have used these indexes as input data? My answer to both of these questions is no. A less harsh answer is that these efforts may have generated some insights insofar as they were an aspect of broader question-raising regarding the role and structure of general purpose forces. But any positive product obtained may have been more than offset by the point that both the firepower scores and the findings of models that used them were highly susceptible to abuse. Their aggregative quality concealed much subjective thinking. They distracted attention and effort to understand combat operations.

To obtain better insights into combat operations, hard thinking and testable models about tactics are necessary. However, this effort must be subject to and can be augmented by testing and other empirical endeavors related to activities that troops carry out. Only by this approach does it appear possible to get some understanding of the feasibility of alternative tactical uses of different systems, which in turn must constitute the foundation of the broader doctrine that should underlie diverse aggregations of major fighting elements.

The conditions described result from an imbalance between empirical and theoretical endeavor in DoD analysis and study. The image of scientific activity -- depicting theories and models independently tested by experiment or by experience, with the empirical work in turn providing new insight that contributes to theoretical advance -- does not seem to prevail in the military establishment. Unverified findings of modeling conducted by one organization can be taken as "fact" by another organization and used as inputs for the latter's model. Sets of numbers that constitute "data" can be admixtures of subtle concepts, subjective evaluations, and limited but hard evidence based on actual physical testing. The particular testing, however, may have been undertaken for purposes remote from the use that another study makes of the data. The lethal area concept and estimates of killing a tank given a hit, P(K/H), illustrate this point.

The overall conditions suggest two sets of recommendations. The first is that any "number," before it is accepted by an analyst, decisionmaker, or any other interested party, should be probed by at least the following questions: Is it the output of a model or the result of some physical measurement? If it is the output of a model, to what extent is it an untested and therefore contestable hypothesis? That is, has the model been validated by some independent test? If not, then what is the structure -- or theory -- of the model? If a model has been tested, or if a set of numbers is the result of physical testing or some other empirical source, then what was the experimental matrix and what are possible instrumentation errors, or what were the reporting methods employed? How was the data filtered and aggregated as it moved upward (and often sideways) in the bureaucratic hierarchy? If the subjective assessments of individuals are used for certain kinds of data generation, who were these individuals and what has been their experience and institutional affiliation?

If these and similar questions were systematically asked and vigorously pursued, a second recommendation, in our view, would suggest itself: The need for more vigorous empirical work, including operational testing, is of such magnitude that a major reallocation of talent from model building to fundamental empirical work is called for. Fortunately, there is now new emphasis on the need for operational testing, motivated primarily by the idea that testing will encourage a "fly-before-you-buy" weapons-acquisition philosophy and a concern for new system-cost increases.

The real payoff from operational testing, as well as from more careful empirical study of past wars, is that these can potentially provide a way to check the assertions that flow from models -- including the models used to justify technical performance specifications for new weapons -- whether these models be "analytic" or "judgmental." And if experience in other applied scientific fields (including the type of operational research conducted during World War II) is any indicator, the empirical effort will suggest insights into how to structure new and better models, or to modify and sharpen judgments.

In line with the idea that more emphasis be placed on empirical testing, model builders might be prevailed upon to convey more carefully the empirical underpinnings of their offerings. If these empirical bases are absent, meager, or ambiguous, modelers might then be obligated to indicate how empirical work could clarify their efforts, for what good is a model if it does not yield something testable? The failure to provide testable assertions negates the potential to generate knowledge.

Operational testing, apart from providing a richer empirical foundation for modeling, may in many instances suggest that costly technical performance features do not provide an increment of effectiveness in proportion to their incremental cost. This kind of finding serves two useful functions. First, it may induce critical examination of assumptions implicit in the performance requirements that drive weapons development. Second, some well-founded empirical estimates (or proxy measures of the operational effectiveness) of weapons and their associated tactical doctrine seem necessary even to begin a reasoned discussion or consideration of tradeoffs among major fighting specialties.

The argument that there should be more testing and empirical work should not be construed to mean that there should be no modeling effort. (Such a conclusion is equivalent to saying there should be no thinking.) Moreover, a coherent and economical experiment can only proceed from the foundation of a well-structured model. Rather, it is my argument that there has been a grave imbalance between empirical and theoretical endeavor in Department of Defense analysis, to an extent that degrades modeling itself. Until a better balance is achieved, the question of whether too much or too little effort is being expended on operational and cost-effectiveness analysis must remain unanswerable.

It should nevertheless be realized that any structured method of inquiry is susceptible to being misused. In the same manner that available ballistics data were misused in the firepower indexes, a field testing program or other empirical endeavor can also be misused, or constrained by prevailing scientific or military beliefs. The resulting danger is exceedingly great in an activity such as conventional-force usage, where tactics and organization have long seemed to carry more weight than weapon performance. Nor is there any convincing and clear evidence that models of combat and military operations conceived by men who have been under fire or who have operated forces in the field are inferior to the creations of professional analysts. The point that formal models "make judgments explicit," whereas the opposite is the case with "judgmental models," is contestable. The serious problem, then, is often not one of methodology. Rather, it is one of people, who are constrained to behave in peculiar ways due to organizational settings and incentives.

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